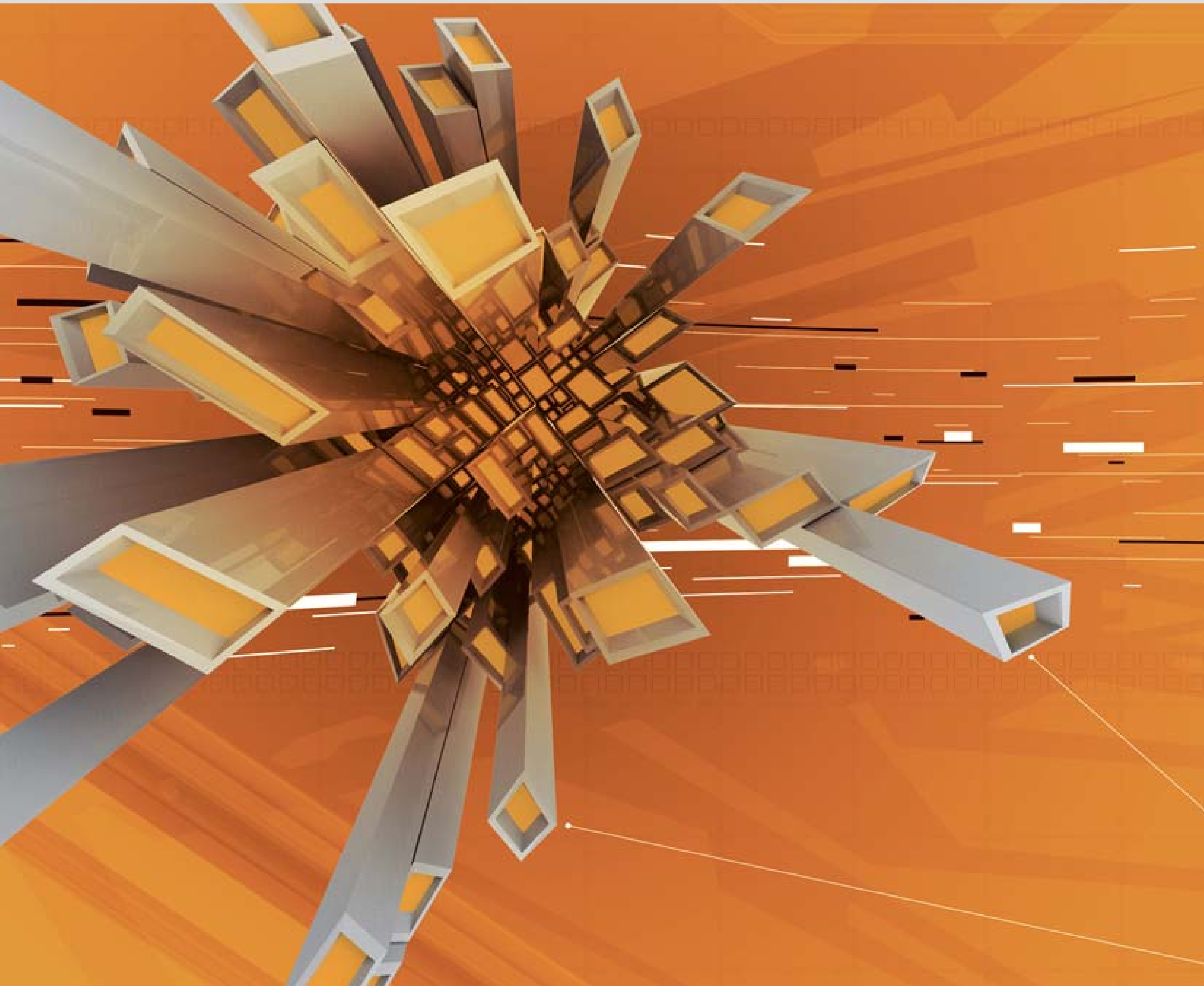
# Ofcom

## The Likelihood and Extent of Radio Frequency Interference from In-Home PLT Devices

21 June 2010



# 1 Executive summary

## Power Line Telecommunications (PLT) devices are used for data distribution in the home

Power Line Telecommunications (PLT) is the collective term for various forms of communication over wiring used for supplying electricity (termed the 'mains' wiring throughout this report). The most recent developments in PLT devices address the consumer market for in home connectivity as an alternative to WiFi or data cabling. It is these in-home PLT devices that are the specific focus of this study. In-home PLT devices are growing in popularity and, in particular, their use in BT Vision installations in the UK has made the UK one of the biggest users of in-home PLT devices in Europe.

## Ofcom has received complaints of interference caused by PLT devices and has requested this study

The majority of PLT devices on the market today operate at HF frequencies and, while they are not intended to radiate, there is evidence of interference to other HF users which has resulted in a number of complaints to Ofcom. While most of these complaints have been resolved, Ofcom is concerned that the problem may grow as the number of PLT devices deployed increases over time. Higher data rate PLT devices operating up to 300MHz have also started to emerge in the UK market and so potential interference at VHF is also a concern.

Ofcom has asked PA to assess the likelihood and impact of RF interference from in-home PLT devices over the next 5 to 10 years.

## Our results show that users of sensitive radio systems may increasingly suffer interference from PLT devices

In this study we have taken a statistical approach to quantifying the probability of interference occurring as PLT devices become more commonplace. We have concluded that if uptake increases in line with our market forecasts, there will be a high probability of interference to some existing spectrum users at both HF and VHF by 2020 if PLT device features do not change from those currently implemented.

However, within this timescale, in addition to the existing practice of notching International Amateur Radio Union (IARU) bands, interference mitigation features such as power control and smart notching are expected to have been implemented in PLT devices. Our results indicate that the introduction of these features will be enough to reduce interference to negligible levels in the majority of these cases. The exception to this is the safety critical aeronautical bands which we recommend are notched by default rather than by smart notching.

It should also be noted that our results generally show the probability of a radio user listening at the edge of the service area suffering interference – this inevitably presents a somewhat pessimistic picture, since the majority of users will be in areas of strong signal strength and may not be impacted at all. It is also important to recognise that our results show the probability of PLT interference being suffered by someone who wants to use a particular service under the conditions considered. They do not show the probability of PLT interference being suffered by the UK population at large.

A summary of our results showing probability of interference is given in the table below:

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Note: Interference effects are estimated at limit of wanted signal / range** | | | |
| **HF - Shortwave broadcast listener** | | | |
| Power control only | High | High | High |
| With power control and notching | Negligible | Negligible | Negligible |
| **HF - Amateur radio** | | | |
| Default IARU notches only | High | High | High |
| With IARU notches and power control | Negligible | Negligible | Negligible |
| **HF - Aeronautical groundstations** | | | |
| Power control only | High | High | High |
| With power control and notching | Negligible | Negligible | Negligible |
| **VHF - FM broadcast listener** | | | |
| No mitigation | - | High | High |
| With notching | - | Low | Medium |
| **VHF - Narrowband FM** | | | |
| No mitigation | - | High | High |
| With notching | - | Medium | Medium |
| **VHF - Aeronautical Navigation** | | | |
| No mitigation | - | High | High |
| With notching | - | Low | Low |

**Probability of Interference for user working at limit of wanted signal range.**

At the end of February 2010, Ofcom had received 208 complaints about interference arising from PLT device, all from users of shortwave broadcast radio and radio amateur reception. Potential reasons for this number being low compared with expectations from the theoretical results presented here are included in Section 3 of this report; the most notable of these being the point mentioned above, that these results show the likelihood of interference for users *at the edge of wanted signal coverage*, not for the population of the UK overall.

## Interference mechanisms are difficult to quantify precisely

RF emissions from PLT devices may reach other spectrum users and create interference via a number of routes. For the purpose of this study we have split these into the following two categories:

- **Radiated emissions directly from the PLT user's home** - The electrical power ('mains') wiring of the house where the PLT device is being used will act as an antenna and radiate the signal injected into the mains wiring by the PLT device. Depending on the distance between the PLT user and victim receiver, a victim receiver may suffer interference from these radiated emissions.
- **Interference from indirect PLT powerline radiation via shared power distribution** - As the consumer unit of a typical house does not specifically filter out PLT signals, the PLT signal injected into the power wiring within the home will potentially be conducted into the power distribution wiring external to the house. This mains connection external to the house will be shared by a number of other households. Interference could therefore be caused by radiated emissions from wiring nearby to the victim receiver that shares a power connection with the PLT user and is carrying a PLT signal.

Whilst there is some good evidence for the magnitude of these interference mechanisms, there is likely to be significant variation associated with differences in house wiring conventions, construction techniques and materials. The results presented here need to be considered with this in mind.

## It is important that mitigating features are implemented in future PLT devices.

The majority of PLT devices in the UK to date have been issued as part of the BT Vision package; however, there is churn in this market, and it should not be assumed that the existing installed base is traceable or could be updated to incorporate these features. We do however assume that the current practice of PLT devices being upgraded in cases where they have been identified by Ofcom as sources of interference will continue and ensure that the existing installed base is gradually replaced where needed.

While power control and smart notching are already part of the product roadmaps of the PLT vendors that we consulted as part of this study, we recommend that where possible the introduction of these features is formalised to ensure that their introduction can be relied upon.

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# 2 Study aims and our approach

This section provides the context for the study, introducing PLT devices and their potential to cause interference to other radio spectrum users. It then states Ofcom's objectives for conducting the study and the specific questions answered.

## 2.1 In-Home PLT devices are increasingly being deployed in the UK

**Power Line Telecommunications (PLT) is the collective term for various forms of communication over mains electrical wiring. The most recent developments in PLT devices address the consumer market for in-home connectivity as an alternative to WiFi or cable.**

Power Line Telecommunications (PLT) is the collective term for various forms of communication over wiring used for supplying electricity (termed the 'mains' wiring throughout this report). This has been used for many years by the electricity companies themselves for monitoring and control of the electricity networks. This was originally at very low frequencies for simple control such as switching street lights or metering tariffs according to the time of day. Around the 1980s Supervisory Control and Data Acquisition (SCADA) control systems appeared and used frequencies up to 148.5kHz with two-way communication. There are very few radio users at such low frequencies so radiated energy from these PLT systems was rarely if ever a problem.

The most recent developments in PLT have two significant differences from the earlier systems described above. Firstly they are aimed at end users outside the electricity company, i.e. the consumer market for in-home connectivity as an alternative to WiFi or cable, with some devices now on the market for less than £20. Secondly the frequencies used are much higher in order to support data rates comparable with Ethernet LANs and VDSL broadband systems. In particular the use of PLT in 'BT Vision' installations in the UK has made the UK one of the biggest users of in-home PLT devices in Europe.

The focus of this study is on in-home PLT devices, which provide a network within the home, rather than access PLT devices, which provide a data connection to the home.

## 2.2 PLT device emissions have the potential to cause interference

**PLT devices operate at radio frequencies and can act as unintentional radiators, effectively using the electricity supply wiring as an antenna. There is a significant body of evidence of interference to other HF users including amateur radio users and shortwave broadcasts from PLT devices.**

The electrical power network is designed for distributing power from a small number of sources to a very large number of loads at 50Hz. The impedance of the network at the high frequencies used by PLT is uncontrolled and often time-varying as electrical devices are switched on and off. In addition, the live and neutral conductors are not always close together, which exacerbates far-field radiation effects. Fundamentally, with PLT, the power network is being used for something for which it was not designed.

When PLT devices send their signal into the mains wiring it propagates not only to the target device but throughout the mains circuit, being stopped usually only by a transformer or, over longer distances, by line attenuation. Typical PLT devices propagate for a range of several hundred metres. Typically there will be many homes on one circuit such as a street or a block of flats. The PLT signal from one home will therefore propagate through many others. Small offices within an office block may be similarly affected.

While the PLT industry standards (which are distinct from the Harmonised European EMC standards) include encryption to prevent accidental or intentional interception of data by devices that are not part of the same network, this does not stop the signal energy from propagating and therefore causing radio frequency interference. Measurements made on PLT deployments by Ofcom have shown significant rises in noise level at up to 300 metres from the power line or installation when PLT equipment is operating [1, 2, 3]. Given that most receivers are likely to be within this distance from a mains cable, the potential for widespread interference is clear.

The frequency range used by the majority of currently available PLT devices is approximately 2-30 MHz. This frequency range is also used by many licensed radio users in the UK including, among others, short wave broadcasting, amateur radio and professional users such as aviation and military communications. The amateur radio and shortwave listener communities, who tend to use sensitive apparatus, have documented instances of interference from in-home PLT devices.

Higher data rate PLT devices operating up to 300MHz have also started to emerge in the UK market. We are unaware of any reported incidents, but in principle PLT device emissions could interfere with VHF systems through similar mechanisms.

## 2.3 Study objective - What is the likelihood and extent of interference from PLT in a 5-10 year timescale?

**The objective of this project is to understand the likelihood and extent of radio frequency interference caused by increased use of PLT devices and evolutions of the technology. A quantitative analysis of expected interference will provide input to any future debate on Ofcom's regulatory duties in this area.**

As noted above, there is evidence of interference from PLT devices to HF users. This has resulted in a number of complaints to Ofcom and while most of these complaints have been resolved, Ofcom is concerned that the problem may grow as the number of PLT devices deployed increases over time and as the technology used in the devices evolves.

Ofcom therefore asked PA to determine the likelihood and impact of RF interference from in-home PLT devices over the next 5 to 10 years. In looking at future trends for interference into other services, as well as potential device takeup, it has been important to take account of developments in the industry standards for PLT devices. Specifically there are plans to increase data rates and to introduce more advanced features to mitigate against the likelihood of interference to other services.

Ofcom provided the following guidance as to the study approach to be followed:

- A study of the relevant trends, developments and roadmaps of PLT devices, covering new and emerging technologies and standardisation activities;
- A study of the options for home networking, including wired Ethernet, WiFi and PLT based approaches, in order to understand under what circumstances PLT networking becomes attractive (or necessary) to users;
- A review of scenarios covering possible future deployment densities of PLT devices;
- A modelling activity, to simulate and quantify the interference effects of PLT devices for each scenario.

The study has been a forward-looking research study. While Ofcom are engaged in investigations in relation to PLT devices, the project scope explicitly excluded providing specific advice on EMC regulations and their interpretation in relation to PLT.

## 2.4 Our approach

PA's approach comprised four key stages.

- ***Start-up and data gathering -*** Conducting desk research and discussions with PLT industry bodies to confirm device characteristics and trends and gathering existing information on PLT interference to avoid duplicating previous work. In addition holding stakeholder discussions with existing relevant spectrum users to understand previous experience of PLT interference and victim receiver characteristics.
- ***Developing usage and density scenarios -*** Defining how and where in-home PLT devices are used and forecasting likely future densities for in-home PLT devices.
- ***Interference modelling -*** Examining the impact interference mechanisms between the PLT devices and victim systems in the relevant frequency bands and performing statistical modelling to determine the likely extent of harmful interference based on forecast device density.
- ***Sensitivity analysis and mitigation -*** Finally, conducting sensitivity analysis on the results by varying a number of assumptions and commenting on the viability of potential methods to mitigate against PLT interference.

An overview of our approach is given in Figure 1 with a detailed description given in Appendix D .

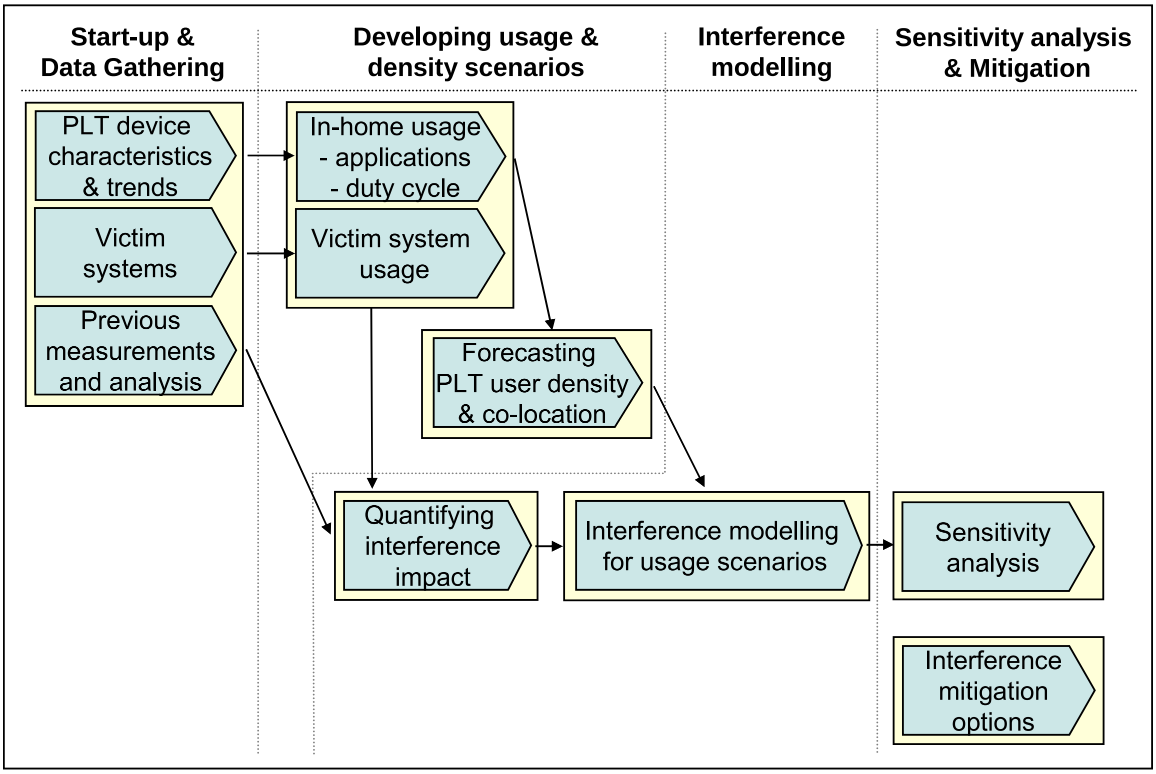

**Figure 1 - PA's approach to this study**

## 2.5 Report structure

This report is structured to present an independent and balanced assessment of this topic, with a logical flow in line with the approach described above.

- Section 3 - Discussion of how our results relate to the levels of interference seen in practice, as evidenced by complaints to Ofcom.
- Section 4 - Overview of our findings for each interference mechanism and top level assumptions on PLT devices and victim receivers.
- Section 5 - Detailed review of PLT devices both now and over a 5 -10 year timeline. Our market estimates for PLT devices are also presented.
- Section 6 - Detailed assumptions for the HF victim receiver types assessed.
- Section 7 - Detailed assumptions for victim receiver types assessed between 30 and 300MHz.
- Section 8 - Description of our assessment of the likelihood of interference radiated directly from PLT user's homes.
- Section 9 - Detailed description and results from our main interference modelling activity, the development of a Seamcat model to quantify interference to ground based HF users via radiated emissions from PLT devices over small areas.
- Section 10 - Detailed description and results from our modelling of potential interference to VHF systems above 30MHz
- Section 11 - Assessment of interference from PLT devices via indirect PLT powerline radiation via a shared mains connection (as opposed to interference from radiated emissions directly from the PLT user's home).
- Section 12 - Summarising conclusions and recommendations for follow up by Ofcom.

A number of Appendices provide additional detail to support the conclusions of the main document.

# 3 Comparing predictions with actual experience of interference

The analysis contained in this report predicts a probability of interference that is higher (even in 2010) than might be expected based on the number of incidents of interference that have been reported to Ofcom.

In September 2009 Ofcom made the following statement about complaints received:

> **What enquiries and complaints has Ofcom received about PLT?**
>
> Over the past 12 months Ofcom has received 143 individual PLT interference complaints; all from radio enthusiasts. Of these 121 have been investigated and referred to the apparatus supplier who has resolved 104. The solutions employed include replacing the apparatus, hard wiring and conventional wireless alternatives.
>
> All of the complaints relate to the inability to receive radio transmissions in the High Frequency (HF) band (3 to 30MHz).
>
> There are many other users of the HF Band including long range aeronautical and oceanic communications, the Ministry of Defence and international broadcasters. Ofcom has not received complaints of interference to these services.
>
> *(Source: Ofcom, 2009)*

The latest Ofcom figures show that between July 2008 and February 2010 a total of 208 complaints have been received in relation to PLT interference. While there have been peaks in certain months, the number of complaints received per month has remained broadly constant over time.

Since the work described in this report has been a theoretical engineering study, we believe it useful and necessary to include some commentary as to why differences may exist between the theory presented here and 'real world' experience, and specifically as to why our results suggest that problems could be significantly worse than currently reported.

## 3.1 Qualitative reasons for apparent differences between theory and experience

The reasons for differences fall into two categories; in this section we discuss these reasons and the potential impact they could have.

- **We combine 'worst case' assumptions in our analysis.** An example here would be assuming that users have best quality equipment (hence most vulnerable to the lowest levels of interference) being used at the edge of wanted signal coverage, and that this is in an urban environment with a higher density of PLT devices than would be found in, for example, rural areas.
- **No account has been taken of the propensity of people to actually use the wanted signal services.** Relatively few people in the overall population are listeners to shortwave radio or active amateur radio users. Large numbers of people listen to FM radio, although this has not yet been affected because only recently have PLT devices using VHF become available in the market.

So, it is important to recognise that the results here show:

- The probability of PLT interference being suffered by someone who wants to use a particular service under the conditions considered

They ***do not*** show:

- The probability of PLT interference being suffered by the UK population at large.

The essential difference between these cases is the proportion of the UK population wanting to use the service under those conditions.

### 3.1.1 The effects of population distribution and coverage areas

Our analysis assumes the victim system is at the edge of coverage.

Throughout this report we have analysed the situation for 'edge of coverage' users, to understand how people may be affected by PLT interference. This approach gives a probability of interference under conditions where the wanted signal is relatively weak. In practice only a small proportion of users are at the edge of coverage and many users will receive a higher wanted signal strength and so have a reduced probability of interference. The impact of this is shown in Figure 2 below which shows how results should be interpreted for the wider population.

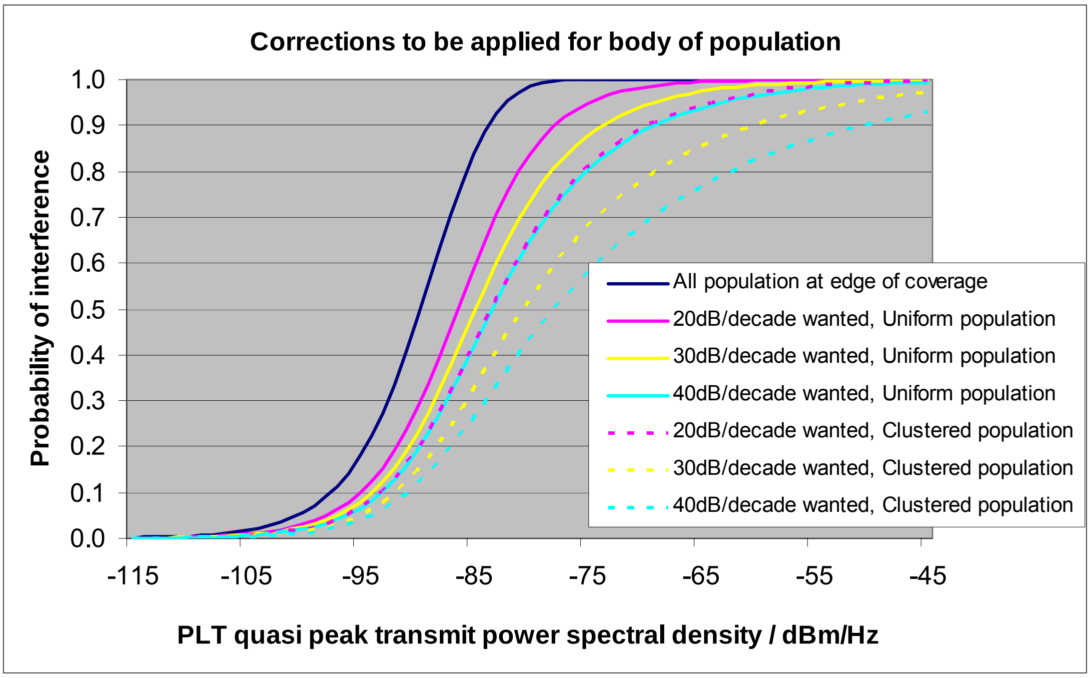

**Figure 2 – Corrections to be applied for body of population, rather than those in 'edge of coverage' areas.**

In Figure 2 the dark line follows the assumption used in generating the charts in this report, which represents the worst case. The other curves show the improvement for the wider population (i.e. reduced probability of interference for the same PLT transmit power), noting that the wanted signal will be stronger towards the centre of its coverage area. The exact level of improvement depends on:

- The signal strength roll-off of the wanted signal. 20, 30 and 40dB per decade roll-offs are shown, to cover the relevant range of propagation environments and frequencies. Where the wanted signal is stronger, it will be more immune to interference.
- How the population is distributed. The curves show a uniform distribution and a distribution where the population is clustered around the wanted signal transmitter, with the population density being inversely proportional to the distance from the transmitter. In the latter case, a smaller proportion of users will experience the edge of coverage conditions.

### 3.1.2 Other factors that may give rise to apparent differences

We next discuss the other factors that may give rise to apparent differences between theory and experience in more detail:

- Our analysis assumes that all user system equipment is of the highest quality and hence will show the effects of interference. In reality there is a wide range of equipment performance; for example, in our discussions, the BBC indicated they have measured a 13dB range in the sensitivity of FM receivers.
- Our analysis assumes that the wanted signal service quality is affected by the interference. This can depend on the nature of the service and may also depend on the ability of the user to detect interference (for example the difference between "BBC engineers' ears" and the general public).

For example, in our shortwave and FM radio tests at home and in the lab we were able to detect the interference on a clean channel, but unable to detect any impact under the same circumstances when the receiver was tuned into an adjacent channel carrying speech or music content.

- People may not complain if their ability to use the service is not affected, whereas we set a noise rise threshold to define interference. For example end users of an operational business service such as private mobile radio service are unlikely to complain if they are still able to operate their business, albeit with slightly degraded quality.
- Different people have a different propensity to complain. They may put up with a somewhat degraded service or indeed may not know how to channel their complaint about interference.
- The probability of interference in practice will be related to the correlation between the penetration/density of PLT devices and their geographic distribution in relation to the victim systems. For example if most users of a particular service (e.g. shortwave listeners) were to be in rural areas, there would be a much lower density of PLT devices and the probability of interference would be much lower. Alternatively, users in areas of very high density housing (e.g. blocks of flats) may well have a higher probability of interference.
- While we have made every effort to use accurate assumptions for all parameters, there is uncertainty in some figures which could have an impact on the results. A specific example is the antenna gain assumed for the house wiring. Specifics of UK wiring could result in a different gain to that measured in previous tests.
- Most significantly, the number of complaints cannot be higher than the number of users of the systems being interfered with.

# 4 If action is taken to ensure that all the planned mitigation techniques are implemented, the probability of interference to the majority of HF and VHF users up to 2020 is low

We have concluded that, if uptake increases in line with our market forecasts, there will be a high probability of interference to HF users by 2020 if PLT device features do not change from those currently implemented. However, based on our discussions with PLT suppliers, within this timescale additional interference mitigation features such as power control and smart notching should have been implemented in PLT devices and will be enough to reduce interference to negligible levels for most HF users. The exception to this is the safety critical aeronautical bands which we recommend are notched by default rather than smart notched.

While power control and smart notching are already part of the product roadmaps of the PLT vendors that we spoke to as part of this study, we believe that action is necessary to ensure their timely and consistent implementation in PLT devices.

In addition our study has considered the potential for interference from emerging PLT devices at VHF. While this is less of a concern than at HF due to reduced PLT device power levels, we conclude that action does need to be taken to protect VHF users including safety critical aeronautical systems.

As PLT devices have the potential to cause interference via a number of mechanisms, this section introduces how we have categorised interference from PLT and our top level findings for each of these categories.

We have taken a statistical approach to defining the probability of interference, and our calculations are based on edge of wanted signal coverage, which is typically defined by the minimum planned signal level of broadcast signals, or the required signal noise ratio for ‘unmanaged’ systems.

## 4.1 Interference via all of the assessed routes is manageable but requires action

Interference from PLT devices may reach victim receivers via a number of routes. For the purpose of this study, as shown in Figure 3, we have split these into the following two generic categories:

- **Direct PLT powerline radiation, radiated emissions directly from the PLT user's home** - The mains wiring of the house where the PLT device is being used will act as an antenna and the signal injected into the mains wiring by the PLT device will be radiated.

- **Indirect PLT powerline radiation** - The PLT signal injected into the mains wiring within the home will potentially be conducted into the mains wiring external to the house. Interference could therefore be caused by radiated emissions from wiring nearby to the victim receiver that shares a mains connection with the PLT user.

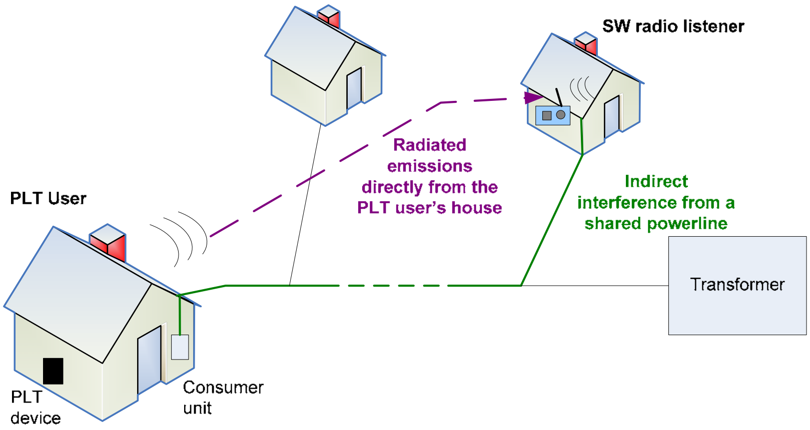

**Figure 3 - Categories of interference mechanisms from PLT devices**

We conclude that potential interference from PLT devices via both of these routes is manageable but needs action to encourage implementation of the required interference mitigation in a timely manner. A summary of our results within these two categories are given in the remainder of this section.

### 4.1.1 Radiated emissions directly from the PLT user's home are manageable but require action

#### Radiated emissions from PLT devices in the HF band

- The majority of current in-home PLT devices operate in the HF band; radiated emissions from these devices may propagate and potentially cause interference via a variety of mechanisms. These are discussed further in section 8.1 but for the purpose of this study have been divided into the following categories:
- Cumulative effect of radiated emissions to ground based HF users arising from PLT devices distributed:
  - over large areas via groundwave and skywave
  - over small areas (i.e. within 1-2km of the victim receiver)
- Cumulative effect of radiated emissions to airborne HF users

**Ground wave propagation occurs a certain distance into the far field, as the wavelengths at HF are long relative to the height above ground of the propagation path. The electromagnetic wave develops from a space wave into a surface wave travelling along the earth-air boundary.**

**Sky wave is an anomalous propagation mode that gives HF radio many of its useful long-range characteristics. Energy radiated at an angle upwards from the earth remains as a space wave rather than a surface wave. Upon reaching the ionosphere it may be reflected back towards the earth. In this case the wave will reach the earth again at a signal level much higher than the ground wave at the same point due to the lower rate of attenuation with distance.**

In the case of interference to ground based HF users we have concluded the following:

- ***Cumulative effect of radiated emissions to ground based HF users over large areas* -** We have concluded that PLT interference from a cumulative ground wave effect over large areas is unlikely, using the GRWAVE[1] tool to confirm this. By scaling results from a previous NATO study [5] to our own market forecasts for PLT devices we have also concluded that there is no significant threat of PLT interference from a cumulative effect of sky wave over large areas.
- ***Cumulative effect of radiated emissions to ground based HF users over small areas*** - The main focus of our analysis of radiated emissions from PLT devices has been the probability of interference from the cumulative effect of radiated emissions to ground based HF users over small areas (i.e. within 1-2km of the victim receiver). Our simulation results show that across the three classes of victim receivers examined in detail, interference from PLT devices is manageable but does require action to ensure that interference mitigation features are implemented in a timely manner.

In practice all victim receivers will receive some interference from PLT devices via all of the mechanisms listed above. However, of these mechanisms the cumulative effects from both skywave and groundwave over large areas are negligible in the majority of cases and so we conclude that interference to ground based HF users will be dominated by emissions from nearby PLT devices.

Table 1 summarises results from our simulation model (modelling radiated emissions over small areas) across the victim receiver types examined over the short, medium and long term. The probability of interference is categorised as follows:

| **Definition used** | **Probability of interference** |
|---|---|
| Negligible | <1% (at edge of coverage) |
| Low | 1-5% (at edge of coverage) |
| Medium | 5-20% (at edge of coverage) |
| High | >20% (at edge of coverage) |

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[1] GRWAVE is a software implementation of the ITU standard for ground wave propagation, ITU-R P.368-7 [4].

It is important to note that these results are for a user situated on the edge of the coverage area at present. For users in a good signal area the probability of interference is reduced as discussed in Section 3.1.1 of this report.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Note: Interference effects estimated at limit of wanted signal / range** | | | |
| **Shortwave broadcast listener** | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added. | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added |
| **Amateur radio** | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added |
| **Aeronautical groundstations** | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied |

**Table 1 - Summary of HF modelling results (forecast for year end of dates shown)**

Note: at end-February 2010, Ofcom has received 208 complaints about interference with shortwave broadcast radio and radio amateur reception. No complaints have been received concerning aeronautical groundstations - see the discussion on possible reasons for this in Section 3.

While the results above represent the majority of HF users, the exception to this is airborne HF users who have line of sight to a large number of PLT devices. Our conclusion for this user group is as follows:

- ***Cumulative effect of radiated emissions to airborne HF users -*** We have considered interference to airborne HF users based on a study of the effects of PLT within ITU-R [6] scaled to our own market forecast for PLT devices. Our analysis has shown that power control, notching and a reduced maxium Power Spectral Density (PSD) of -55dBm/Hz for PLT devices need to be applied to the aeronautical bands to bring interference to manageable levels, assuming 2020 PLT device density.

## Radiated emissions from PLT devices in the VHF band

Future PLT devices will increasingly operate above 30MHz, with devices already in the UK market operating up to 300MHz. We have therefore also examined potential victim receivers at VHF.

Our simulations show that while PLT transmit power levels have been greatly reduced in the VHF bands compared with lower frequencies there is still scope for interference and that notching will be required at these bands in a similar way to the default IARU notches currently implemented at HF. In addition our results highlight safety critical aeronautical Instrument Landing System (ILS) localisers as being a borderline case for suffering from interference and we recommend that these are notched as a precaution. Notching of these bands would lead to only a small reduction in the peak data rate capability of the PLT devices. Table 2 summarises results from our simulation model across the three victim receiver types examined (details are given in Section 7) over the short, medium and long term.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Note: Interference effects estimated at limit of wanted signal / range** | | | |
| **FM listener** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Reduces to low probability of interference if smart notching is applied. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if smart notching is applied. |
| **Narrowband FM** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if notching is applied. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if notching is applied. |
| **Aeronautical radionavigation** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Low probability of interference if notching is applied | High probability of interference if no mitigation is applied<br>Low probability of interference if notching is applied |

**Table 2 - Summary of VHF modelling results (forecast for year end of dates shown)**

Note: at mid-April 2010, no complaints have been received by Ofcom concerning these systems - see the discussion on possible reasons for this in Section 3.

### 4.1.2 Power control is needed to mitigate indirect interference from a shared mains connection

Interference from indirect PLT powerline radiation via a shared mains connection can be encountered:

- Outdoors via overhead powerlines
- Indoors via radiated emissions from the wiring of the victim receiver's house due to the house sharing a mains connection with a PLT user.
- Section 11 illustrates that the likelihood of interference via both routes, but in particular via the second, will grow to a significant level in the next 5 to 10 years if no action is taken. However, power control, which is planned to be included in PLT devices by mid 2010, should significantly reduce the risk of interference via both of these routes to low levels.
- It should be noted that there is uncertainty over interference via both of these routes due to a lack of data on the filtering effects of consumer units for PLT signals. Further measurements to confirm this effect in UK homes are recommended.

## 4.2 Inputs to our interference assessment

To assess the potential for interference from PLT devices via each of the routes discussed in section 4.1 we first confirmed the following inputs:

- PLT device technical characteristics and uptake, both now and over a 5 to 10 year timeline
- Technical characteristics of existing HF and VHF users.

During the study we contacted stakeholders from the PLT industry to understand the current state of PLT standards[2], the likely future direction of these, technical characteristics of PLT devices and PLT product roadmaps in particular for interference mitigation features. Details of our findings in these areas along with our market forecast for PLT devices are given in Section 5.

In summary, in each of the interference scenarios discussed above we have assumed the following characteristics for PLT devices:

- Below 30MHz, a quasi peak transmit power level of -50dBm/Hz as is the maximum for UPA devices which are currently the dominant standard in the UK
- Between 30MHz and 300MHz, a quasi peak transmit power level of -80dBm/Hz as is being discussed for future standards such as ITU G.hn
- Default notching of IARU bands
- Notch depths of 30dB
- Power control available from mid 2010

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[2] We refer here to manufacturers standards, not harmonised standards

- Smart notching available from Q3 2010.

During this study we have also engaged with existing HF and VHF spectrum users to check our assumptions in terms of victim receiver characteristics.  We have concentrated on the following three victim receiver scenarios at HF:

- Shortwave broadcast listener
- Amateur radio user
- Aeronautical ground station.

The following victim receivers were examined at VHF:

- FM radio listener
- Narrowband FM user
- Aeronautical radionavigation.
- In Sections 6 and 7 we give details of how these victim receivers were selected and the technical characteristics that we assumed for each.
- A full list of the organisations that were contacted during the study is given in Appendix A  and we thank them for their contributions.

# 5 Applications, market forecast and technical characteristics for PLT devices

To analyse interference from PLT devices we require an understanding of the technical characteristics of PLT devices, where they are used and how many PLT devices we expect to be deployed in the UK over the next 5 to 10 years. This section presents an introduction to PLT devices on the market today, our market forecast for uptake of PLT devices in the next 5 to 10 years and the technical characteristics of PLT devices now and in the future.

## 5.1 Applications of in-home PLT devices

There are two main types of PLT devices for consumer applications (as opposed to internal use by electricity utilities). These are Access PLT, also called broadband over powerline or BPL, and in-home networking. Access PLT is not deployed commercially in the UK and is not within the remit of this study, so we focus on in-home networking applications.

For in-home networking, PLT devices inject a high frequency data signal, typically in the frequency range of 2-30MHz, into the consumer's existing mains wiring. At any power outlet in the house this data signal can then be filtered and recovered from the underlying 50Hz mains via a second PLT device thus providing a data connection between rooms without having to install dedicated network cables.

These devices are increasingly being used in the UK and Ofcom estimated that at September 2009 there were approximately 750,000 pairs of PLT devices in the UK [7]. In-home PLT products are also becoming more widely available from retailers with typical search results for PLT products in February 2010 returning:

- 41 at DABS
- 49 at Amazon
- 18 at PC World.

The chipsets for the majority of these products come from Intellon (recently acquired by Atheros) and DS2 with big brands such as Netgear and Belkin amongst those offering in-home networking PLT devices. The most common data rates on offer are 14Mbps, 85Mbps and 200Mbps, but recently Belkin devices at 1Gbps have also become available in the UK.

Depending on the target application, in-home PLT devices come in various forms such as:

- Single Ethernet connections
- Ethernet hubs

- Combined devices giving the option of networking via power line or coaxial
- PLT combined with a WiFi access point
- PLT combined with an ADSL modem
- Part of a multimedia package such as BT Vision.

By far, the largest population of in-home PLT devices in the UK is from BT Vision installations rather than from retailers. BT Vision provides a video-on-demand service to consumers via their BT broadband connection and includes a pair of Comtrend in-home networking PLT devices to allow the subscriber to extend their BT broadband connection to the location of their TV.

Smart grid applications for monitoring energy usage are gaining interest in the electricity industry. However, current PLT standards for monitoring energy usage and controlling home heating or air conditioning systems, such as Homeplug Command and Control, operate at low data rates in the CENELEC frequency band (9 - 149 kHz) and are unlikely to cause interference. Future industry standards, such as Homeplug Green PHY, that expand smart grid applications to include monitoring throughout a utility company's infrastructure are considered not to be in-home networks and so are outside the scope of this study.

In summary, in-home networking PLT devices currently on the market generally target:

- Networking of IT equipment such as sharing a broadband connection around the home or connecting to peripherals such as a printer.
- Distribution of audio visual signals around the home in particular for IPTV applications.

Throughout this study we have assumed PLT usage scenarios based on the two applications listed above. A fuller description of PLT usage scenarios and their position relative to competing technologies is given in Appendix E . These usage scenarios have been used throughout this study when considering:

- Market forecasts for PLT devices
- Proximity of PLT devices to victim receivers
- Duty cycles of PLT devices incorporating the correct split between the number of devices in idle mode and those transmitting data.

## 5.2 Expected uptake of PLT devices

To model interference from PLT devices over the next 10 years, PA needed to understand how many PLT devices would be deployed over this timescale. We therefore produced a model to estimate the expected consumer market uptake of PLT devices from now until 2020. The market model is summarised in this section and a full description is given in Appendix F .

Our market estimates have been derived as follows:

- From PLT device shipment figures and our discussions with stakeholders we understand that approximately 3% of UK households in 2009 had a PLT device, with BT Vision dominating this figure.
- From section 5.1, we have assumed that the increase in uptake of PLT devices will depend on two main markets; IPTV with PLT distribution (e.g. BT Vision) and Home networking (i.e. retail sales).
- We have assumed that the uptake of PLT-distributed IPTV will be driven by:
- The number of UK homes with broadband
- The positioning of IPTV relative to other TV packages available via cable or satellite
- The propensity for IPTV providers to supply their package with alternative distribution.
- We have examined the uptake of competing technologies such as WiFi, statistics from market surveys on in home networking, the number of homes with broadband connections and the uptake of IT equipment such as PCs to understand the uptake of home networks over the next 10 years.
- We have estimated the total number of PLT devices that will be deployed by combining our estimates from the IPTV and home networking markets and allowing for an appropriate overlap between these two markets.

Our model includes a low, medium and high uptake for PLT devices based on the following scenarios:

- ***Low Scenario*** - We assume that BT Vision has reached its maximum market share and continues to grow slowly allowing for the fact that the number of homes with broadband and therefore potential BT Vision customers will increase. In the home networking market PLT struggles to differentiate itself against WiFi and takes a low share of this market.
- ***Medium Scenario*** - We assume that BT Vision continues to increase its market share slightly behind BT's own market forecast on the basis that the uptake has been below forecast until now. In the home networking market we assume that PLT devices slowly increase their market share but remain a minor player in this market due to the lack of convergence of standards and continuing dominance of WiFi.
- ***High Scenario*** - We assume that BT Vision reach their previous target of 2-3 million customers by 2011 and continue to grow at a similar rate over the subsequent years. In the home networking market we assume that PLT steadily increases its market share to 20%. Again, even in a high scenario, we do not anticipate PLT dominating the home networking market in the next 10 years

due to absence of a single standard, no obvious cost advantage (especially as interference mitigation solutions are implemented) and the current dominance of WiFi.

- The low, medium and high scenarios are driven by our assumptions on the proportion of UK broadband households that by 2020 will have IPTV and the proportion of the home networking market that PLT devices will have captured. These assumptions are shown Table 3.

Based on these assumptions our model estimates the uptake of PLT devices as shown below. The number of UK households with PLT devices is shown in Figure 4 and the proportion of UK households with PLT is shown in Table 4.

| | Low | Medium | High |
|---|---|---|---|
| **Proportion of broadband homes with PLT-distributed IPTV** | 10% | 20% | 30% |
| **Proportion of home networking market using PLT** | 2% | 10% | 20% |

**Table 3 - Assumptions on PLT uptake for 2020**

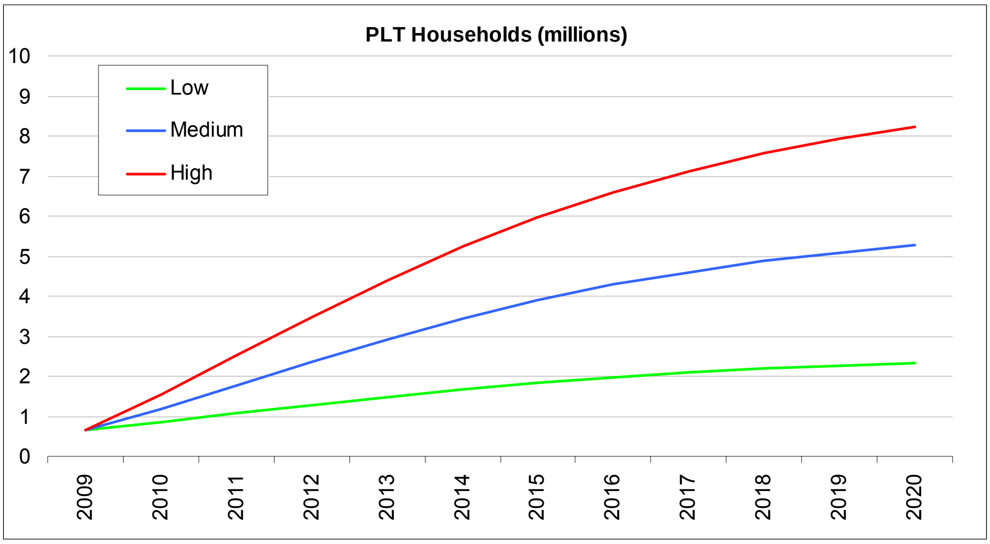

**Figure 4 - Estimated number of UK households with PLT devices up to 2020**

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Low scenario** | 4% | 8% | 9% |
| **Medium scenario** | 5% | 16% | 21% |
| **High scenario** | 7% | 25% | 33% |

**Table 4 - Estimated proportion of UK households with PLT devices up to 2020**

Our assessment in the remainder of this report is based on the medium scenario forecast. The high and low scenarios are considered in the sensitivity analyses in sections 9.3.1 and 10.3.1.

A housing density representative of an urban area is used for the modelling for two reasons:

- The small distance between households means that it is the worst case in terms of proximity of PLT devices to radio receivers
- The UK has a high degree of clustering, meaning that the majority of the population live in a small proportion of the land area and hence in relatively high housing density areas

Multiplying the household density by the forecast market uptake of PLT gives the densities of PLT users, summarised in Table 5.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Households per km2** | 3074 | 3184 | 3298 |
| **PLT users per km2** | 159 | 518 | 703 |

**Table 5 – Market forecast of UK households with PLT devices up to 2020**

## 5.3 Technical characteristics of PLT devices now and in the future

This chapter details progress in industry standards for in-home PLT devices that have been agreed amongst PLT vendors. It is not mandatory for all PLT devices to comply with these standards, but these standards give guidance on the technical parameters that PLT vendors must meet to ensure interoperability, compatibility and certification against a known industry benchmark.

There is much debate and concern around EMC testing for PLT devices. While it is not within the remit of this study to comment on this subject, we have given an overview of the relevant standards in Appendix G.3 and future changes to these that are currently under discussion in Appendix H.3. It should be noted that in Europe the Harmonised Standards used for EMC testing are not mandatory and while introducing features to these standards would generally encourage their uptake within the PLT industry, this would not directly make these features mandatory in all PLT devices.

### 5.3.1 Current PLT industry standards

There are three industry standards[3] widely used in in-home PLT devices on the market today; Homeplug, Universal Powerline Alliance (UPA) and High Definition Powerline Communication (HD-PLC). Of these UPA is understood to be the most common in the UK due to the widespread usage of the Comtrend powerline adapters in BT Vision installations. An overview of these three standards and their likely evolution is given in Figure 5.

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[3] Note that we refer here to Industry standards rather than Harmonised standards. Industry standards are either proprietary to one manufacturer or common across a range of manufacturers, possibly because silicon vendors implement a feature and sell devices to several equipment vendors. Harmonised standards have to be created by a recognised standards body (e.g. CENELEC, ETSI); compliance with harmonised standards is not mandatory, but may be used as a presumption that essential requirements of a European Directive have been met.

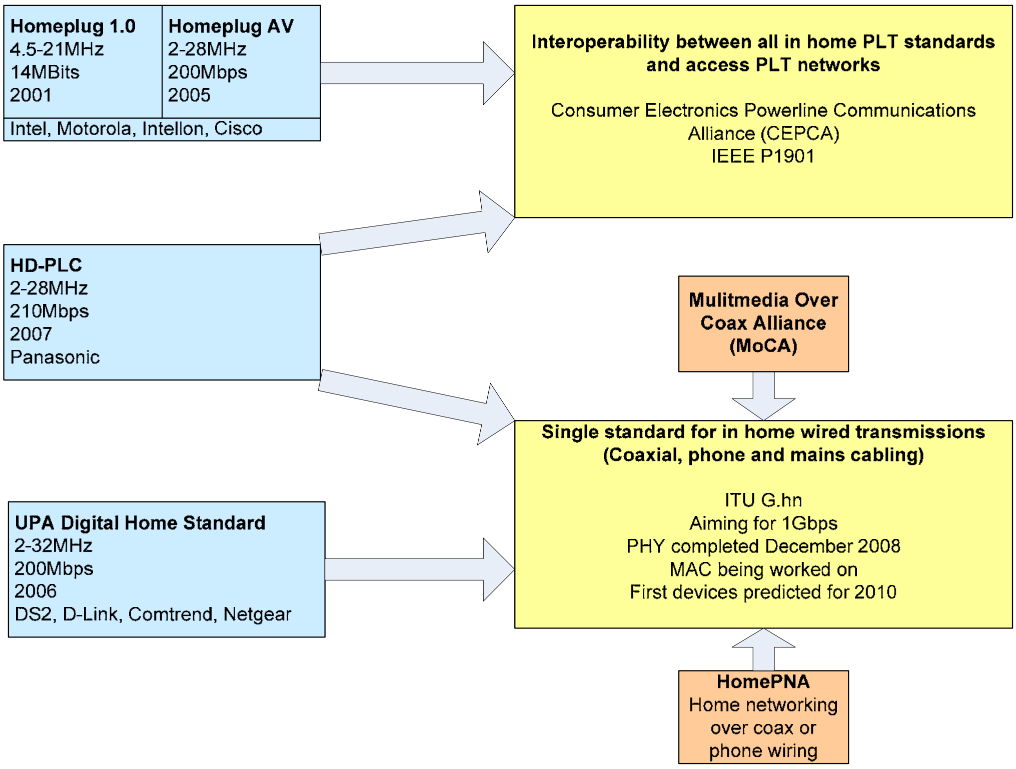


**Figure 5 - Overview of the standards landscape for in-home PLT devices**

The latest generations of each of today's three main standards are very similar and have the following features:

- An OFDM waveform
- Data rates around 200Mbps
- Frequency range from 2 to 30MHz +/- 2MHz
- Default notches applied in the IARU bands of 30 to 40dB in depth.

There are some differences between the standards such as sub-carrier spacing and operation in idle mode and these are detailed in Appendix G . In terms of interference, the main differences are:

- The maximum quasi peak transmit power for UPA is -50dBm/Hz whereas Homeplug operates at -50dBm/Hz in the US and -55dBm/Hz in Europe
- UPA uses a token passing Medium Access Control (MAC) which means the device has a 30% duty cycle in idle mode. In contrast Homeplug AV has a 1.25% duty cycle in idle mode due to its TDMA based MAC.

### 5.3.2 Future PLT technical standards

As shown in Figure 5 there are two new standards in development. These are:

- IEEE P1901 which aims to define protocols to ensure interoperability between existing standards
- ITU G.hn which creates a completely new in-home networking standard to replace the existing three PLT standards and combines PLT with networking via coaxial and telephone cables.

From our stakeholder discussions there is no sign of these two routes converging and support from PLT vendors and existing standards is split between the two. This lack of a single industry standard may affect the market uptake of PLT devices and continue confusion amongst consumers and service providers over the technology.

The future direction of PLT standards is discussed in more detail in Appendix H . While future PLT standards look set to be based on OFDM waveforms in a similar way to today's technology, the following two main developments are anticipated:

- Higher speed devices operating above 30MHz
- Improved interference mitigation.

### 5.3.3 Higher speed devices operating above 30MHz

One trend that does look set to continue across the standards is development of higher data rate devices. This will require wider bandwidths and means that we can expect PLT devices to be expanding their operating frequency range to above 30MHz.

Indeed, 1Gbps PLT devices have recently been entering the UK market in Belkin products based on a Gigle chipset. This chipset combines Homeplug AV with a proprietary technology that uses spectrum up to 300MHz. These devices do not represent an official extension of the Homeplug or UPA standards, but give an indication of how higher data rate future PLT devices may operate.

Notably the transmit power of the Gigle chipset is much lower above 30MHz at -80dBm/Hz compared to -50dBm/Hz below 30MHz. This reduced transmit power above 30MHz has been selected with the aim of ensuring that the radiated emissions from PLT devices using this chipset fall below the CISPR guidelines and are claimed to be fully EMC compliant.

The proposed ITU G.hn standard includes the option of operation up to 200MHz. As with the Gigle chipset the transmit power is greatly reduced above 30MHz to a maximum transmit PSD of -80dBm/Hz.

### 5.3.4 Improved interference mitigation

From discussions with stakeholders the two main interference mitigation features on PLT device manufacturers' roadmaps are:

- Dynamic power control estimated to be available Q2 2010. This will adjust the power between two PLT devices to the minimum level to achieve the required data rate and will provide an overall reduction from the current situation where maximum transmit powers are used constantly.
- Smart notching is estimated to be available from Q3 2010. This provides a monitoring function in the chipset which will detect the presence of transmissions to which PLT devices may cause interference and apply a frequency notch as appropriate.
- Smart Notching has been investigated within ETSI with guidelines for signal detection and notch depth published in 2008 [8]. Plugtests, carried out in 2007 by ETSI using Sony and DS2 smart notching demonstrators, have shown the feasibility of smart notching and have given the encouraging results that shortwave radio stations were received as well when smart notching was activated as when there were no PLT devices active [9]. It is worth noting that the IP for smart notching via this route is owned by Sony and so there could be an additional cost to PLT vendors if this feature was required. However, it is quite usual in communications standards, such as 3GPP, that vendors will own IP that is essential to implementing that standard. In this case ETSI have arrangements with such vendors that they will licence their IP at a fair cost so that royalty fees do not prohibit other vendors from implementing the standard. Something similar could perhaps be done for smart notching in PLT. Alternatively vendors could use a different approach such as for example using a database of victim receiver systems and applying notches based on knowledge of the PLT device's location. It should be noted that Smart Notching does not necessarily operate effectively down to ambient noise level, but it has been demonstrated to the 'minimum planned signal level' of other systems such as short wave radio.
- Transmissions during idle time are also a concern and ITU G.hn is currently looking at power saving solutions which will reduce transmissions and interference particularly in idle mode.

While these interference mitigation features are part of PLT product roadmaps in the near future, they are not currently implemented in HF PLT devices today. From our discussions with stakeholders we also understand that interference mitigation techniques are not currently applied in PLT devices operating above 30MHz. This is because interference is not anticipated due to the reduced power level of -80dBm/Hz and the higher loss of mains cabling with increasing frequency.

*For practical confirmation of the interference potential above 30MHz, we placed a FM radio next to a PLT device operating above 30MHz and heard an audible background "clicking" noise when the PLT was active. However, this interference was at a much reduced level compared to when a shortwave radio was placed next to the same PLT device and was not audible with all FM radios that we tested.*

ITU G.hn is the only PLT industry standard we found which included operation above 30MHz. This does not specify interference mitigation techniques above 30MHz but does specify that all sub-carrier power levels are controllable which would facilitate interference mitigation techniques being added if required.

While interference mitigation is difficult to mandate directly it could be implemented by its inclusion in Harmonised Standards relating to EMC compatibility of PLT devices. Indeed power control and smart notching are already being discussed in CISPR 22.

### 5.3.5 Summary of in-home PLT features now and in the future

In Figure 6 we summarise the roadmap of features that we anticipate in PLT devices. When modelling interference from PLT devices over the next 5 to 10 years, we have considered the impact of the interference mitigation features that are planned to be available in these timescales.

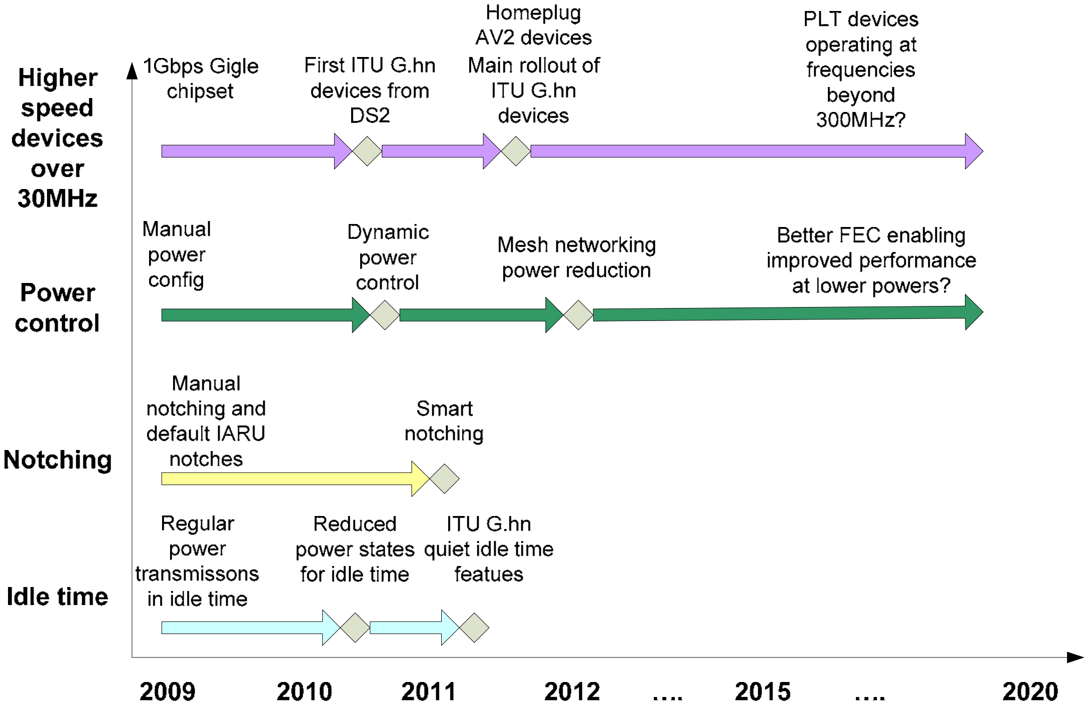


**Figure 6 - Roadmap for PLT devices over the next 5 to 10 years**

# 6 HF Victim systems

This section introduces the existing HF spectrum receiving systems which may suffer interference from PLT devices; these are termed "victim receivers". Throughout this study we have focused on three HF victim receiver types. This section discusses our selection of these three victim receiver types and the technical characteristics we have assumed for each of these based on our stakeholder discussions.

## 6.1 2 - 30 MHz radio frequency usage in the UK

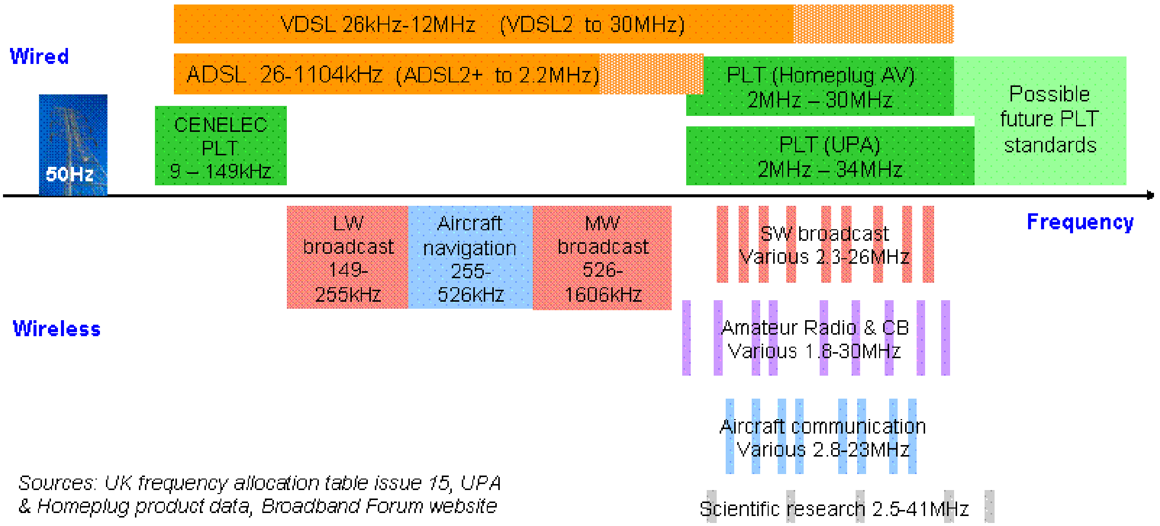
PLT devices operate in a range of approximately 2 to 30MHz, depending on which standard is selected. This frequency range is used by other radio and wired communication systems and where the frequencies overlap there is potential for interference. The main wired system at risk from PLT usage is broadband to the home being delivered via VDSL.

The 2 to 30MHz range is used by radio systems that require long range communications. Long range in this context means over-the-horizon paths that cannot be achieved reliably with VHF or higher frequencies. The UK Frequency Allocation Table contains entries for the following uses:

- Short wave broadcast
- Amateur Radio
- Aeronautical
- Marine (Coastal waters)
- Military and Diplomatic
- Scientific Research including Radio Astronomy
- Analogue Cordless Phones

In addition Citizens' Band (CB) radio is a licence-exempt use at 27MHz, on the basis of being a secondary user in spectrum that is primarily allocated to the MoD.

The frequencies involved are illustrated in Figure 7.



*Sources: UK frequency allocation table issue 15, UPA & Homeplug product data, Broadband Forum website*

**Figure 7. Wired and wireless spectrum usage**

As discussed in section 5.3.3, there are currently PLT devices on the market that operate above 30MHz and this trend is set to continue in future standards. Potential victim systems for these devices are considered in section 7.

## 6.2 Selection of example receivers and focus of this study

In the initial prioritisation we considered the following potential 'victim receivers':

- ***Shortwave broadcasting*** has already been the subject of a number of other studies examining potential interference from PLT. However due to the international protection agreements in place we have decided to include this in the modelling.
- ***Amateur radio*** is a relatively high priority as most of the complaints about PLT received by Ofcom have come from this user group, often in the context of shortwave broadcast listening.
- ***Aeronautical ground stations*** have an important safety role and so are a high priority.
- ***HF maritime land stations*** no longer exist in the UK, and MF (up to 3MHz) is used in coastal waters only[4]. Distress calls are being migrated from MF to VHF or UHF for monitoring by satellite and aircraft in all waters for which the UK is responsible. Maritime land stations were therefore not modelled.
- ***Defence and diplomatic users*** are few and from our discussions with MOD there have so far been no reports of PLT causing interference with defence HF systems in the UK. In addition defence users have been the subject of a detailed study carried out recently by NATO. They have therefore not been modelled in this study.
- ***Scientific research*** at HF appears to be mostly radio astronomy. This uses specialised receivers and antennas, and various techniques are used to mitigate noise in order to observe signals well below the existing noise floor. Radio astronomy requirements in relation to PLT have been the subject of a recent ITU report [6]. Additionally, this type of use is far removed from most other uses of HF in the UK. It was therefore not modelled.
- ***Analogue cordless phones*** use HF for historic reasons and only operate over a very short range. They are being phased out and so were not modelled.

The following three victim user types were therefore selected for detailed modelling:

- Shortwave broadcast listener - a listener to (usually foreign) broadcast radio stations. Programme content rather than technology is important.
- Radio amateur – technically literate and has passed exams to obtain licence. Has probably invested significant time and money.
- Aeronautical ground station professional user - full-time trained operating staff with expert technical back up. Controlled environment with funding available. This user type will also act as a proxy for other professional HF users.

In addition to radio systems, the potential for interference from PLT to DSL services was considered though not modelled in detail as with the other victim receiver types.

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[4] Source: Maritime and Coastguard Agency, October 2009

## 6.3 Victim receiver characteristics and proximity to PLT

From discussions with user representatives and examination of equipment data we have drawn up profiles of the three victim user types. These are described in this section.

### 6.3.1 Shortwave Broadcast Listener

| | |
|---|---|
| **Devices being interfered with** | Consumer grade multi-band AM receiver. (Migration to DRM is starting but small market share and slow uptake so not included here) |
| **Correlation with PLT use** | Similar locations and probably similar hours |

### 6.3.2 Radio Amateur

| | |
|---|---|
| **Devices being interfered with** | Various types in use, but most common is a multi-band SSB transceiver |
| **Correlation with PLT use** | Similar locations and probably similar hours |

### 6.3.3 Professional User (aeronautical ground station)

| | |
|---|---|
| **Devices being interfered with** | Multi-band SSB transceiver |
| **Users & Locations**[5] | Easyjet are known to use HF for operations management and are understood to have ground stations at Luton and East Midlands airports.<br>Airliners use HF in the air and on the ground. In the case of foreign airliners they will be communicating over a long range to their home country whilst on the ground in the UK.<br>The only HF ground station used by NATS is in Ireland and so outside Ofcom's area of jurisdiction. It is in a rural area with no major urban areas nearby. |
| **Correlation with PLT use** | Assume 24 hour, 365 day use possible. Immediate area probably has little or no PLT. Suppression of nearby mains cables may be possible |

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[5] Source: Civil Aviation Authority, October 2009.

Based on our discussions with various HF user stakeholders, the three victim receivers have been specified in the model as described in Table 6.

| **Victim User Type** | **Shortwave Broadcast Listener** | **Radio Amateur** | **Professional User** |
|---|---|---|---|
| **Rx sensitivity** | -115dBm | -118dBm | -116dBm |
| **Rx noise bandwidth** | 4kHz | 2.2kHz | 3kHz |
| **Antenna type** | 0.5m vertical whip | G5RV horizontal dipole | Equivalent to G5RV |
| **Source of noise level** | ITU-R BS.703 (3.5uV/m) | ITU-R P.372, Residential | ITU-R P.372, Business |
| | | | |
| **Frequency 1** | 2.3MHz | 3.5MHz | 3.0MHz |
| **Antenna gain at f1** | -3dBi average | +2dBi average | +2dBi average |
| **Noise level at f1** | -78dBm | -84dBm | -78dBm |
| | | | |
| **Frequency 2** | 7.1MHz | 7.1MHz | 9.0MHz |
| **Antenna gain at f2** | -4dBi average | +1dBi average | +1dBi average |
| **Noise level at f2** | -89dBm | -94dBm | -92dBm |
| | | | |
| **Frequency 3** | 26MHz | 28MHz | 23MHz |
| **Antenna gain at f3** | -5dBi average | 0dBi average | 0dBi average |
| **Noise level at f3** | -101dBm | -111dBm | -104dBm |

**Table 6 – Victim receiver characteristics**

The above figures have been derived by the following methods:

- Receiver sensitivity - comparing published performance data, or standards for the broadcast receiver, and adjusting where necessary to give the RF power level into 50Ω needed to obtain a 12dB signal to noise ratio (SNR).
- Receiver noise bandwidth – published performance data, or standards for the broadcast receiver.

- Antenna type – examination of example broadcast receivers; discussions with amateur radio representatives; professional users assumed to have equivalent antenna performance to radio amateurs' equipment.
- Frequencies – for each user type, the lowest and highest bands within the range 2 to 30MHz as given in UK Frequency Allocation Table, and a band near 7.75MHz (the geometric mean of 2 & 30MHz).
- Antenna gain – average gain as determined by modelling the selected antenna in EZNEC [10].

  Note that the antenna types used have broadly omni-directional characteristics. This is appropriate given that each user will either have portable equipment or be receiving transmissions from a wide range of azimuths. We are aware that some better equipped amateurs use Yagi style directional antennas with rotators. It is also possible that some professional users may have a similar arrangement.

  As these directional antennas are presumably aligned towards the wanted transmission, the effect will be to attenuate PLT emissions from azimuths outside the main lobe, whereas those in the main lobe will be amplified to the same extent as the wanted signal. Such configurations will therefore be less prone to interference than the omni-directional antennas that have been modelled.
- Noise level – sources as described in the table.

## 6.4 Potential interference with ADSL and VDSL

Whilst not formally within scope of this work, during our stakeholder discussions there have been some suggestions that PLT may cause interference to ADSL and VDSL services. However, we were unable to find evidence of deployed PLT devices causing interference to ADSL or VDSL services to support and quantify these claims. Ofcom has not as yet received any complaints of PLT devices causing interference to xDSL services, although such complaints would typically be referred to the user's broadband provider, who may or may not pursue it. However, we recommend that Ofcom monitor this area to see if the situation changes as the UK migrates to ADSL 2 and VDSL.

Most xDSL deployed in the UK so far is ADSL. This has a maximum frequency of 1.1MHz and so does not overlap with the spectral mask of PLT devices. BT has recently announced that 40% of the population can now receive ADSL 2+ [11]. This operates up to 2.2MHz so has a slight overlap with in-home PLT devices. However, this overlap is too small for most users to have noticed any impact on data rate that might be due to PLT devices.

The real impact will only be seen if and when VDSL is rolled out as this operates up to 12MHz or 30MHz for VDSL2. The first trial deployments of VDSL were taking place during this study and results were not available at the time of writing. ETSI have conducted a "Plugtest" of VDSL alongside current in-home PLT devices, which showed that some level of interference could be created. The worst case was when the mains and telephone (i.e. VDSL) cables were tied together over a length of 40m. In this instance the PLT signal was picked up on the VDSL cable at -121dBm/Hz, which represents a 19dB degradation in the signal to noise ratio and would reduce the VDSL capacity to around 1% of its nominal level. However reducing the parallel cable run to 5m and separating the cables by just 1cm cut the pickup to -135dBm/Hz which would give a VDSL capacity around 60% of nominal. The potential impact is therefore highly sensitive to the proximity of the VDSL cable to the mains cables carrying PLT, with a rapid improvement achieved by a small separation of the cables.

If PLT is proven to couple into telephone cabling at a significant level then headline data rates will suffer and complaints may follow. As there are no commercial deployments of VDSL in the UK as yet, we recommend that Ofcom work closely with BT to monitor the situation of potential interference issues in this area.

# 7 VHF Victim Receivers

## 7.1 30-300 MHz radio frequency usage in the UK

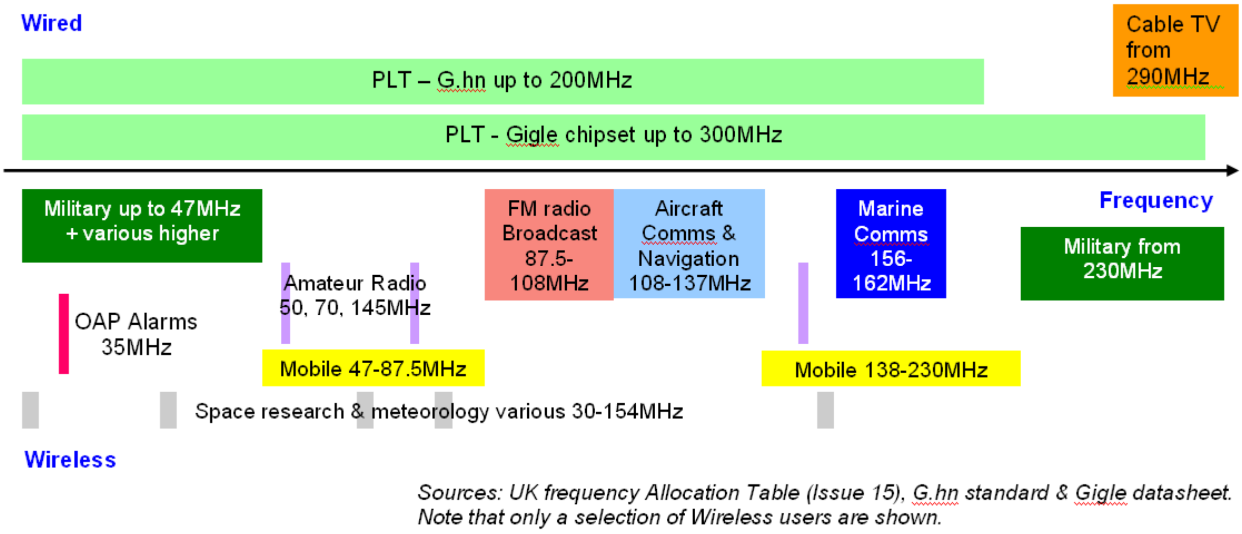
Future PLT devices (including the new Belkin device using the Gigle chipset) are expected to operate using frequencies up to 300MHz. This frequency range is used by other radio and wired communication systems and where the frequencies overlap there is potential for interference. The main wired system using frequencies above 30MHz is cabling for TV and broadband internet access.

The 30 to 300MHz (VHF) range has a wide variety of radio users. This frequency range offers radio systems with engineering that is well proven and economical, having ranges up to and slightly beyond the horizon. Under suitable conditions some over-the-horizon paths can be achieved particularly at the lower end of the frequency range. It is therefore a popular range for wide area coverage of voice and narrowband data systems. It is less suitable for broadband data due to the relatively small bandwidth available compared to the higher UHF and microwave bands that are now available.

In the UK Frequency Allocation Table we have identified the VHF radio user groups to be:

- Broadcast - FM radio
- Amateur Radio
- Land mobile
- Fixed links
- Aeronautical radionavigation
- Aeronautical mobile
- Military fixed, mobile and satellite
- Programme Making and Special Events (PMSE)
- Maritime mobile
- Paging
- Alarms for the elderly and infirm
- Radio controlled models
- Weather radar
- Industrial, Scientific and Medical (ISM)
- Railway video via leaky feeder
- Satellite communications
- Space research.

The frequency bands for many of these user types are illustrated in Figure 8.



*Sources: UK frequency Allocation Table (Issue 15), G.hn standard & Gigle datasheet. Note that only a selection of Wireless users are shown.*

**Figure 8 Wired and wireless spectrum usage in the range 30-300MHz**

## 7.2 Selection of example receivers and focus of this study

In this section we discuss the merits of including analysis of each of these user groups in our study, commenting on the potential impact of PLT interference. This leads to a recommendation as to the three groups that should be analysed in detail.

- Broadcast - FM radio. Broadcast radio stations such as BBC Radios 1 to 4 and commercial radio stations use the 87.5-108MHz band. This attracts many listeners as it is included in nearly all receivers and offers better reception for most users than MW or LW. Broadcast radio as a whole attracts 89% of the UK population at least once a week[6] so interference to this service is likely to impact the largest number of end users. It is therefore considered a high priority.
- Amateur Radio uses several bands across the VHF range and often operates close to the existing noise floor. Equipment may be fixed, mobile, or handheld and the performance characteristics are similar to those of Land Mobile users. This user group has generated most of the complaints received by Ofcom about PLT interference at HF and so is considered a high priority. The most common transmission format at VHF is narrowband FM voice. This is the same as several other user groups, so a generic narrowband FM user has been defined for the purposes of this study.
- Land mobile has one of the largest number of licensees, reflecting its many uses. This covers mobile businesses such as taxis and utilities, transport organisations, local authorities, on-site communications such as security guards, telemetry, wide area paging and many others. The variety of users means that a typical user is difficult to define, however the more sensitive installations will use narrowband FM and will be similar in characteristics to a radio amateur. This group is therefore considered along with Amateur Radio as a generic narrowband FM user.
- Fixed links at VHF will typically be narrow band data or voice, similar in characteristics to Land Mobile systems. For the same reasons as Land Mobile it is therefore covered by the generic narrowband FM user group.
- Aeronautical radionavigation uses the 108 to 118MHz band for the Instrument Landing System Localiser signal (ILS LOC) used at all major airports and for VHF Omnidirectional Range (VOR) radio beacons used for en route navigation. There are also a small number of rarely used beacons that use a band at 75MHz. In poor visibility the ILS signals are the primary means of navigating the aircraft to a safe landing and so interference has major safety implications. Additionally aircraft in flight have been shown to be particularly susceptible to interference from a widespread deployment of PLT [6]. For these reasons this is a high priority. As background, a fuller description of ILS localiser signalling is given in Appendix N.1.
- Aeronautical mobile uses the band from 118 to 137MHz for air traffic control (ATC) communications, using Amplitude Modulation. For reasons similar to those above for aeronautical radionavigation, this is considered a high priority. The bandwidth of AM and hence the amount of PLT power received on a given channel are very similar to narrowband FM. The narrowband FM

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[6] Source: RAJAR figures for 3rd quarter 2009

user is therefore taken as a proxy for ground based ATC receivers, whilst the effects of the receiver being airborne are covered in the analysis of ILS receivers.

- Military fixed, mobile and satellite has primary user status in all of the VHF range up to 47MHz plus various smaller bands at higher frequencies. The MoD also has many allocations at HF but has not reported problems from the many PLT deployments using HF. As the PLT emission levels are lower and the propagation range is shorter at VHF, this is considered a low priority. A new VHF system ‘Link 22’ will be introduced in future, but this is an ECM-resistant system so should not be impacted by PLT.
- Programme Making and Special Events (PMSE) at VHF is typically wireless microphones used at public events, in theatres and similar, and talkback facilities used during filming and outside broadcasts. They may also be used for ground to air links that do not fall within the aeronautical communication category. As for other categories, users within a controlled environment, such as a theatre, are a low priority for this study as the use of PLT can be limited. The wide area uses are similar to Land Mobile/Amateur Radio or Aeronautical Mobile. The narrowband FM user is therefore taken as a proxy for PMSE.
- Maritime mobile uses frequencies around 156 to 162MHz for ship to ship and ship to shore. Ship to ship is considered low priority as PLT use is only likely onshore. Ship to shore however includes distress calls and the receiver station is onshore so this use is regarded as a high priority. The transmissions use narrowband FM and so the narrowband FM user type again covers this application.
- Paging has bands allocated for on-site paging systems at 31MHz (hospitals only) and 49MHz (any site). It is assumed that on-site systems are in locations where PLT use can reasonably be controlled or excluded. All wide area paging systems use either UHF or a few channels within the main Land Mobile VHF band. It should also be noted that currently available PLT devices do not use the frequency range 32-50MHz in which the ‘any site’ paging systems operate. Analysis of paging as a distinct user group is therefore a low priority.
- Alarms for the elderly and infirm have an important safety role and are usually used in a domestic environment. This means that they are liable to be in proximity to wiring carrying PLT signals. However, these devices operate at 35MHz and, as described above, this is not used by the majority of currently available PLT devices, so they have not been considered in detail here. Due to the combination of the probability of being exposed to nearby domestic PLT signals and the impact of any problems with the equipment, this user group will become of increasing concern as higher frequency PLT devices become more commonplace.
- Radio controlled models have allocations at 35MHz (aircraft) and 40MHz (land and water craft) for control of the models. Downlinks such as video feeds are not permitted in these bands. The only receivers therefore are similar to land or aeronautical mobiles with reduced range and transmitter powers compared to the full sized craft. While model aircraft have the potential to cause a safety hazard if their control is compromised by interference, the models are unlikely to be used in close proximity to PLT. And as for the previous categories, currently available PLT devices do not use these frequencies. Radio controlled models are therefore considered low priority for the study.

- Weather radar is allocated 46-68MHz as a secondary user that must be co-ordinated with the other users. It is also likely to be located in a controlled area from which PLT can be excluded. It is therefore considered a low priority.
- Industrial, Scientific and Medical (ISM) is a licence exempt class of use with no protection from radio interference caused by other ISM users. It is therefore a low priority for assessment of interference caused by PLT.
- Railway video via leaky feeder is used to enable a train driver to monitor CCTV cameras on the platform (often on underground systems). There is a small distance between antennas and it is in the controlled environment of a railway platform from which PLT can be excluded. It is therefore a low priority for assessment of PLT interference.
- Satellite communications at VHF are mostly professional or military communication systems, plus an allocation at 145MHz for Amateur Radio. VHF is used for both uplink and downlink. Ground stations will tend to have high gain antennas inclined upwards (i.e. not usually towards PLT sources) and so are considered a low priority. Satellites will have many PLT sources within their coverage area, and could be considered as an extreme case of Aeronautical Mobile with the caveat that the coverage area will not be solely urban and so will have a lower PLT density than for the aircraft case.
- Space research has a primary user allocation at 30.005MHz plus several secondary user allocations. This uses specialised receivers and antennas, and uses various techniques to mitigate noise in order to observe signals well below the existing noise floor. This type of use is sufficiently far removed from most other uses of VHF in the UK that it is not considered to be a priority for analysis.

On the basis of the preceding discussion, we have selected the following user groups as the three for more detailed analysis:

- Broadcast – FM radio listener. This has the largest volume of users and a much wider bandwidth (270 kHz) compared with most users in the VHF band
- Narrowband FM – including Amateur Radio, Land Mobile, Aeronautical Mobile and Maritime Mobile. These groups are sufficiently similar (voice services with only small variations in receiver characteristics between groups) that one analysis can be performed to cover these user groups. As previously noted, although Aeronautical Mobile uses AM rather than FM the characteristics relevant to this study are sufficiently similar that it can be included within this category.
- Aeronautical radionavigation - Instrument Landing System Localiser. This is a safety critical application operating in line of sight of a potentially large number of PLT interferers and which uses sufficiently different transmission characteristics from voice services to warrant separate analysis.

## 7.3 Victim receiver characteristics and proximity to PLT

From discussions with user representatives and examination of equipment data we have drawn up profiles of the three victim user types. These are described in this section.

### 7.3.1 FM radio listener

| | |
|---|---|
| **Devices being interfered with** | Consumer grade wide band FM receiver. (Migration to DAB is starting but small market share so far so not included in detail here[7]) |
| **Correlation with PLT use** | Similar locations and probably similar hours |

### 7.3.2 Narrowband FM

| | |
|---|---|
| **Devices being interfered with** | This represents various users including Radio Amateur, Land Mobile, Aeronautical Mobile and Maritime Mobile. Receivers are mostly narrowband FM, with AM for Aeronautical users. |
| **Correlation with PLT use** | Radio amateur usage is likely to be similar locations and probably similar hours to PLT. Aeronautical Mobile usage will be used at airports which could be in built up areas e.g. London City airport. |

### 7.3.3 Aeronautical Radionavigation

| | |
|---|---|
| **Devices being interfered with** | Medium bandwidth AM receiver |
| **Users & Locations** | Used in most commercial aircraft |
| **Correlation with PLT use** | Assume 24 hour, 365 day use possible. Immediate area probably has little or no PLT. Suppression of nearby mains cables may be possible |

Based on our discussions with various VHF user stakeholders, the three victim receivers have been specified in the model as described in Table 7.

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[7] In Section 10.4 we consider briefly the potential effect of PLT interference on Digital Audio Broadcast (DAB).

| Victim User Type | FM radio listener | Narrowband FM | Aeronautical Radionavigation |
|---|---|---|---|
| **Rx sensitivity** | From discussions with the BBC we understand the quality of receivers is highly variable. Our model is therefore based on minimum planned field strength rather than receiver sensitivity. | 0.3µV (-117dBm) for 12dB SINAD | -97dBm, considering the following sources:<br>-93 to -113dBm (NASA survey)<br>Bendix King KX155 -107dBm typical<br>Honeywell RMA55B -97dBm |
| **Minimum planned field strength** | 54dBµV/m (BBC local radio at rooftop level). Equivalent to -73 dBm for antenna gain 0dBi and assuming 10dB reduction for lower level indoor use. | Varies | 40µV/m (ITU-R SM.1009)<br>Equivalent to -86 dBm for antenna gain 0dBi |
| **C/I used for planning** | C/I 32dB (Derived from ITU-R BS.641) | Not applicable as minimum field strength varies | C/I 14dB (ITU-R SM.1009, interference type A1)<br>Allow an extra 2dB for impulsive Gaussian effect of PLT in a narrowband |
| **Receiver noise bandwidth** | 270kHz | 9kHz | 32kHz (Bendix King KX155 product data) |
| **Antenna type** | Short (<λ/2) vertical monopole | Vertical half-wave dipole | Horizontal V-dipole |
| **Frequency** | 98MHz | 155MHz | 110MHz |
| **Propagation model** | Extended Hata SRD | Extended Hata | Free space |
| **Antenna gain** | 0dBi<br>Antenna gain could be less than this but this gives a worst case | +2.2dBi | +1.6dBi peak<br>Average of 0dBi |
| **Noise level** | -110dBm (270kHz)<br>(KTB + 10dB noise figure) | -129dBm<br>(KTB +5dB noise figure) | -124dBm<br>(KTB + 5dB noise figure) |

**Table 7– Victim receiver characteristics**

The above figures have been derived by the following methods:

- Receiver sensitivity, receiver noise bandwidth and antenna types - based on published performance data, or standards and figures given in stakeholder discussions.
- Frequencies - Frequencies are chosen as the middle of each band.
- Antenna gain – average gain as determined by modelling the selected antenna in EZNEC [10].

  Note that the antenna types used have broadly omni-directional characteristics. This is appropriate given that each user will either have portable equipment or be receiving transmissions from a wide range of azimuths. We are aware that some better equipped amateurs use Yagi style directional antennas with rotators. It is also possible that some professional users may have a similar arrangement.

  As these directional antennas are presumably aligned towards the wanted transmission, the effect will be to attenuate PLT emissions from azimuths outside the main lobe, whereas those in the main lobe will be amplified to the same extent as the wanted signal. Such configurations will therefore be less prone to interference than the omni-directional antennas that have been modelled.
- Noise level – Based on thermal noise in the receiver bandwidth and typical noise figure.

## 7.4 PLT to cable TV Interference

In the study we have not examined in detail the potential for interference from PLT to wired cable TV services in any detail.

This is because, as discussed in section 6.4, PLT interference into VDSL at frequencies up to 30MHz would require very specific deployment circumstances and because cable TV services are much less susceptible than VDSL to PLT interference. This reduction in susceptibility is because:

- The PLT emission levels in the cable TV band are much lower than in the VDSL band
- Cable TV is often delivered through optical fibre to the street cabinet, which is immune to electrical pickup, rather than copper (which is then a relatively short underground connection to the house).

Where copper is used for cable TV it is coaxial cable, which has much greater resistance to picking up stray electrical signals than the untwisted pair telephone cable typically used for VDSL.

# 8 Radiated emissions directly from the PLT user's home are a concern over the next 5 to 10 years but are manageable through planned interference mitigation

This section considers interference via the first of the two main interference mechanisms introduced in section 4; interference caused by radiated emissions directly from the PLT user's home. There are a number of propagation effects at HF to consider when examining the potential routes of interference from radiated emissions directly from the PLT user's home. We have concluded that the biggest causes for concern are interference to aeronautical users, both when airborne and on the ground, and interference to shortwave radio listeners. In both of these cases the likelihood of interference is significant over a 5 to 10 year timescale, but can be brought to manageable levels if power control and appropriate notching are implemented.

Looking to the future, interference above 30MHz is a concern with emerging PLT industry standards targeting VHF. We have therefore also assessed PLT radiated emissions at VHF and found that the most likely users to be affected are sensitive, narrowband existing users which we have classed as "narrowband FM". In addition our results show that interference to Aeronautical radionavigation is borderline and that notching should be implemented as a precaution in these bands.

## 8.1 HF propagation creates multiple radiated emission effects

As described earlier, the mains wiring of a house where in-home PLT devices are being used will act as an antenna and generate radiated emissions. This section reviews propagation at HF and the resulting potential routes whereby PLT devices may cause interference to existing users of the HF spectrum.

As shown in Figure 9, there are four regions around the PLT wiring to be considered for propagation purposes:

- Near field propagation occurs within approximately one radian wavelength ($\lambda/2\pi$) of the radiating element. This is direct magnetic field coupling similar to a transformer and not a travelling wave. Consequently normal radio propagation models do not apply.
- Line of sight far field propagation occurs beyond the near field boundary and consists of a propagating electromagnetic wave. This is characterised by the received power falling in proportion to the square of the distance, or -20dB/decade.

- Ground wave propagation starts from a certain distance into the far field, as the wavelengths at PLT frequencies are long relative to the height above ground of the propagation path. The electromagnetic wave develops from a space wave into a surface wave travelling along the earth-air boundary. The power in this propagation mode falls with the fourth power of distance, 40dB/decade. The distance at which this change occurs depends on the electrical characteristics of the ground.
- Sky wave is an anomalous propagation mode that gives HF radio many of its useful long-range characteristics. Energy radiated at an angle upwards from the earth remains as a space wave rather than a surface wave. Upon reaching the ionosphere it may be reflected back towards the earth. In this case the wave will reach the earth again at a level much higher than the ground wave at the same point due to the lower rate of attenuation with distance. This effect is critically dependant on the characteristics of the ionosphere which in turn are dependent on factors including direction, time of day, time of year, phase of the sunspot cycle and recent solar flares.

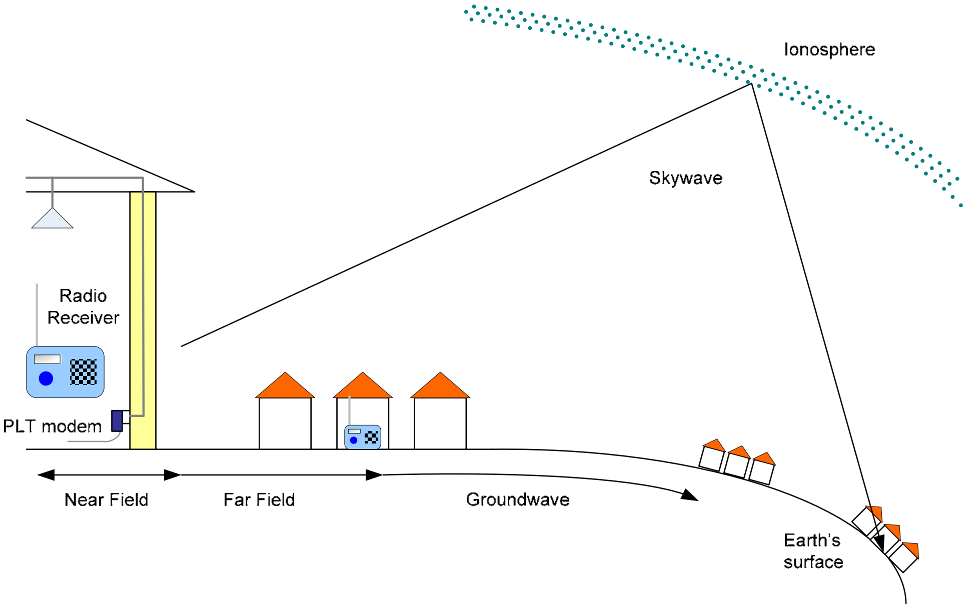

**Figure 9 - Variation of propagation mode with distance**

There have been many reports published over the last 8 years or so looking at radio interference effects of PLT. We have drawn on these throughout this report as listed in the references given in Appendix C . Based on these previous studies and propagation effects at HF, we have concluded that that there are four main mechanisms of interference from radiated emissions directly from and PLT user's home to consider. These are:

- Cumulative effect of radiated emissions to ground based HF users over large areas
  - Via ground wave
  - Via sky wave
- Cumulative effect of radiated emissions to airborne HF users
- Cumulative effect of radiated emissions to ground based HF users over small areas
- Our conclusions for interference via each of these routes are given in sections 8.2 to 8.5.

## 8.2 The cumulative ground wave effect over a large area is unlikely to cause interference

Ground wave propagation causes an attenuation that increases at 40dB per decade of distance and whose absolute value is dependent on factors including frequency, ground conductivity and electric field polarisation[8].

There is concern that as the number of PLT devices deployed increases, the ground wave signals will accumulate and cause interference even though the PLT devices may be distributed at long distances from victim receivers.

However, we anticipate that in the ground wave mode the interference effect will be dominated by devices closest to the receiver and that the cumulative effect of an even distribution over a wide area is negligible. This can be shown by considering a series of concentric rings around the victim receiver as illustrated in Figure 10. The area A of each ring is:

$$A = 2\pi . r\delta r \qquad (r >> \delta r)$$

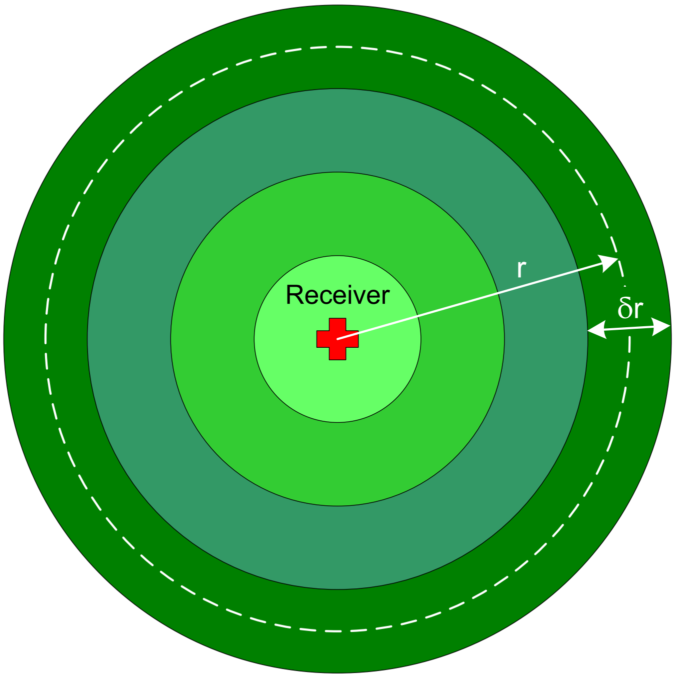

**Figure 10 - Wide area PLT deployment as a series of concentric rings**

With a uniform PLT deployment density there will a number of PLT devices within each ring proportional to A. If these rings are of the same thickness δr, this means the number of devices in each ring, and thus the total power transmitted from each ring, is proportional to radius r.

---

[8] The electric field component of the far-field radiation is oriented in line with the radiating parts of the antenna. Where these are mounted vertically, the transmitted signal is said to have vertical polarisation. A groundwave with horizontal polarisation has higher attenuation and will therefore propagate less far than a transmission of the same power with vertical polarisation

The propagation loss in groundwave mode from a device at distance r is proportional to $r^4$. Combining these two factors, the total power seen at the receiver from a ring of PLT devices at distance r is proportional to $r^{-3}$. Thus the extra power from increasing the deployment radius (an extra outer ring in terms of the figure above) will have minimal effect compared to the power from the small number of devices close to the receiver.

This can be calculated in absolute terms by the program GRWAVE, which is a software implementation of the ITU standard for ground wave propagation ITU-R P.368-7. The results of this are plotted in Figure 11.

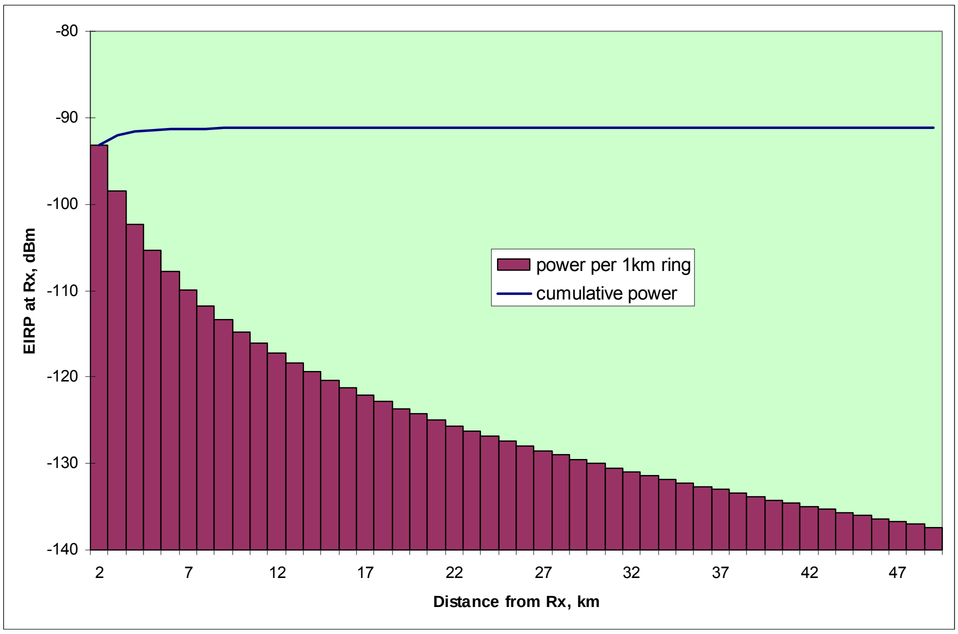

**Figure 11. Cumulative effect of ground wave propagation**

The maroon vertical bars represent the power at a receiver in the centre originating from each of the concentric rings with radii at 1km intervals from 2 to 50km. The blue line represents the cumulative power as each ring is successively added outwards from the centre[9]. The first ring at 2km radius contributes -92.7dBm. The second ring adds 1.1dB to this. All the other rings out to 50km combined add just 0.9dB. We therefore do not anticipate that the cumulative groundwave components contributed from PLT devices spread over large areas will have a significant interference effect. Instead interference from radiated emissions will be dominated by the PLT devices local to the victim receiver and this is discussed further in section 8.5.

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[9] GRWAVE with the right parametersThe calculation assumed a PLT power of -50dBm/Hz, in a 2.2kHz bandwidth and a density 29.3 devices per $km^2$ corresponding to market forecast for suburban areas. The frequency was 8MHz, the effective antenna gain of the house wiring -30dBi, the receiver antenna gain 0dBi, and the ground conductivity 14mS/m representing the Midlands.

## 8.3 Interference from a cumulative sky wave effect over a large area is only significant in quiet rural areas

Sky wave propagation occurs due to the action of the ionosphere as a mirror to reflect radio waves back to the surface of the earth. The earth itself can then reflect the radio wave back upwards to create multiple ‘hops’.

The effect of this on HF radio coverage is that, beyond the range at which the ground wave mode has attenuated the signal into the noise, the signal strength can increase due to the ionospheric reflection. Beyond that area the signal level falls again, and then rises at still further range due to the second hop and so on.

Due to the distances involved, typically hundreds or thousands of km, the attenuations are large. However these long distances also create large coverage areas. Considering incoming interference to a receiver, a potentially large number of PLT devices may be in the area that can propagate via sky wave to the receiver. This tends to offset the high attenuation when considering the cumulative effect of a wide area deployment of PLT.

As described in Appendix J , sky wave propagation is difficult to predict and will vary with time of day. We have therefore based our evaluation of cumulative sky wave effects on previous work in this area.

NATO has carried out a detailed assessment of likely received power levels from PLT emissions via sky wave at various locations, convolving the path loss with the population density over a large area and scaling to allow for an arbitrary market penetration of 0.05 per capita [5]. We have taken these results and re-scaled to allow for our own market forecasts.

In our medium market uptake we estimated that 21% of UK households will have PLT devices by 2020. In the UK there are on average 2.7 persons per household, meaning that the NATO assumption of 0.05 per capita is equivalent to 13.5% of households, at the lower end of our forecast range. If we scale this up to 21%, the radiated power levels will increase by 2dB over those in the NATO report.

NATO's predicted PLT emissions for locations at Bodo, Winnipeg and Augsburg show that in nearly all cases the statistical spread was over 20dB. Therefore an adjustment of 2dB to the results is not considered particularly significant in these forecasts and the NATO results are taken as still valid for this study. The wide spread of received power levels is attributed to the highly variable nature of the ionosphere and the parameters that influence it.

The threshold that NATO used to judge whether interference was occurring was based on the PLT emissions being “in the range of 10 to 1 dB below the ITU-R Quiet Rural noise curve”. It is estimated that around 1% of the UK population live in areas of the type that could expect to have “Quiet Rural” noise levels, the other 99% live in areas that can expect higher ambient noise levels. We therefore consider that the threshold used, whilst appropriate for military use, is unduly pessimistic for most of the UK's population.

The Rural noise level is also plotted on the NATO graphs. This shows that in Augsburg, which of the three locations is the most similar to the UK, the upper end of the spread of received powers exceeds the Rural noise level by around 5dB worst case with the median values around 5-10dB below the Rural noise level. Although not plotted on the results in the NATO report, the ITU-R noise levels for Residential and Business areas exceed the Rural area by 5dB and 10dB respectively.

The conclusions are therefore that sky wave propagation from a widespread deployment of PLT devices can significantly increase the radio noise floor in quiet locations. However the reason they are quiet is that there are few homes or businesses in the area, and so few people are affected by the rise in noise floor. In the areas where most homes and businesses are located there will be a rise in noise floor though this will only be apparent at times and frequencies where the sky wave conditions create a sufficiently low path loss to another populated area. This is likely to be a very minor effect in business/urban areas but will occur often enough to be noticeable in rural areas.

## 8.4 Notching, dynamic power control and maximum power reduction are required to protect airborne HF users

Nearly all HF users are close to ground level and hence ground and sky wave modes apply for cumulative effects of wide area PLT deployments. The exception is aircraft in flight. They are clear of the ground and so do not have the impact of nearby PLT devices. However they have line of sight to a large area so free-space propagation can occur from a large number of distant PLT devices. Analysis of this effect was carried out by J.Stott of the BBC [12] who concluded that significant interference to aircraft at any height was possible. This had caveats that at the time the standards for in-home PLT networking and the antenna gain of home wiring at high elevations were unknown.

A recent study by ITU Working Party 1A has carried out similar analysis of the current UPA standard and results of measurements from flight tests [6]. We have two comments to add to this work:

- The assumed PLT device density of 250 per km² is lower than our market forecast for urban areas. At our estimated 703 PLT devices per $\text{km}^2$ by 2020, the power at the aircraft receiver would rise by 4.5dB. The impact of this is that PLT devices examined by ITU would exceed the criteria for a 0.5dB rise in the noise floor across most of the HF band even if power control and notching of the aircraft bands were both implemented. The PLT device power would need to be reduced by a further 8dB to meet the interference criteria. As a transmit power of -55dBm/Hz is given for the PLT device we assume these findings apply to European Homeplug AV devices.
- If Homeplug AV devices raise the noise floor by 0.5dB that implies their contribution is 9dB below the existing noise floor. Throughout this study we have assumed that UPA devices have a maximum quasi peak output power level of -50dBm/Hz and so 5dB higher than the level assumed in the ITU results. UPA with power control and notching would therefore not be expected to meet the interference criteria if operating at its maximum permitted PSD, even at 250 per $\text{km}^2$.

It is therefore recommended that power control and default notches in conjunction with a maximum PSD of -63dBm/Hz are required for the aeronautical bands to protect these safety critical services.

The table below applies our market forecast for 2010 and 2015 as in the 2020 example above.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Airborne HF user** | Power control and notching required to avoid interference.<br>PLT transmit power will need to be reduced to -57dBm/Hz to avoid interference across HF. | Power control and notching required to avoid interference.<br>PLT transmit power level will need to be reduced to -62dBm/Hz to avoid interference across HF. | Power control and notching required to avoid interference.<br>PLT transmit power level will need to be reduced to -63dBm/Hz to avoid interference across HF. |

**Table 8 - Interference mitigation required to protect HF airborne receivers**

Note: at mid-April 2010, no complaints have been received by Ofcom concerning these systems - see the discussion on possible reasons for this in Section 3.

## 8.5 Interference to ground based HF users is manageable but requires action

As discussed in sections 8.2 and 8.3, the cumulative effects of the long range HF mechanisms of sky wave and ground wave are not thought to present a significant threat of interference. The main source of interference to ground based HF users will be the PLT devices local to the victim receiver i.e. within the same town.

Previous studies have measured radiated emissions from a single home using PLT devices. However, we were unable to find previous studies that examined the cumulative effect of multiple PLT devices located close enough to a victim receiver to contribute significantly to interference. The main focus of our simulation work has therefore been to further investigate this effect.

Interference caused by radiated emissions will increase with the number of homes using PLT devices within a particular range of the victim receiver and will still reach the victim receiver regardless of whether that victim receiver shares the same mains circuit as all the PLT users or not. To simulate this effect we have modelled large numbers of PLT devices randomly distributed around a victim receiver. The observed interference level at the victim receiver was calculated via a link budget calculation for the path between each PLT device and the victim receiver. This link budget has been based on the injected power of the PLT device, the antenna gain of home wiring, a suitable propagation model between the PLT device and victim receiver, victim receiver performance and the interference threshold.

Section 9 gives details of the interference modelling approach and results. Table 9 gives an overview of these results with the probability of interference categorised as follows:

| Definition used | Probability of interference |
|---|---|
| Negligible | <1% (at edge of coverage) |
| Low | 1-5% (at edge of coverage) |
| Medium | 5-20% (at edge of coverage) |
| High | >20% (at edge of coverage) |

It is important to note that these results are for a user situated on the edge of the coverage area at present. For users in a good signal area the probability of interference is reduced as discussed in Section 3.1.1 of this report.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Note: Interference effects estimated at limit of wanted signal / range** | | | |
| **Shortwave broadcast listener** | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added. | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added | High probability of interference with power control alone<br>Negligible probability of interference if smart notching is added |
| **Amateur radio** | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added | High probability of interference with default IARU notches alone<br>Negligible probability of interference if power control is added |
| **Aeronautical groundstations** | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied | High probability of interference with power control alone<br>Negligible probability of interference provided notching and power control are applied |

**Table 9 - Summary of results from HF modelling[10] (forecast for year end of dates shown)**

Note: at end-February 2010, Ofcom has received 208 complaints about interference with shortwave broadcast radio and radio amateur reception. No complaints have been received concerning aeronautical groundstations, - see the discussion on possible reasons for this in Section 3.

Overall these show that if PLT devices remain unchanged from today there is a high likelihood of interference to most HF users. However, this interference is manageable and, if introduced in line with current product development roadmaps, power control and notching (including smart notching in the case of broadcasting) should bring the likelihood of interference down to negligible levels. Consideration should be given to encouraging the introduction of power control and smart notching to ensure that these are deployed in PLT devices in the required timescales indicated in Table 9. Aeronautical ground stations give the most cause for concern and notching of the aeronautical bands is recommended to protect these safety critical services.

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[10] Note that these results are for the low frequency end of the potential interference range and hence represent a worst case as the interference signals do not propagate as far at higher frequencies.

## 8.6 Interference from future PLT devices at VHF is feasible and requires action

As discussed in section 5.3.3 there is a growing trend of PLT devices operating above 30MHz. We have therefore also modelled interference caused by radiated emissions from homes using PLT devices operating above 30MHz within range of a selection of VHF victim receivers. As in the HF case, the link budget used in this model has been based on the injected power of the PLT device, the antenna gain of home wiring, a suitable propagation model between the PLT device and victim receiver, victim receiver performance and the interference threshold. Unlike in the HF case, groundwave and skywave propagation mechanisms do not apply at VHF and so were not considered. In addition, due to a lack of previous work in this area, we have included an airborne user in the form of an ILS localiser in the victim receiver scenarios that we have considered.

Section 10 gives details of the interference modelling approach and results at VHF. Table 10 gives an overview of these results with the probability of interference categorised as follows:

| Definition used | Probability of interference |
|---|---|
| Negligible | <1% (at edge of coverage) |
| Low | 1-5% (at edge of coverage) |
| Medium | 5-20% (at edge of coverage) |
| High | >20% (at edge of coverage) |

It is important to note that these results are for a user situated on the edge of the coverage area at present. For users in a good signal area the probability of interference is reduced as discussed in Section 3.1.1 of this report.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Note: Interference effects estimated at limit of wanted signal / range** | | | |
| **FM listener** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Reduces to low probability of interference if smart notching is applied. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if smart notching is applied. |
| **Narrowband FM** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if notching is applied. | High probability of interference if no mitigation is applied<br>Reduces to medium probability of interference if notching is applied. |
| **Aeronautical radionavigation** | Not significant due to small number of PLT devices operating in VHF band. | High probability of interference if no mitigation is applied<br>Low probability of interference if notching is applied | High probability of interference if no mitigation is applied<br>Low probability of interference if notching is applied |

**Table 10 - Summary of results from VHF modelling (forecast for year end of dates shown)**

Note: at mid-April 2010, no complaints have been received by Ofcom concerning these systems - see the discussion on possible reasons for this in Section 3.

Our simulation results show that while the transmit power level of PLT devices has been greatly reduced (by around 30dB) in the VHF bands, there is still scope for interference to sensitive, narrowband systems including amateur radio, and that notching will be required at these bands in a similar way to that implemented currently for the IARU bands at HF.  In addition our results highlight safety critical ILS systems as being likely to suffer from interference above urban areas in the near future and we recommend that these are notched as well.

## 8.7 Detailed modelling of interference margin is required

In order to validate the modelling approach and assumptions used here, two VHF use cases were examined. One of these was with a defined minimum field strength for the coverage area, and one where the coverage was assumed to continue until the signal dropped to the receiver's sensitivity limit. The accompanying diagrams illustrate the link budgets in each case.

**FM Broadcast**

In this case the coverage area is defined by the BBC as a minimum of +54dBµV/m at rooftop level for local radio stations, with higher levels for national stations and urban areas. Allowing for a 10dB reduction for indoor reception at lower heights and a 0dBi antenna gain, this translates to -73dBm received power at 98MHz, the centre of the FM broadcast band. The planning criteria also specify that a 50dB SNR should be achievable by suitable equipment, which equates to 32dB C/I ratio, so the interference level should not exceed -105dBm.

In an urban area in 2020 we have estimated a density of PLT users of 703 per km$^2$. As a first approximation, if these are arranged on a regular rectangular grid there will be a spacing between adjacent devices of 38m. Placing the FM receiver equidistant between four PLT devices will mean they are each at a distance of 27m from the receiver.

The PLT device power is -26dBm in the receiver's 270kHz bandwidth. With the antenna gain of the house wiring plus the path loss over 27m, this will produce a power at the receiver input of -97dBm. Four PLT devices will increase this by 6dB to -91dBm. This gives a margin below the maximum interference level of 14dB. This is illustrated in Figure 12.

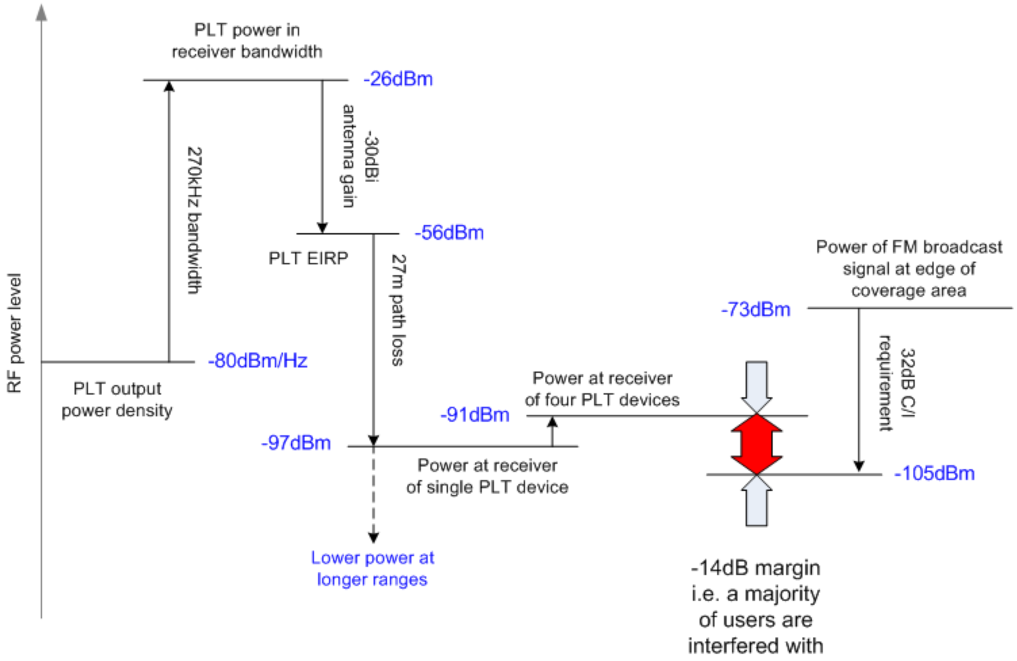

**Figure 12. Link margin calculations for FM broadcast receiver at edge of coverage**

In practice there will be statistical variation in the parameters including PLT locations relative to the receiver, effective antenna gain of the house wiring, and propagation loss. In addition this has only considered the four closest PLT devices whereas others further away will also contribute some interference. Conversely the PLT devices will not be transmitting continuously which reduces the overall PLT power seen by the receiver. A more detailed model that includes these factors is required.

The Seamcat modelling tool, described in Appendix K, performs this function. The median of the FM broadcast result from modelling with Seamcat showed good correlation against the result above.

### Land mobile

A similar process was carried out for the land mobile use case. In this instance there was not a defined field strength, but a minimum receiver sensitivity of -117dBm. A SNR of 12dB is typically taken as the limit of useable audio quality in Private Mobile Radio (PMR) equipment. For narrowband analogue equipment this gives a 12dB C/I ratio also, so the maximum noise level should be -129dBm.

The higher frequency of PMR relative to the FM broadcast band gives a higher propagation loss, with a slight increase in range as the antennas used by PMR base stations and repeaters are typically mounted above rooftop level and hence above the house wiring. PMR equipment also has a narrower bandwidth so the PLT power falling within the receiver bandwidth is reduced. This leads to a signal at the receiver from one device of -115dBm or -109dBm from four devices. This is 20dB above the maximum interference level, meaning that interference would occur. The factors contributing to this are shown in Figure 13.

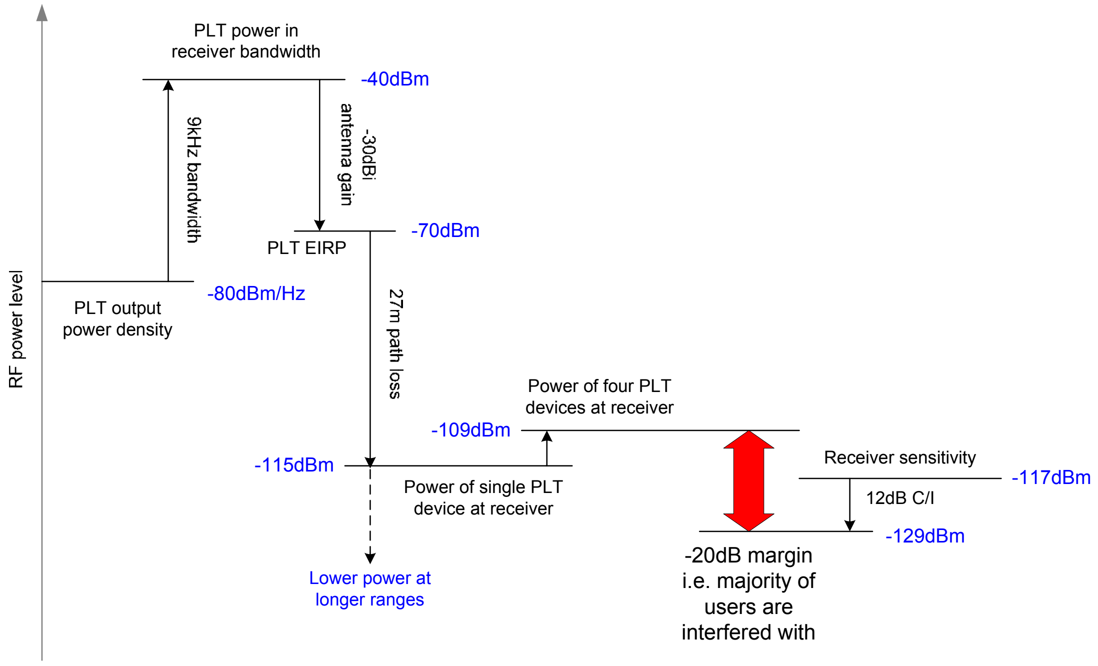

**Figure 13. Link margin calculations for narrowband FM receiver at limit of receiver sensitivity**

Again a more detailed statistical model is required. The result from the Seamcat model shows most Land Mobile users being interfered with so again this is consistent with the simple model given here.

# 9 Modelling results show that HF interference from PLT is manageable but requires action

The main analysis of interference from radiated emissions directly from PLT user's homes has been carried out using a Monte Carlo simulation modelling tool, SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool). This chapter describes our approach to simulating interference via SEAMCAT, our assumptions and our results across the three victim receiver types examined. Our simulation model shows that without mitigation action, interference from PLT is an issue for most HF user types, both now and in the future. However, planned interference mitigation techniques from PLT device vendors will bring the probability of interference down to negligible levels in most cases. It is recommended that these planned features are implemented through Harmonised Standards to ensure that they are deployed in a timely manner. The most concerning case is that of aeronautical ground stations and we recommend that notching is implemented in these safety critical bands.

## 9.1 Model structure and methodology

For this study we have built up models to represent a low, medium and high frequency operation for each of the three victim receiver types:

- Shortwave radio
- Amateur radio
- Aeronautical ground station representing professional users.

UPA PLT devices have been simulated with the following characteristics:

- Quasi peak transmit PSD -50dBm/Hz
- 30MHz bandwidth from 2-32 MHz.

Based on our discussions with various HF user stakeholders, the three victim receivers have been modelled as described in section 6.3 and in particular using the parameters listed in Table 6.

To complete the link budget calculation between victim receiver and PLT devices, the model requires:

- Antenna gain of mains wiring to translate the power injected into the mains by the PLT into EIRP.
- Propagation model for radiated emissions from PLT devices.

To complete the interference calculations we required an understanding of:

- Interference criteria for victim receivers

- Duty cycle of PLT devices.

Our assumptions in these areas are discussed in the remainder of this section.

### 9.1.1 Antenna gain of in home wiring

Theoretical analysis of the average antenna gain of house wiring is difficult due to the wide variety of installations. We have therefore instead based our antenna gain for PLT devices on practical measurements reported in the following two sources:

- The NATO study summarises these emission level measurements and recommends an antenna gain of -30dBi with a variation of ±5dB to ±10dB due to variations in the wiring [5].
- Our analysis of recent measurements of field strengths for UPA and Homeplug PLT devices in Canada show that these correspond to an average antenna gain of -30dBi [13] (see appendix L.2).
- We therefore assumed an antenna gain of -30dBi with a variation of ±5dB to ±10dB in our model.

### 9.1.2 Propagation model

The existing propagation models built into Seamcat are not specified at frequencies below 30MHz. PA therefore developed a custom model based on information from several sources. As discussed in section 8.1 and illustrated in Figure 9, there are four relevant propagation modes. Of these sky wave has been evaluated separately in section 8.3. Similarly aircraft in flight are analysed separately in section 8.4.

For the remaining scenarios the custom propagation model has been derived to cover the following effects:

- Near field
- Far field
- Ground wave

A number of previous studies [5, 13] have measured the radiated emissions from mains wiring using PLT devices to within 3m of the mains wiring. This is within the near field for frequencies below 16MHz. The majority of such measurements show signal strength to distance relationships, known as distance conversion factor, of around -20dB/decade in both the near and far field. This matches the free space path loss “inverse square law” that we would expect for far field radiation.

At distances beyond the far field the propagation changes to a surface wave phenomena at the earth/air boundary. This has distance conversion factor of -40dB/decade. The distance at which this change occurs is where the ground wave path loss intersects the free space loss and is described in detail in appendix J.3.

In our custom propagation model we have therefore applied a distance conversion factor of -20 dB/decade up to the ground wave transition distance and then applied a distance conversion factor of -40dB/decade. A more detailed description of our propagation model is given in Appendix J .

### 9.1.3 Interference criteria

The HF noise floor from natural and man-made sources is usually higher than thermal noise of a HF receiver and so devices operating at these frequencies are normally limited by the background noise level rather than receiver sensitivity. An increase in the background noise floor will result in a corresponding decrease in SNR for HF users. As a baseline throughout this study, for HF systems we have assumed that interference will occur if the equivalent AWGN interference signal resulting from PLT devices is at the same level as the background noise and hence gives a 3dB increase. This baseline was agreed with Ofcom as a starting point for our analysis and is supported by the NATO study into PLT [5] which quotes an earlier study on HF noise floor measurements as "an increase above 3dB over the existing noise floor would reduce availability on HF circuits". We have examined the effect of changing this interference criteria baseline in our sensitivity analysis in section 9.3.4.

Arguably PLT devices may not have the same interference impact on a narrowband receiver as an AWGN interference signal. In-home PLT devices are based on an OFDM waveform and have a relatively flat wideband spectrum. If a PLT signal is received by a wideband victim receiver then, based on the contribution of a large number of uncorrelated sub-carriers making up the PLT signal, the interference signal will be Gaussian in nature. However, if the PLT signal is received in a narrow bandwidth the interference effect may not be the same as with a Gaussian interference source.

In a narrow band the PLT signal will still have a flat spectrum but may not be Gaussian in nature as it will be made up of a small number of sub-carriers that will display the characteristics of the underlying modulation scheme.

In addition, PLT devices transmit regular beacon signals when in idle mode. This is part of both the Homeplug and UPA standard although there are different duty cycles associated with each (see Appendix G ). This “bursty” transmission may have a more detrimental effect on the receiver, particularly when multiple beacon signals of many PLT devices are summed.

We were unable to find any previously published studies evaluating the interference impact of a wideband PLT signal being received in a narrowband victim receiver. However, as described in Appendix L , the UWB community has examined this issue and based on their results we have assumed that, due to the bursty nature of PLT signals, the effect of PLT radiated emissions is similar to an impulsive noise source of interference. We have applied a correction factor to our original interference criteria of a 3dB rise in the background noise floor to allow for this impulsive noise effect.

As detailed in Appendix L , this gives our final interference criterion:

$$\frac{I}{N} = -2dB$$

When comparing the radiated emissions from PLT devices against the background noise we have used the quasi peak power level for the PLT radiated emissions because this is the standard approach taken for measuring interference from a "bursty" transmission signal as the RMS power level would give an unfairly low transmit power level due to gaps in the transmission.

### 9.1.4 Interference from Idle time versus continuous transmission

Our model repeatedly calculates the instantaneous interference signal observed at the victim receiver over a large number of events. We have used our market forecasts from section 5.2 to set the density of PLT devices around each type of victim receiver. However, at a given instant not all deployed PLT devices will be transmitting and the transmit duty cycle will vary depending on how many devices are in idle mode. While some PLT devices may be switched off and not transmitting at all we understand that this is unlikely as most users will tend to leave their PLT devices plugged in and switched on at the mains once initially set up rather than restarting the network each time they want to use them. We have applied the following assumptions with regard to idle time:

- We assume that the transmit power of an idle PLT device is the same as for one transmitting data. From our lab tests (see Appendix I ) and our discussions with stakeholders, we understand that there is no difference in the peak power transmit level of a PLT device during idle time compared to continuous transmission. Therefore a PLT device will generate as much interference in an instant during the “on” time of its idle mode duty cycle as it will in the “on” time of its data transmission mode.
- We have assumed that the probability of a PLT device transmitting is 58% which is the weighted average duty cycle that combines the duty cycles of PLT devices in idle mode and data transmission mode according to the expected proportion of devices in each mode at peak usage times (see L.4).
- We assume in our baseline model that the idle time transmissions across PLT devices are uncorrelated. As the UPA idle sequence is based on a token passing sequence this should be largely uncorrelated between networks. The beacon signals used by Homeplug AV in idle mode are synchronised to the 50Hz AC mains supply, but we understand that each network beacon has an offset relative to the AC line cycle zero crossing and that this differs between networks. However to allow for the possibility that idle sequences may be synchronised our sensitivity analysis has examined the worst case scenario of when all idle mode devices are synchronised.
- We have already accounted for any worsening of interference due to the PLT devices transmitting in short bursts when in idle mode by assuming the worst case scenario of impulsive noise and adjusting the I/N as discussed in 9.1.3.

### 9.1.5 Check of Seamcat model against PLT measurements

To ensure consistency between the PLT emission levels being modelled in this study and what has been observed in real PLT field measurements, we set up a Seamcat workspace to model emissions from a single PLT device at observation points 3 and 10m from the PLT device as was the set up for recent PLT field trial measurements in Canada. When expected field strengths from the model were compared against the measurements for a UPA pair given in [13] the results were within 1dB of each other. This shows that the combination of PLT transmit power level, antenna gain of household wiring and propagation model used in this study gives a reasonably accurate representation of existing measurements of real PLT devices.

## 9.2 Baseline simulation results

The results in this section assume a medium market uptake, weighted average duty cycle of 58% and a fixed protection radius (i.e. distance around the victim receiver where no PLT devices are permitted) as appropriate to each of the victim receiver types. We call it our baseline case. A sensitivity analysis is given in 9.3 to understand how the results from this baseline are affected by changes in the market uptake, duty cycle and protection radius.

### 9.2.1 Interference is dominated by the nearest PLT devices

In the simulation model, we can vary the distance between the source of interference (PLT) and the victim receiver using two parameters:

- Number of active sources per simulation run
- Density of interfering sources given in devices per km²

Figure 14 shows the cumulative interference at a SW radio victim receiver for an increasing number of PLT devices around it. The density of PLT devices was kept constant for each of the results shown (at the density estimated for 2010 in the medium suburban scenario by our market model).

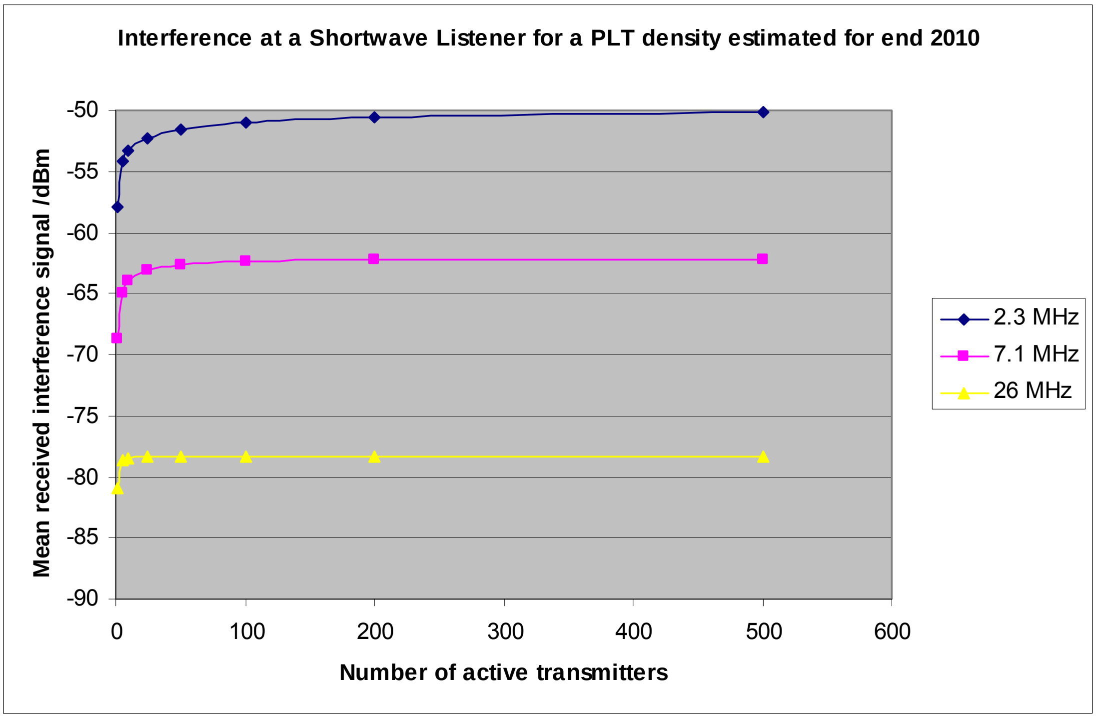

**Figure 14 – Total interference experienced as a function of the number of PLT devices**

Keeping the PLT density fixed but increasing the number of active PLT devices means that the area around the victim receiver that the PLT devices are distributed across also increases. This graph therefore shows whether the cumulative interference signal grows as a wider area, and hence higher number of PLT devices around it, is considered or whether the interference signal is dominated by the PLT devices closest to the victim receiver.

Figure 14 shows that the interference observed by the shortwave victim receiver type is dominated by a few PLT devices at close range. This is the case at low, medium and high frequencies within the HF range. This effect is most prominent at the highest frequency as the transition in path loss from -20 dB/decade to -40 dB/decade occurs at shorter distances as the frequency increases. This matches the result given in section 8.2 for the cumulative groundwave effect.

In each instance the interfering signal level is stable to within 1dB for a number of active PLT devices of 100 or more, so for the remaining simulations we have set the number of active devices to 100. We have observed the same effect at different device densities and, although a higher device density does generally mean that more active transmitters must be simulated before the interference reaches a stable level, we have observed at device densities up to 1100 devices per km² that the interference level is stable by 100 active transmitters.

### 9.2.2 Notes on interference probabilities

The graphs in this section show the probability of interference to a service for a user at the edge of wanted signal coverage; they do not show the probability of interference of users throughout the UK. For services which have been designed to meet a specific coverage range, they therefore represent the likelihood that the service will no longer meet the original expectations of the radio planners, although the majority of locations may be unaffected by interference from PLT devices. Section 3 of this report considers possible reasons why the number of complaints (208 until February 2010) to Ofcom is relatively low when considered in the light of our results presented here.

### 9.2.3 Probability of interference by victim receiver type

The remaining graphs in this chapter show the probability of interference at the victim system as the power of the interfering PLT sources is varied. The slope of the probability curve is due to a number of factors including (a) the random distribution of interferers around the victim and (b) the variation in the effective gain of the PLT interferer (for example due to the orientation of the in-house wiring with respect to the victim).

For each of the three victim receiver types we first examine the probability of interference for a low, medium and high shortwave broadcast band from 2-30MHz using a medium market uptake estimate for 2010. This shows if particular frequency bands are likely to suffer more than others. We then look at the potential for interference over the next 5 to 10 years. This is based on the victim receiver at a fixed frequency, but PLT device density changed in line with our medium uptake market forecasts for 2015 and 2020.

For each of the graphs we have marked:

- Transmit power for today's UPA devices. The -50dBm/Hz power level marked corresponds to the maximum UPA power spectral density of -50dBm/Hz in a 30MHz bandwidth. We have used UPA as our baseline as this dominates the UK PLT market today through BT Vision.
- Potential PLT power reductions due to interference mitigation features including:

- 22dB reduction for power control. According to a recent submission to CISPR 22 by Koch [14], the introduction of power control to PLT devices is estimated to reduce the transmit power by 22dB. From discussions with PLT vendors it should be available by mid 2010.
- 30dB reduction for fixed or smart notching. We understand that PLT devices can generate notch depths up to 40dB. However, we have reduced this to 30dB to allow for intermodulation from neighbouring bands which may increase power in the notch. This effect has been highlighted as a concern amongst victim receivers [15] and in our own observations of PLT devices we have seen variability in notch depth (see I.2). Currently the IARU bands are notched by default and smart notching is in development and planned to be released Q3 of 2010.

For each of the three victim receivers we have assumed the following protection distances and environments:

- ***Shortwave broadcast listener, protection distance 1m***. We have assumed that it will always be feasible to move a SW radio at least 1m away from mains causing interference and that SW radios will be used largely in domestic settings.
- ***Amateur radio user, protection distance 5m.*** We have assumed that amateur radio antennas will be mounted external to the building and can be at least 5m from the source of interference. We have also assumed that amateur radio sets will be used largely in domestic settings.
- ***Aeronautical ground stations, protection distance 100m.*** We have assumed that a professional user such as this will be protected by a protection distance of 100m, but could be located in built up (i.e. urban) areas.

### Interference to SW Listeners is manageable via power control and smart notching

Figure 15 shows that the predicted effect of interference to a SW listener is worst at the lowest frequency band. This is because far field propagation at -20dB/decade will exist for the largest distance at low frequencies. We show a high probability of interference in all cases if PLT devices do not change. The introduction of power control would not be sufficient to remove interference to shortwave listeners on the edge of coverage, in the short term at least.

Figure 16 shows that while power control reduces the interference level, additional mitigation features will also be needed. If smart notching was applied this would potentially reduce the PLT transmit level by another 30dB and bring the probability of interference down to negligible levels. We therefore recommend that power control and smart notching are implemented to mitigate interference to shortwave listeners.

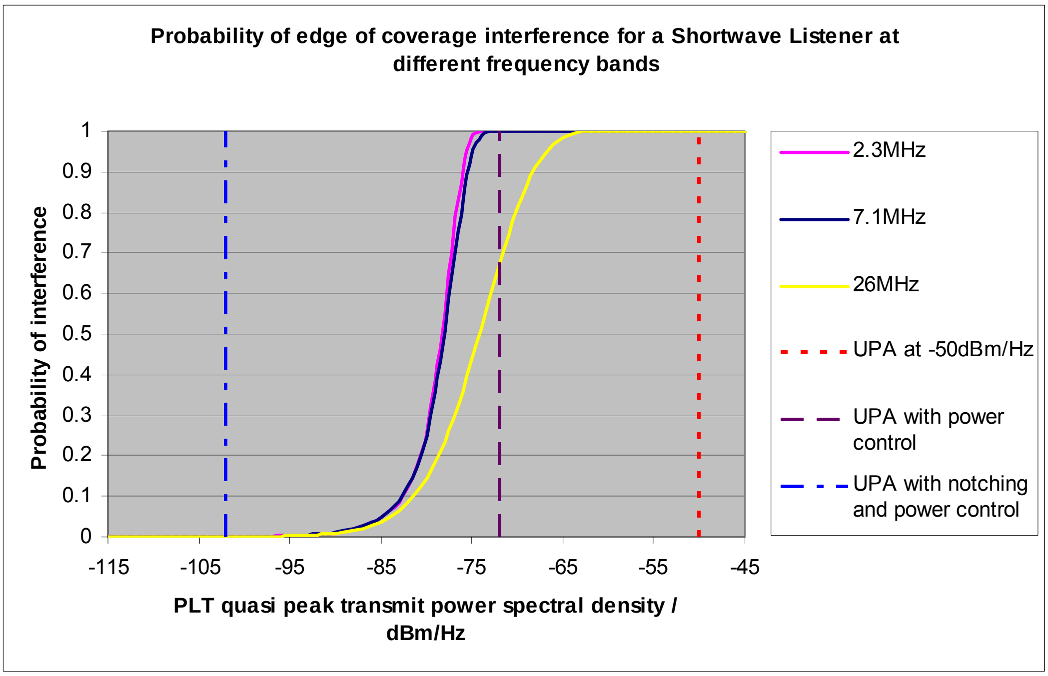

Figure 15 - Probability of interference for SW broadcast listeners against PLT power for 2010

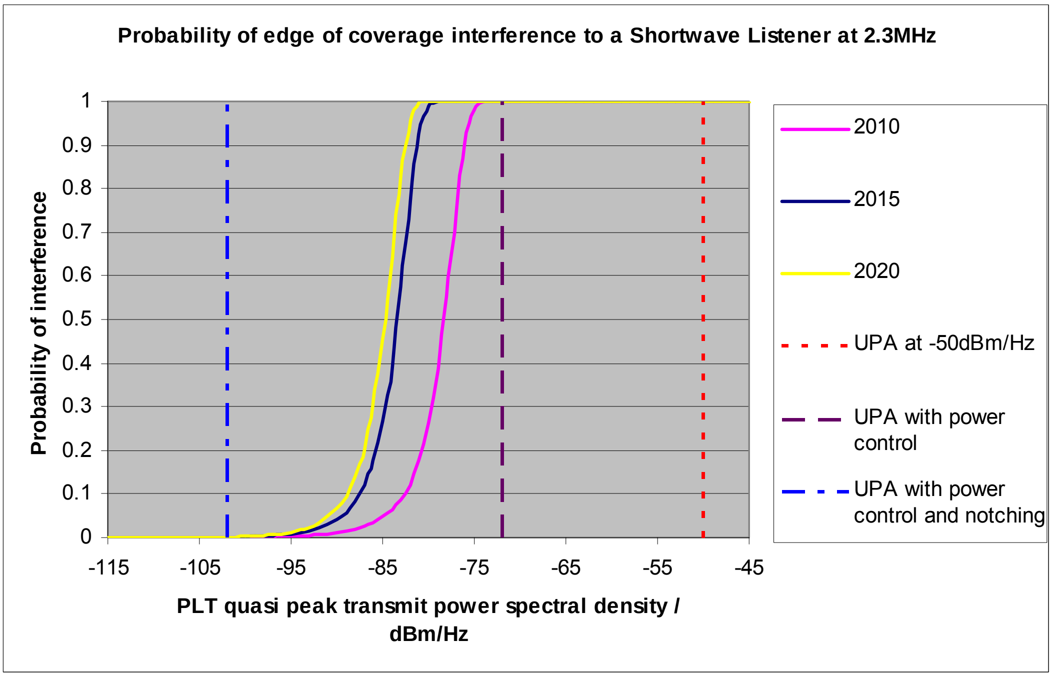

Figure 16 - Probability of interference to a shortwave broadcast listener over a 5 to 10 year timeline

## Existing IARU notches alone are not sufficient to maintain a low likelihood of interference to Amateur Radio users

Amateur radio bands are already notched by default in most PLT devices on sale today. However, it is worth noting that there will be certain level of earlier devices already deployed which may not include these. Figure 17 shows that, taking this notching into account, the probability of interference for an amateur radio user in marginal reception conditions across a range of frequency bands is high in the short term. The introduction of power control would reduce the probability of interference to negligible levels.

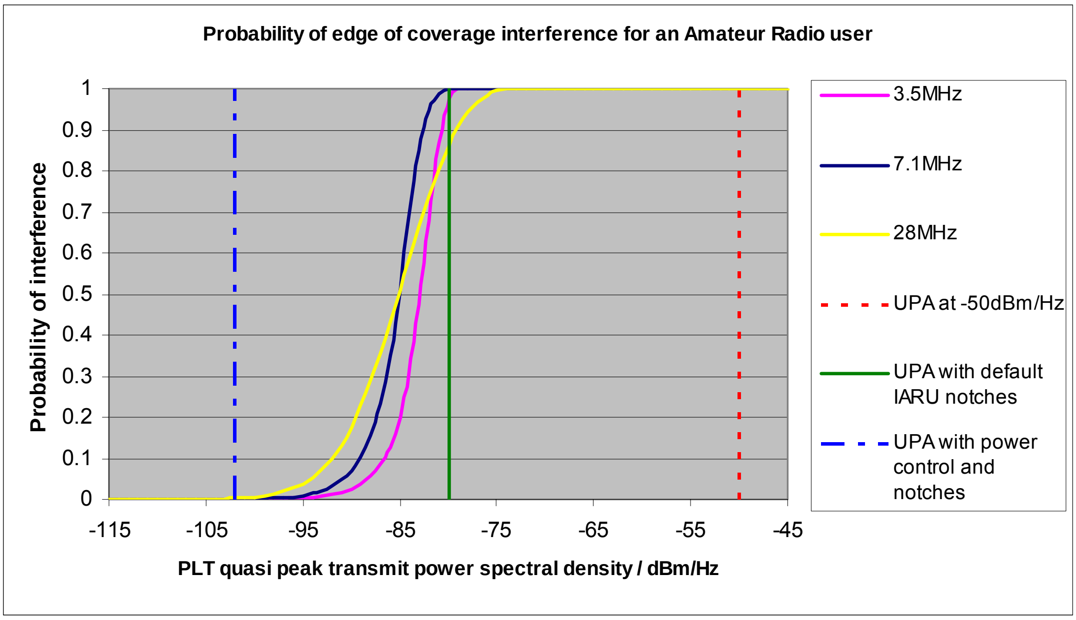

**Figure 17 - Probability of interference for Amateur Radio Users against PLT power for 2010**

As shown in Figure 18, even with the current notching, interference to amateur radio under marginal coverage conditions is high and will require the addition of power control to bring interference to negligible levels out to 2020. We therefore recommend that power control is implemented in addition to notching.

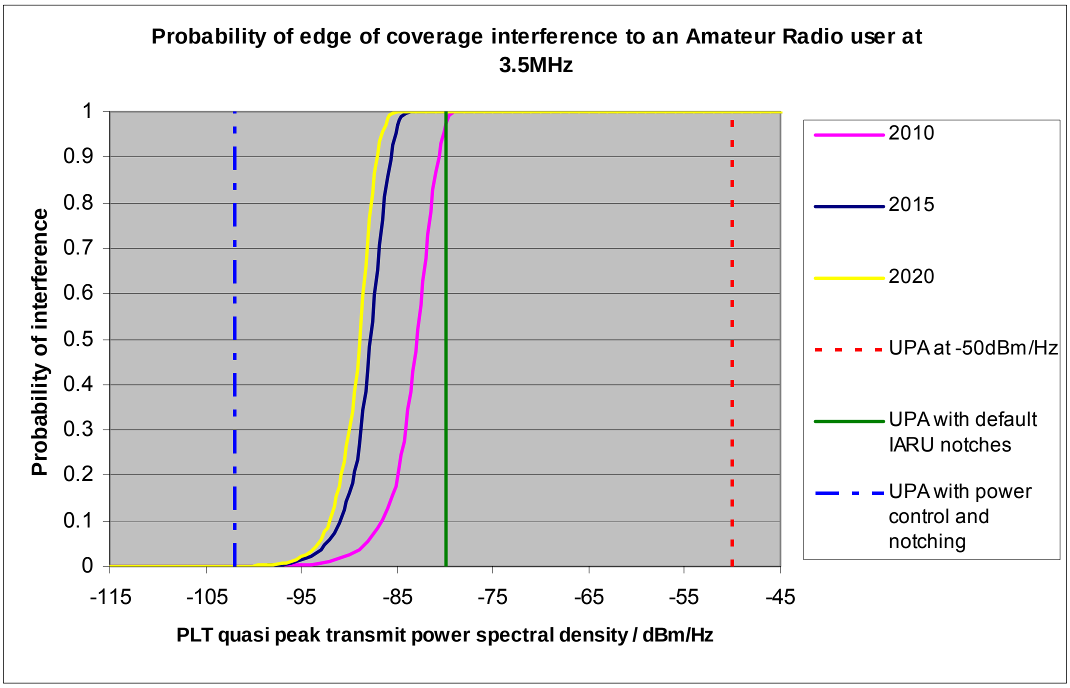

**Figure 18 - Probability of interference to an amateur radio user in a 5 to 10 year timescale**

### Power control and notches in the aeronautical bands are required to protect safety critical aeronautical ground stations over a 5 to 10 year timescale

Figure 19 shows that the probability of interference to aeronautical ground stations is high if PLT devices do not change from those currently deployed. The introduction of power control will improve the situation slightly at higher frequencies but additional notching is needed to bring interference to negligible levels in the short term across all frequency bands.

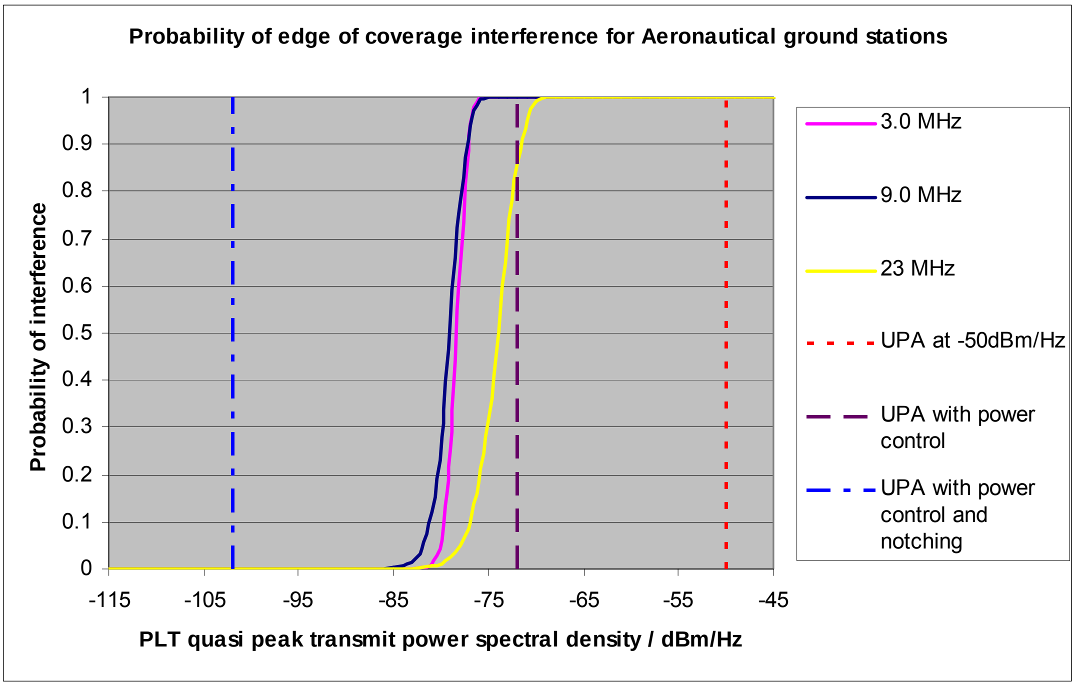

Figure 19 - Probability of interference for Aeronautical ground station against PLT power

Figure 20 shows that the potential interference problem continues to grow in the medium and long term and that power control will not be sufficient. In addition section 8.4 describes a significant risk to airborne HF users above urban areas, so we recommend the notching of all aeronautical bands in PLT devices.

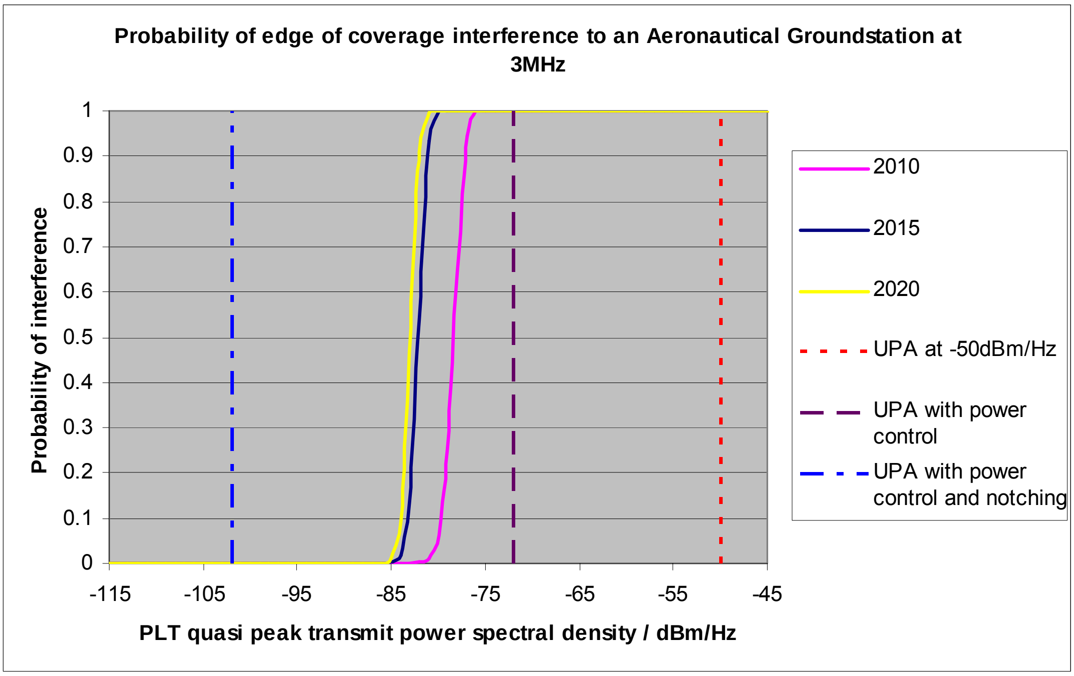

**Figure 20 - Probability of interference to an aeronautical groundstation over a 5 to 10 year timescale**

It is noticeable that the interference curves for the aeronautical ground station case are much steeper than those for the SW and amateur radio cases (i.e. change from high probability of interference to low probability of interference over a reduced PLT transmit power range. The reason is that the relative statistical variation in the range of the PLT interferer from the victim receiver is much reduced because of the larger exclusion zone.

### 9.2.4 Comparison across users shows that aeronautical ground stations give the most cause for concern

Figure 21 compares the probability of interference across the three victim receiver types examined. This shows that the target transmit power for PLT devices to minimise interference is in a similar range for each of these three victim receivers. The aeronautical ground station case gives the most cause for concern as, unlike the amateur radio bands, no interference mitigation is currently applied to protect this safety critical service.

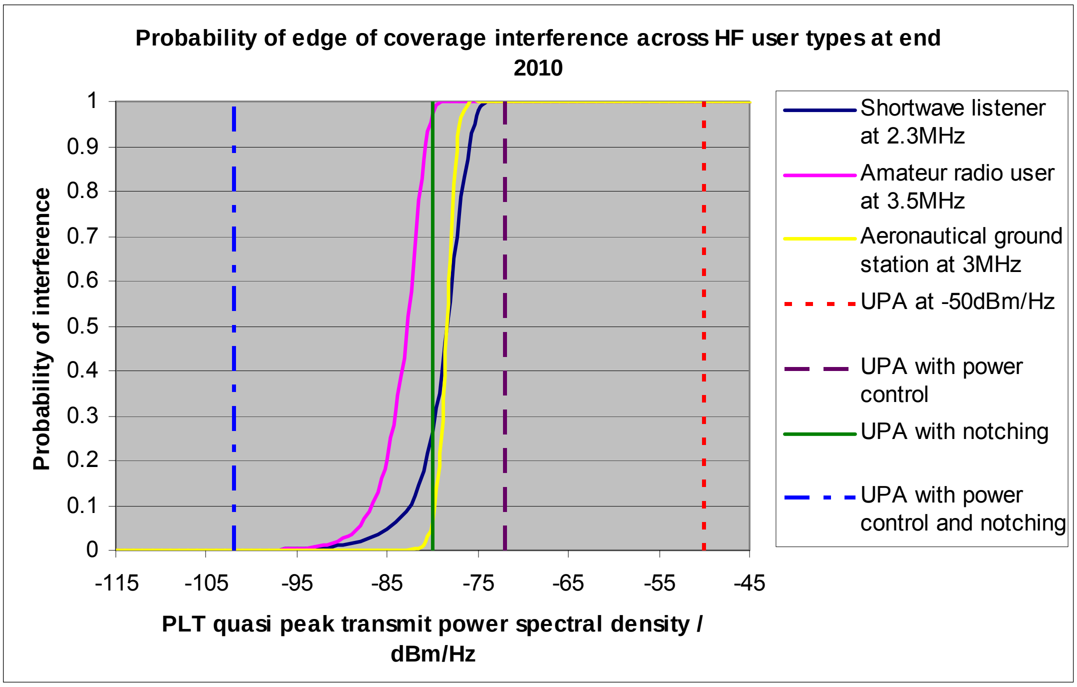

**Figure 21 - Comparison of probability of interference across victim receivers**

## 9.3 Sensitivity analysis

The results in section 9.2 assume a medium market uptake, weighted average duty cycle of 58% and a fixed protection radius. In this section we investigate the difference between the worst case and best case scenarios for these parameters to understand how sensitive these results are to our baseline assumptions.

### 9.3.1 Market uptake

Our market forecast described in 5.2 produces low, medium and high scenarios depending on how fast we believe PLT uptake will be and the proportion of the home networking market that we believe PLT devices will win. Figure 22 shows how the long term risk of interference varies depending on the market uptake scenario applied. As an example of a typical victim receiver we have used an amateur radio scenario for this simulation. This shows that the interference mitigation options applied in our baseline scenario should allow for the PLT transmit power level being approximately 3dB higher in this worst case scenario for market uptake. The interference mitigation options already recommended in section 9.2 will already deliver this additional factor and so this result does not change our previous conclusions.

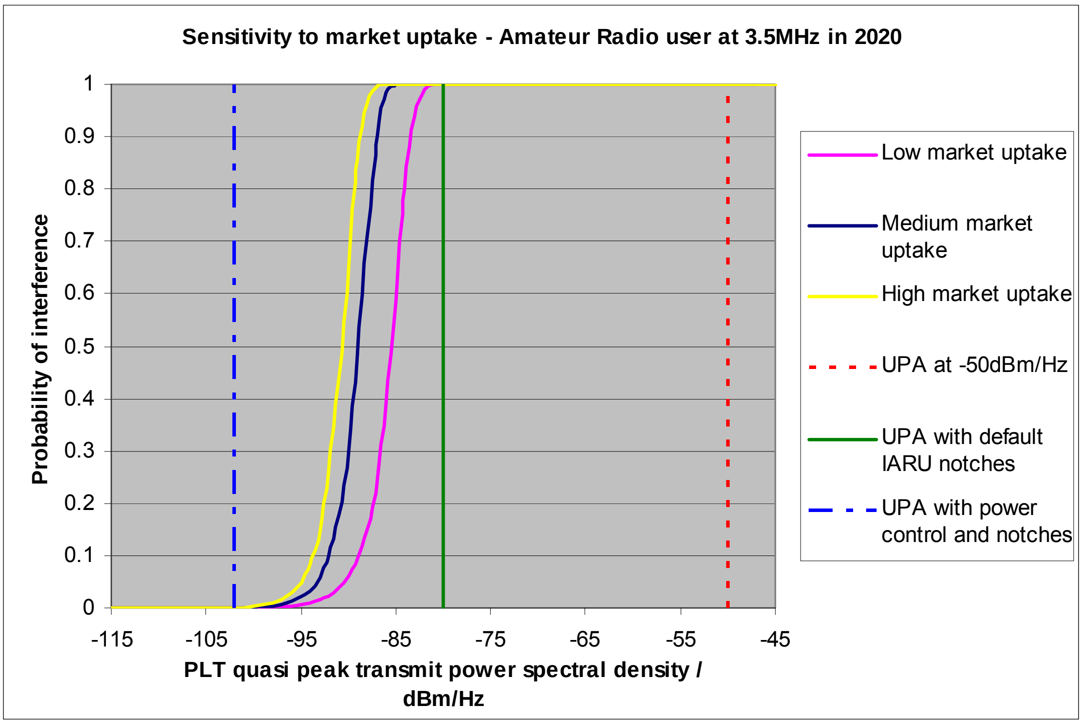

**Figure 22 - Sensitivity to market forecast**

### 9.3.2 Idle time

As discussed in section 9.1.4, our baseline simulation model allows for PLT devices in idle mode by taking a weighted average between the duty cycle for a PLT device in idle mode and one transmitting data which gives a duty cycle of 58%. However, in a worst case scenario all idle signals may be synchronised and generate periodic bursts of interference.

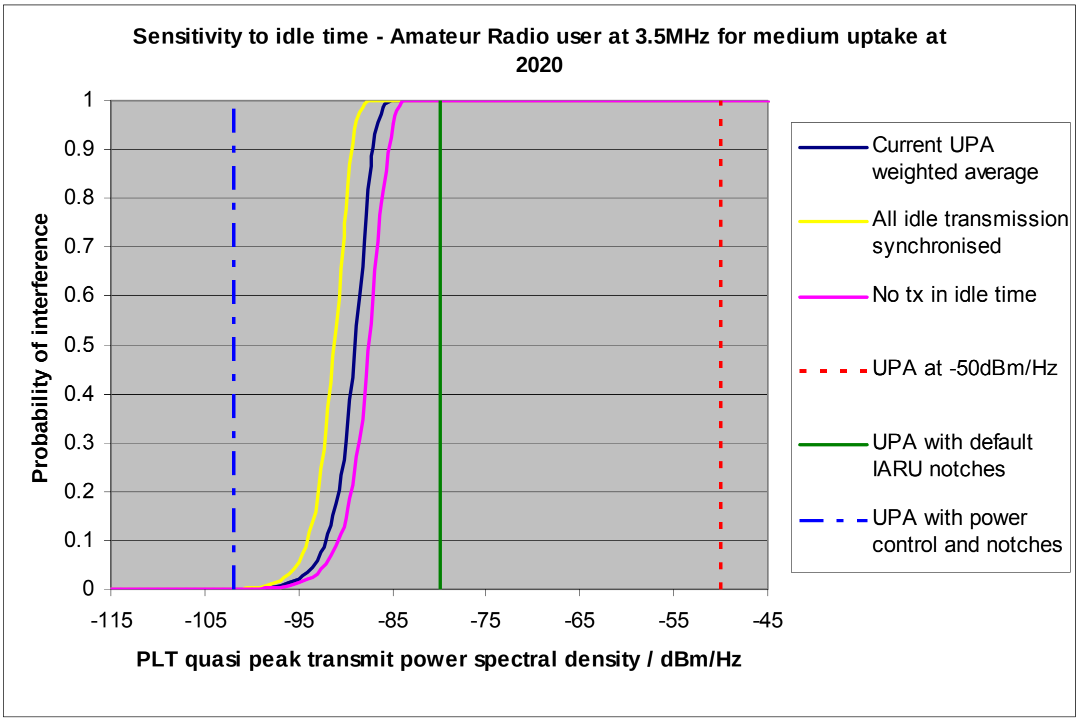

**Figure 23 - Sensitivity to idle time**

Figure 23 illustrates the difference in likelihood of interference between this current case and worst case scenario and shows that in the worst case scenario our interference mitigation must allow for the PLT transmit power level being 2 - 3dB higher than the baseline case. This is within the margin of the interference mitigation techniques already recommended and so does not therefore change our previous recommendations.

### 9.3.3 Protection radius

Of the three victim receivers examined the aeronautical groundstation gives the most cause for concern in the next 5 to 10 years. We have recommended notching of aeronautical bands but another option might arguably be to extend the protection radius around this type of victim receiver.

Figure 24 examines the effect of applying a larger protection radius to the aeronautical ground station using the medium market uptake for 2020. This shows the protection radius would need to be extended to around 1km to bring the likelihood of interference from PLT devices with power control alone to low levels. Based on the specific users in this category and their locations, identified in section 5.3.3, we conclude that notching of the aeronautical bands will be more practical than extending the protection radius to these levels. In addition, as discussed in section 8.4, notching of aeronautical bands will be required to mitigate interference to airborne HF users anyway.

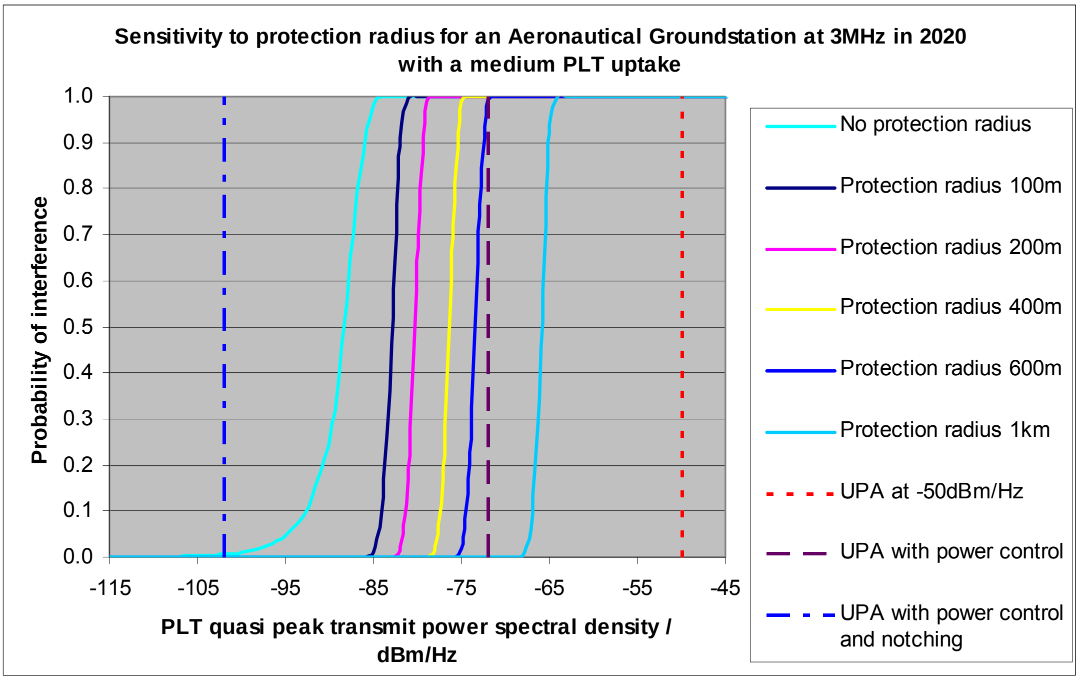

**Figure 24 - Sensitivity to protection radius**

## 9.3.4 Interference criteria

As discussed in section 9.1.3, the interference criteria used in our baseline analysis assumes that a rise in noise floor of no more than 3dB can be tolerated. However, other studies into interference effects from PLT devices have suggested an interference criteria of a 0.5dB rise in noise floor [5][6].

Figure 25 illustrates the effect of applying this stricter interference criteria to a SW listener. As shown this would require a further reduction in PLT transmit PSD of 9dB compared to our baseline scenario.

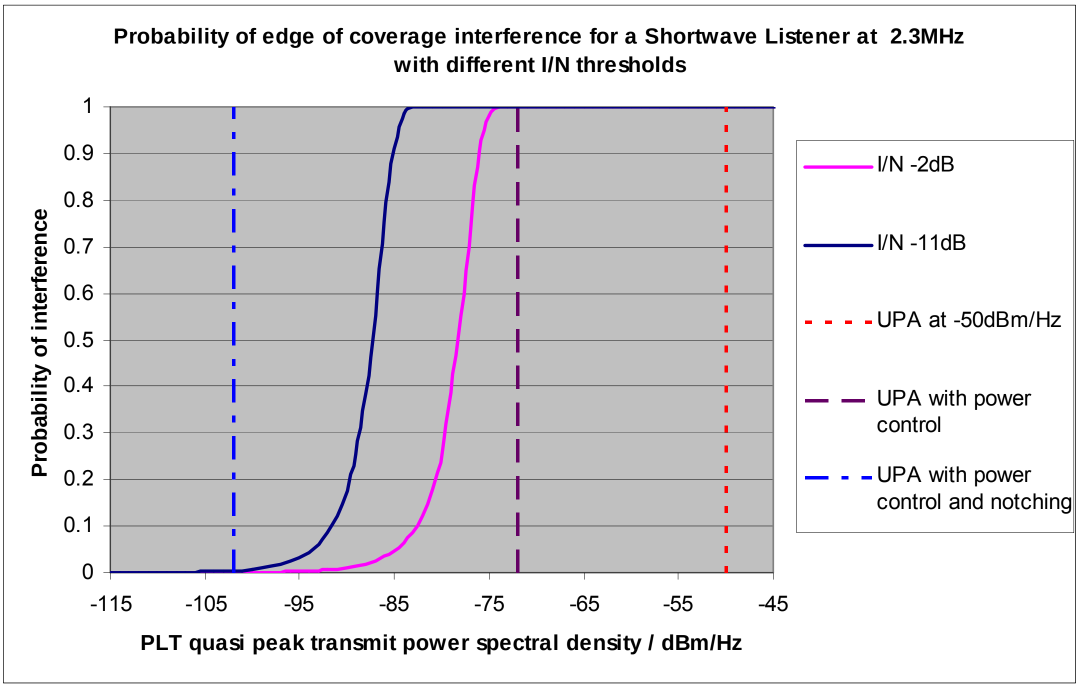

**Figure 25 - Sensitivity to interference criteria**

## 9.3.5 Power level

In our baseline scenario we have assumed that PLT devices will be operating at the UPA maximum quasi peak PSD of -50dBm/Hz. However, in practice PLT product manufacturers may back off the chipsets that they use from this maximum limit. Recent measurements of PLT devices in Canada indicate that this may be the case by as much as 7dB (see appendix L.1). We also note that the CISPR 22 standards group is considering a maximum transmit power level for PLT devices of -55dBm/Hz.

The result of using a reduced power level can be seen on all our graphs by assessing the interference curve against the reduced power level looked up on the horizontal axis.

# 10 Modelling results show that VHF interference from PLT is manageable but requires action

Given that PLT operation is already starting to extend above 30MHz, this chapter describes our approach, assumptions and results of modelling interference from PLT as a result of direct radiated emissions at VHF. We have used Seamcat to model potential interference to VHF users in a similar way to the HF scenarios described in section 9.

Our results show that, even though the PLT transmit power level is greatly reduced above 30MHz, there is still a probability of interference to some sensitive narrowband receivers, which we have termed "narrowband FM" and we recommend that notching is applied in these bands. In addition our results show that the probability of interference to safety critical aeronautical radionavigation becomes high for small variability in PLT transmit power level or the antenna gain of household wiring. We therefore recommend that notches are considered as a precaution to protect these safety critical services.

## 10.1 Model structure and methodology

For this study we have built up models to represent each of the three VHF victim receiver types selected in section 7:

- FM radio listener[11]
- Narrowband FM
- Aeronautical radionavigation.

We have simulated future PLT devices (i.e. operating above 30MHz) assuming the following characteristics:

- Quasi peak transmit PSD -80dBm/Hz
- Operation from 30-300MHz.

Based on our discussions with various VHF user stakeholders, the three victim receivers have been modelled as described in section 7.3 and in particular using the parameters listed in Table 7.

Our assumptions in the following areas to complete the model are detailed in following subsections:

- Antenna gain of mains wiring at -30dBi
- Propagation model for radiated emissions from PLT devices.

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[11] In Section 10.4 we also consider briefly the potential effect of PLT interference on Digital Audio Broadcast (DAB).

- FM radio listener - extended Hata Short Range Devices (SRD) for suburban environment
- Narrowband FM - extended Hata urban environment
- Aeronautical radionavigation - free space path loss.
- Interference criteria:
- FM radio listener C/I = 32dB
- Narrowband FM I/N = -2dB
- Aeronautical radionavigation C/I = 16dB
- Average duty cycle of PLT devices - 40% to allow for improvements in idle time transmission.

### 10.1.1 Antenna gain

We have assumed the same antenna gain for household wiring at VHF as we used at HF. We anticipate that in practice the antenna gain of household wiring is likely to be less at VHF than at HF due to the PLT signal wavelength at VHF being relatively small compared to a length of household wiring whereas at HF the wavelength is longer and a length of household wiring will be closer to an ideal antenna.

In the absence of any existing measurements of radiated emissions from PLT devices above 30MHz we were unable to quantify any reduction in radiated emission at VHF compared to HF for a given PLT transmit power level injected into the house wiring. We have therefore kept our assumption that the PLT antenna gain at VHF will be -30dBi with a variation of ±5dB to ±10dB due to variations in the wiring.

### 10.1.2 Propagation model

Propagation at VHF is more straightforward than at HF as groundwave and skywave effects do not need to be taken into account. We have therefore used Seamcat's standard built in propagation models for each of the victim receivers as follows:

- FM radio listener - extended Hata Short Range Devices (SRD) for urban environment. We have used the short range variant of the extended Hata model as this takes into account that there may be a near line of sight path between the victim receiver and interfering transmitter. In the case of FM radio listeners, it is feasible that there will be line of sight between the PLT house and FM radios in passing cars or nearby homes.
- Narrowband FM - extended Hata urban environment. We have used the Hata model as is the standard approach of modelling propagation at VHF. We have allowed for an urban environment as interference is likely to be at it's highest in built up areas where PLT device densities are highest.
- Aeronautical radionavigation - free space path loss. As the receiver for the ILS localiser navigation signal will be on board the aircraft, we have assumed that there will be a line of sight path between this airborne victim receiver and a large deployment of PLT devices on the ground below.

### 10.1.3 Interference Criteria

Across the three victim receivers we have set the following interference criteria:

- FM radio listener C/I = 32dB. This is based on ITU-R BS.641 and the minimum planned signal level used in BBC national networks as described in appendix O.1. Unlike the other two victim receivers, we have not allowed an extra 2dB in this interference criteria to allow for the impulsive noise effect of the PLT signal. This is because the bandwidth of FM radio is wide enough to accommodate a number of PLT sub-carriers and results from Nasri and Lampe [23] show that in this case the interference effect is likely to be similar or better than if AWGN at the same level was applied.
- Narrowband FM I/N = -2dB. As no planned minimum field strengths were available for the users within this group we have assumed that the noise floor of the receiver is the limiting factor for reception and, as used in the HF case, that interference from PLT should have no more than the effect of an AWGN signal at the same level as the existing receiver noise floor. This would give I/N=0dB but we have allowed an additional 2dB for the impulsive effect of PLT noise (see 9.1.3).
- Aeronautical radionavigation C/I = 16dB. ITU-R SM.1009 gives an interference criteria of C/I 14dB for this category of receiver. We have also allowed an extra 2dB for impulsive Gaussian effect of PLT in a narrowband receiver.

### 10.1.4 Interference from Idle time versus continuous transmission

Improvements in idle time performance are highly likely in future PLT devices and indeed the current ITU G.hn draft is aiming for transmissions during idle time to be negligible. It is also worth noting that the beacon signals transmitted during idle times are more likely to be transmitted below 30MHz due to lower cable loss at these frequencies compared to above 30MHz.

Compared to the HF simulations, we have adjusted the weighted duty cycle of PLT devices to allow for negligible idle time transmission giving an average duty cycle of 40% i.e. the maximum proportion of PLT devices in transmit mode from our earlier analysis of duty cycles at HF.

## 10.2 Baseline simulation results

This section contains our results for modelling potential interference from PLT devices operating from 30-300MHz. In each case we have assumed a medium market uptake, 40% duty cycle and a fixed protection radius as appropriate to each of the victim receiver types. It should be noted that we have used the same PLT market uptake as was the case for our analysis at HF. This is very much a worst case scenario as in practice it will take time for higher data rate PLT devices to gain a foothold in the market and replace existing PLT devices which mainly operate below 30MHz. Indeed it could be the case that higher rate devices retain a premium status and achieve only marginal market share.

### 10.2.1 Interference is dominated by the nearest PLT devices

- As with the HF case described in section 9.2.1, we found that interference at VHF is also dominated by the nearest PLT devices. This is illustrated by Figure 26 which shows the cumulative interference level received at different receiver types as the interference signal from an increasing number of PLT devices is considered.

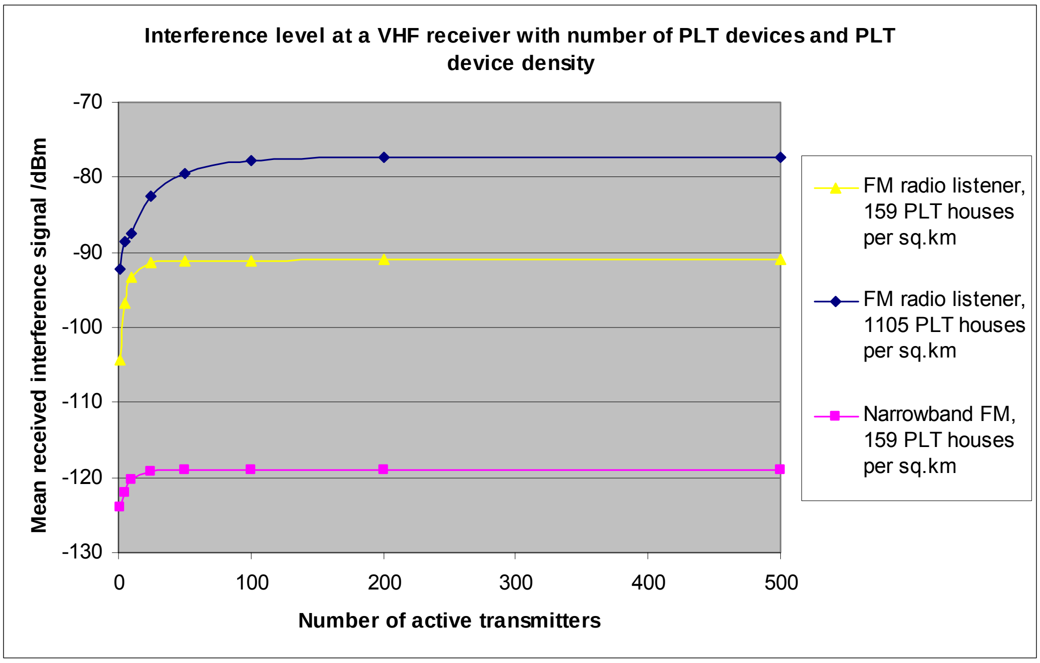

**Figure 26 – Total interference experienced as a function of the number of PLT devices**

In each instance the interference is stable to within 1dB for a number of active PLT devices of 100 or more, so for the remaining simulations we have set the number of active devices to 100.

The exception to this is for aeronautical radionavigation as the ILS receiver will be installed on aircraft which when airborne will have line of sight to a larger number of PLT devices than the other victim receivers situated on the ground. The effect of the victim receiver being airborne is considered further in appendix N.2. This shows that when the victim receiver is above ground the effect of having line of sight with a larger number of PLT devices roughly cancels out with the increased path loss. We have therefore assumed a receiver height of 200m for the aeronautical radionavigation case in our simulations. In addition we have simulated 100,000 PLT users in this case to ensure that the larger simulation area visible to the airborne user is captured.

### 10.2.2 Notes on interference probabilities

As in Section 9 the graphs in this section show the probability of interference to a service for a user at the edge of wanted signal coverage; they do not show the probability of interference of users throughout the UK. For services which have been designed to meet a specific coverage range, they therefore represent the likelihood that the service will no longer meet the original expectations of the radio planners, although the majority of locations may be unaffected by interference from PLT devices. Section 3 of this report considers possible reasons why the number of complaints (208 until February 2010) to Ofcom is relatively low when considered in the light of our results presented here.

### 10.2.3 Probability of interference by victim receiver type

The remaining graphs in this chapter show the probability of interference at the victim system as the power of the interfering PLT sources is varied. As with the HF results discussed earlier, the slope of the probability curve is due to a number of factors including (a) the random distribution of interferers around the victim and (b) the variation in the effective gain of the PLT interferer (for example due to the orientation of the in-house wiring with respect to the victim).

For each of the three victim receiver types we examine the probability of interference over the next 5 to 10 years. This is based on the victim receiver at a fixed frequency but with the PLT device density changed in line with our medium uptake market forecasts for 2015 and 2020. 2010 is not included as very few of the installed base of devices today are operating above 30MHz.

For each of the graphs we have marked:

- Transmit power for PLT devices operating above 30MHz -80dBm/Hz
- 30dB reduction for fixed or smart notching (as was assumed at HF). This takes the PLT transmission power to -110dBm/Hz which is close to the minimum out of band emission levels given during our stakeholder discussions with the PLT industry. We therefore have not considered power control as an additional interference mitigation step.

For the three victim receivers we assumed the following protection distances and environments:

- ***FM listener, protection distance 1m***. We have assumed that FM radios will typically be at least 1m away from mains carrying PLT and that they will be used largely in domestic settings.
- ***Narrowband FM, protection distance 5m.*** We have assumed that narrowband FM antennas will be mounted external to the building and can be at least 5m from the source of interference. We have also assumed that narrowband FM sets will be used in urban areas.
- ***Aeronautical radionavigation, height above ground 200m.*** We have assumed that an aircraft using ILS could fly directly over a PLT deployment and so has no horizontal protection radius. The vertical distance been the aircraft and PLT deployment is taken into account in the victim receiver

height which has been set at 200m. The interference level is relatively insensitive to the aircraft height as described in Appendix N . We have assumed an urban deployment of PLT devices.

### Interference to FM Listeners is manageable via smart notching

Figure 27 shows that if all PLT devices deployed were operating above 30MHz then there would be a high probability of interference to FM radios. However, it should be noted that as these simulations are based on minimum planned field strengths that the probability of interference represents the probability that an FM radio at the edge of coverage (rather than all FM radio listeners) suffer from interference. It is also worth noting that this assumes an ideal FM radio with a receiver sensitivity adequate to meet the planned audio SNR of 50dB. Through our discussions with the BBC we have been advised that the quality of FM radios does vary substantially and indeed in our own testing of a PLT device operating above 30MHz we found that the PLT interference wasn't audible on all the FM radios we tested. In addition, it is worth noting that we have used the minimum planned field strength for BBC local radio in our analysis as this had the lowest minimum field strength of all the radio networks quoted by the BBC. Other FM broadcast radio networks are therefore likely to be more robust to interference. For example, BBC national networks in towns and villages use a minimum planned field strength which is 6dB higher at 60dBμV/m. The BBC say that these field strengths are “back stop” minimum levels and in most cases the networks are interference limited and higher “minimum protected field strength” levels are used.

As there are few devices above 30MHz today, interference to FM radio listeners is likely to be minimal in the short term at least. While smart notching has not been proven at VHF frequencies, these results show that fixed or smart notching could be introduced as a precaution to protect these bands.

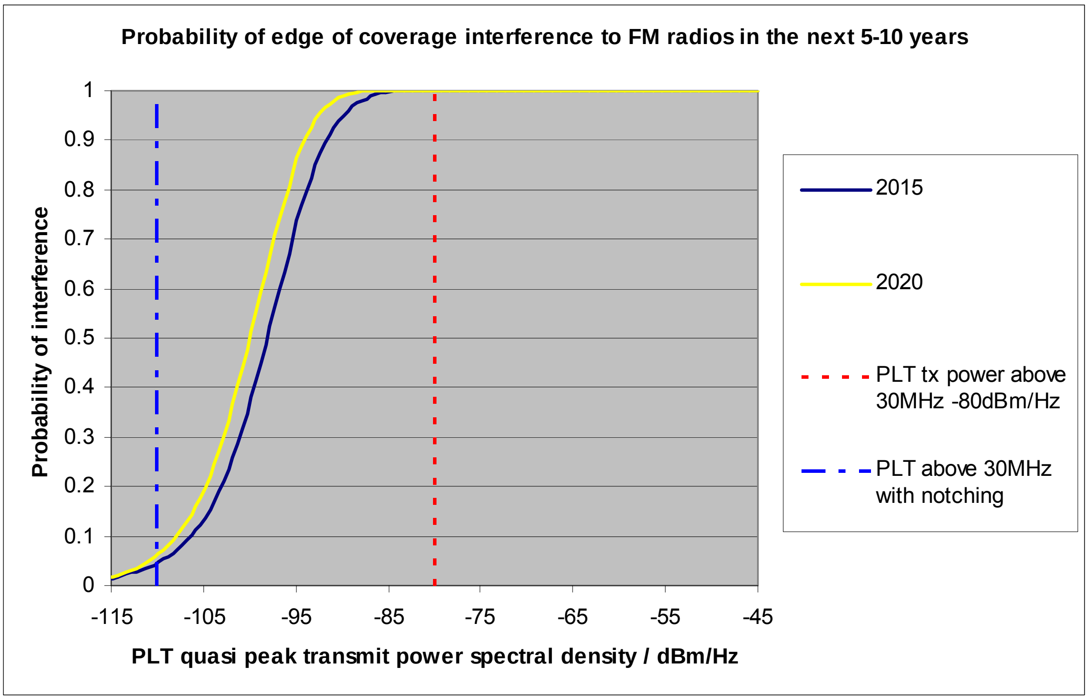

**Figure 27 - Probability of interference for FM radio listeners against PLT power over 5 to 10 years**

### Notching is required to protect sensitive, narrowband FM receivers

Figure 28 shows that narrowband, sensitive receivers such as amateur radio users and land mobile systems operating close to their sensitivity limits are likely to experience interference from future PLT devices operating above 30MHz. However, it also shows that if notches are added to protect these bands, as is common practice for PLT devices below 30MHz, then the probability of interference will be reduced to a low level in the short term rising to a medium level in the longer term.

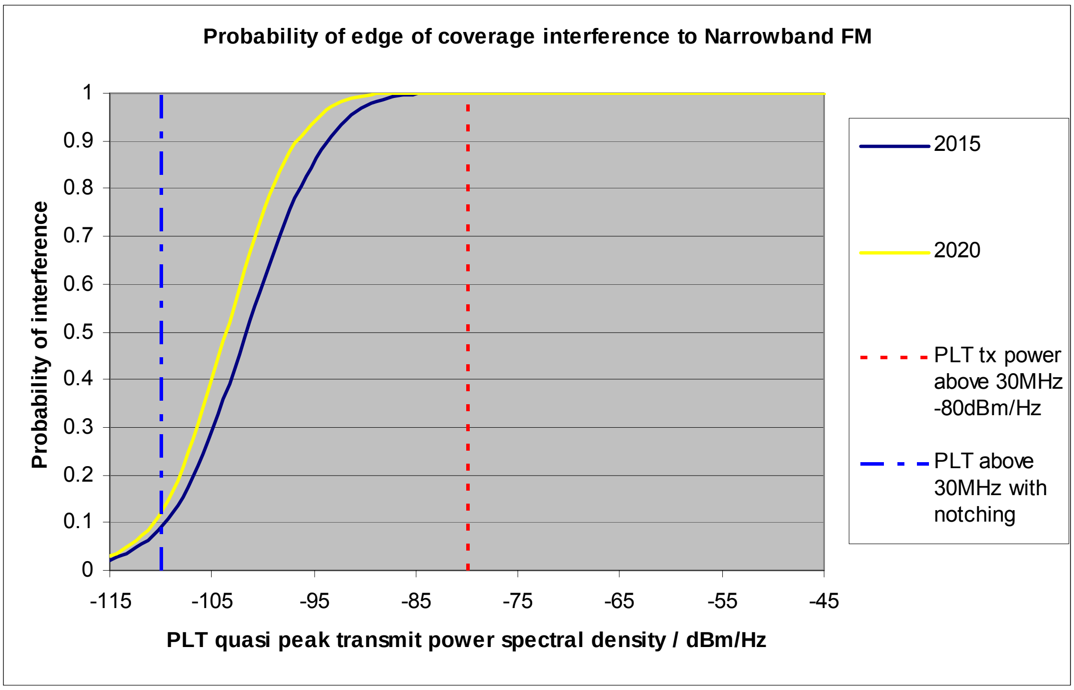

**Figure 28 - Probability of interference for narrowband FM against PLT power over a 5 to 10 year timescale**

## Notching is required to protect safety critical aeronautical radio navigation

Figure 29 shows the simulation results for an ILS localiser representing the aeronautical radionavigation victim receiver. Interference in this case is based on the minimum planned field strength and so our results show the probability of interference to a ILS localiser on the edge of coverage. This shows that, due to the cumulative effect of the airborne receiver having line of sight to a large number of PLT devices, a small change in PLT power or variability in the antenna gain of household wiring could change this result to a high probability of interference. If all PLT devices deployed in 2010 were operating above 30MHz, instrument landing systems would be on the threshold of high levels of interference from PLT. As the PLT device density increases this would move the probability more clearly into the high category. We therefore recommend that these bands are notched as a precaution.

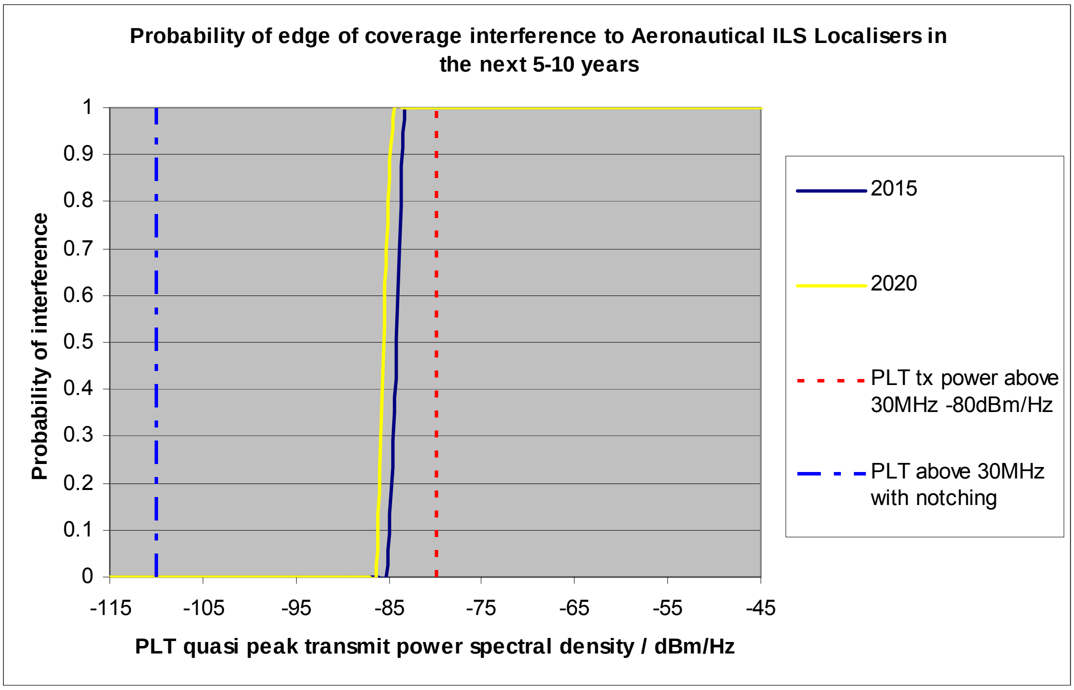

**Figure 29 - Probability of interference for Aeronautical radionavigation against PLT power over a 5 to 10 year timescale**

## 10.3 Sensitivity analysis

### 10.3.1 Market uptake

Our baseline scenario has assumed a medium market uptake for PLT devices. However, our market forecast includes a high uptake scenario which would be the worst case in terms of PLT density. As described in section 9.3.1, applying a high market uptake has the effect of reducing the required PLT transmit power level to minimise interference by 3dB. Applying this 3dB offset to our baseline cases does not change our conclusion in the majority of cases. The exceptions are the Narrowband FM and FM broadcast cases where this additional 3dB may need to be incorporated into the notch depth to keep the probability of interference low if a high PLT uptake looks likely.

### 10.3.2 Idle time

We have not performed a sensitivity analysis at VHF as beacon signalling during idle times is more likely to use HF where the cable loss is lower than VHF. In addition, it is a future trend in PLT devices to incorporate quieter idle time exchanges.

### 10.3.3 Protection radius

Of the three victim receivers examined it is unlikely that increasing the protection radius will be a practical mitigation approach as:

- There is little control over the deployment of PLT devices around the victim receiver or the location of the victim receiver in the cases of FM radio listeners or narrowband FM users
- In the case of aeronautical radionavigation, while there could be an exclusion area around the aircraft at the airport this protection distance will be impractical to implement during flight, which is when the instrument landing system is required.

We therefore have not examined the effect of changing the protection distance at VHF.

### 10.3.4 Interference criteria

As discussed in section 9.3.4, other studies have suggested that an interference criteria of an increase in noise floor of 0.5dB may be more appropriate than the 3dB assumption we have used in this study. If this revised criteria is applied it has the effect of reducing the required PLT transmit power level to minimise interference by 9dB. Applying this offset to our baseline cases does not change our conclusion in the majority of cases. The exceptions are the Narrowband FM and FM broadcast cases where this additional 9dB may need to be incorporated into the notch depth to keep the probability of interference low if this interference criteria is applied.

### 10.3.5 Power level

Our baseline simulations assume a PLT quasi peak transmit power level of -80dBm/Hz. This is the suggested maximum transmit power level in future PLT standards but PLT manufacturers may choose to transmit below this in practice. However, it should be noted that there is limited scope for reducing this power level and including notching as from our stakeholder discussions we understand that the power level on unused sub-carriers in PLT devices reach a minimum level of -110 to -120dBm/Hz.

## 10.4 Digital Audio Broadcast (DAB) is likely to be more robust than FM broadcast.

In our detailed assessment we covered FM broadcast due to its large current market share compared to DAB. In this section we make a brief assessment of the interference risk to DAB reception in comparison to FM broadcast.

The principal VHF DAB frequency band in the UK is 209-230MHz. Therefore while this lies above the frequency band proposed in ITU G.Hn, it is within the range of the current Gigle chipset.

DAB planning [31, 32] assumes:

- A minimum edge of coverage field strength of 58dBuV/m for a 10m receiver height:
  - this corresponds to 48dBuV/m at a typical receiver height of 1.5m or -74dBm input power
- Under a typical DAB modulation scheme, a signal to noise ratio of 14dB is required.

Comparing these figures with the FM broadcast link budget figures shown in Figure 12 we find that DAB is able to accept PLT interference up to a level of -88dBm compared with -105dBm for FM. Therefore we conclude that DAB is 17dB less susceptible to PLT interference than FM broadcast. Given the conclusions for FM broadcast, this suggests there still may be a need for mitigating action in the DAB bands if the number of PLT devices using frequencies above 200MHz becomes significant.

It should be noted that the edge of coverage field strength of 58dBuV/m assumed above is for national DAB services. If the same planning approach is taken for DAB as for FM broadcast, local services may have been planned with a few dB lower signal strength.

# 11 Interference via a shared mains connection will become significant if no action is taken

This section considers interference via the second of the two main interference mechanisms introduced in section 3; interference from indirect PLT powerline radiation via a shared mains connection. This is split into interference radiated from overhead cables and interference conducted close to a victim receiver and then radiated in the victim receiver's location. In both cases the probability of interference is linked to the probability of the victim receiver having a mains connection shared with a PLT user and carrying a PLT signal. In both cases we also conclude that power control is required in PLT devices to bring the likelihood of interference to negligible levels for the predicted uptake of PLT over the next 5 to 10 years.

The analysis in this section uses the parameters for HF PLT device operation as this is the worst case. Higher cable losses at VHF will result in a lower likelihood of interference.

## 11.1 We have examined mechanisms for interference from indirect PLT powerline radiation via a shared mains connection

As discussed in section 3, during the study we have divided interference from PLT devices into interference via radiated emissions directly from the PLT user's home and interference resulting from the victim receiver being nearby to a power line that is carrying a PLT signal.

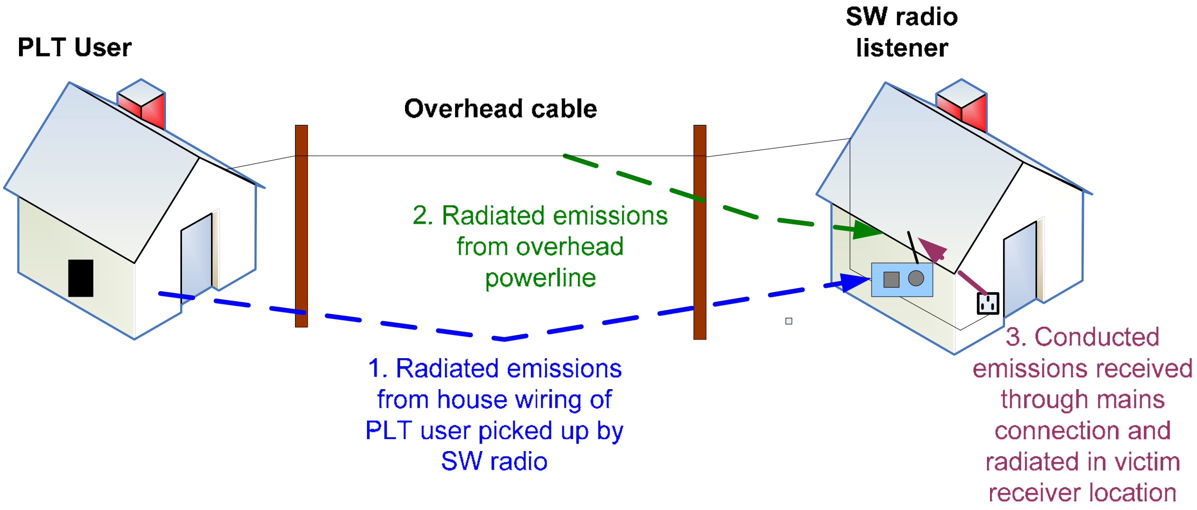

**Figure 30– Different Routes of Interference from PLT devices**

Figure 30 recaps on the difference between these two interference mechanisms and further sub divides interference from a shared mains connection carrying a PLT signal as follows:

**1. Radiated emissions from the PLT user's house**. The mains wiring of the house where the PLT device is being used will act as an antenna and radiate the signal injected into the mains wiring by the PLT device. This has been discussed in detail in sections 8, 9 and 10.

**2. Radiated emissions from nearby overhead power lines (due to a shared mains connection carrying a PLT signal)**. If no filtering is applied at the consumer unit in the PLT user's home then the conducted emissions from the PLT device will continue to be transferred into mains wiring external to the house. In the case where overhead cabling is used to provide power to the PLT user's home, our tests have shown that the overhead cable will continue to radiate emissions from the PLT device and could cause interference to a SW radio located nearby to the overhead power line (see appendix I.7).

**3. Conducted emissions received via the mains connection and then radiated close to the victim receiver (due to a shared mains connection carrying a PLT signal)**. As discussed above, the conducted emissions from PLT devices may continue to be transferred into the mains network external to the house. Depending on the attenuation of the mains cabling between homes, these conducted emissions may be transferred into the mains wiring of neighbouring homes sharing the same mains transformer and phase. The mains wiring of this neighbouring home will also act as an antenna and radiate the received conducted PLT emissions. If the victim receiver, such as a SW radio, is being used in a neighbouring property, it is possible that it may suffer PLT interference radiated from its own mains wiring.

The remainder of this chapter evaluates interference related to mechanisms 2 and 3 i.e. those caused by a shared mains connection carrying a PLT signal external to the PLT user's home.

## 11.2 Radiated emissions from nearby overhead power lines require mitigation via power control

To illustrate the likelihood of interference via radiated emissions for nearby power lines, Table 11 provides the link budget for the example scenario shown in Figure 31 where a Shortwave Radio Listener is located 5m from an overhead power line that is carrying interference from a PLT device being used in a house down the street. This calculation works back from the interference criteria at the victim receiver to estimate the minimum cable length that could be tolerated between the PLT device and the victim receiver for no interference to occur.

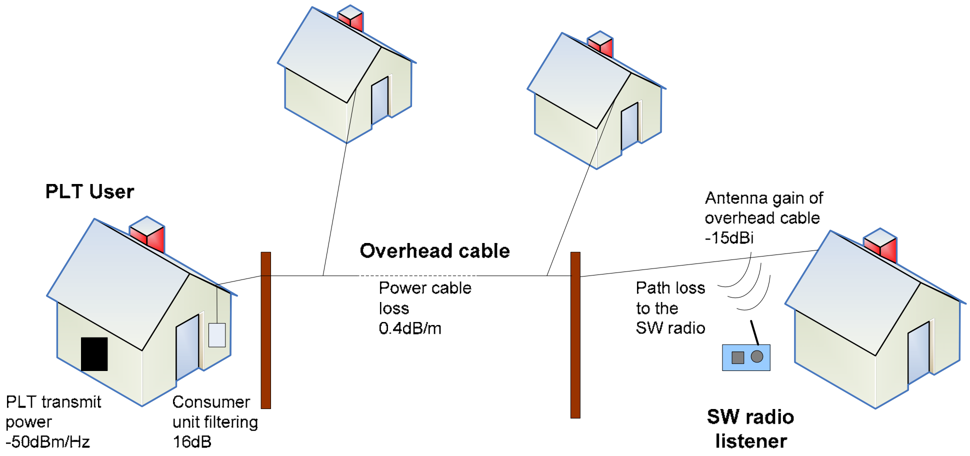

Figure 31 - Example scenario for interference from overhead cable

| **Link Budget Component for SW radio in a small bandwidth at 7.1MHz** | | **Value** |
|---|---|---|
| Background noise at victim receiver | | -89 dBm |
| + Acceptable I/N at victim receiver | | -2dB |
| *Maximum permitted PLT interference level received by the SW radio* | | *-91dBm* |
| - Victim receiver antenna gain | | -(-4dBi) |
| + Propagation loss for 5m | | 18dB |
| - Overhead cable antenna gain | | -(-15dBi) |
| **Maximum permitted PLT power in the overhead cable 5m from the victim receiver** | | **-54dBm** |
| | | |
| Original PLT injected power -50dBm/Hz in 4kHz | | -14dBm |
| - Loss from PLT user's consumer unit | | -(16dB) |
| **PLT power injected into overhead cable from PLT user's house** | | **-30dBm** |
| | | |
| Minimum loss allowed in the overhead cable between PLT user's home and victim receiver location if no interference is to occur | | 24dB |
| **Minimum cable length from PLT device to victim receiver location (cable loss 0.4dB/m as per assumptions)** | | **60m** |

Table 11– Example link budget for SW radio receiver suffering PLT interference via overhead power lines

Assumptions in this calculation include the following:

- The victim receiver is a Shortwave Radio Listener with a 4kHz bandwidth operating at 7.1MHz with an antenna gain of -4dBi with background noise used for broadcast planning as described in 6.3.1.
- Assumes a UPA PLT device operating with a transmit power of -50dBm/Hz.
- The interference criteria is set so that the PLT device does not raise the background noise floor by more than 3dB and allowing for the fact that the PLT signal in a narrow band is non Gaussian (see Appendix L ).
- The distance between the victim receiver and the overhead power line is at least 5m.
- The distance conversion factor at close range and 7.1MHz is 25.5dB/decade based on recommendations by NATO [5] who estimate a distance conversion factor of 23dB/decade at 5MHz and 29dB/decade at 10MHz.
- The effective antenna gain of an overhead power line is -15dBi based on recommendations by NATO [5].
- Filtering loss of a home consumer unit (fuse / switchbox) is 16dB. The consumer unit of each home is designed to conduct 50Hz mains signals. Therefore we would expect a certain amount of the PLT signal to be reflected at the consumer unit and not be conducted outside the home. It should be noted that there is little data available on this subject. The best source we found was a draft report from ITU-R study group 1A who are currently examining the impact of PLT devices on radio communications below 80MHz [6]. Even in this report there is significant variation between the optimistic and pessimistic measurements of the filtering effects of consumer units reported to the ITU-R group. Our 16dB assumption is based on an average of these reported measurements.
- The attenuation of power cables is 0.4dB/m as used in an analysis by Koch submitted to CISPR 22 to inform discussions regarding PLT devices [14].

Table 11 shows that having one PLT device with 60 metres of cable between it and a shortwave radio victim receiver could cause interference via the overhead cabling. This is consistent with our sample field observations. If more than one house sharing the same mains circuit uses PLT devices then the interference signals will add in the overhead cable and the minimum required separation to avoid interference will potentially increase. However, the increase in the interference signal level will be partially cancelled by the cable loss between houses. For example, if two adjacent houses with 10m of overhead cable between them both used PLT devices the increase in interference would be 1.5dB rather than 3dB. We conclude that in the example above interference would occur if one or more PLT user's homes were on the same overhead cable circuit and within 60m of the victim receiver.

Table 11 shows the link budget for this interference scenario assuming that no interference mitigation is applied. If we assume that power control is incorporated into PLT devices shortly, in line with the expected PLT roadmap, then the average power reduction of 22dB delivered by this would be close to providing the required loss between the PLT device and victim receiver of 24dB. It is therefore anticipated that the introduction of power control will greatly reduce the likelihood of interference via this mechanism.

## 11.3 Conducted emissions received via the mains connection and then radiated close to the victim receiver will require mitigation via power control

Table 12 estimates the minimum cable distance there would have to be between a PLT device and the home where a victim receiver was being used in order to avoid interference via conducted emissions received through a shared mains connection. This scenario is shown in Figure 32.

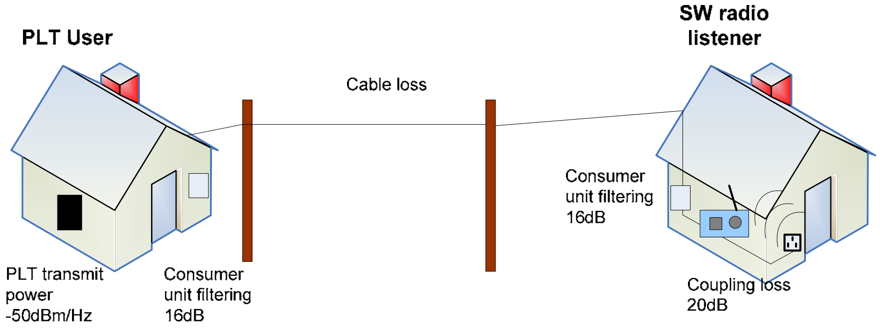

**Figure 32 – Example Scenario for interference via conducted emissions and radiated in victim location**

| Link Budget Component for SW radio in 4KHz Bandwidth at 7.1MHz | Value |
|---|---|
| | |
| Background noise at victim receiver | -89dBm |
| + Acceptable I/N at victim receiver | -2dB |
| + Coupling loss between mains in victim receiver location and the victim receiver | 20dB |
| + Loss from victim receiver's consumer unit | 16dB |
| **Maximum permitted PLT power entering the victim receiver consumer unit** | **-55dBm** |
| | |
| Original PLT injected power -50dBm/Hz in 4kHz | -14dBm |
| - Loss from PLT user's consumer unit | -(16dB) |
| **PLT power injected into external mains cable** | **-30dBm** |
| | |
| Allowed loss between the PLT device and the victim receiver's mains wiring | 25dB |
| **Minimum separation between PLT house and shortwave listener's house** | **62.5m** |

**Table 12 - Example link budget for a SW radio suffering from PLT interference radiated from the mains wiring in the house where the SW radio is located**

In Table 12 we have assumed the following:

- The victim receiver will be at least 1m from any mains wiring.
- At 1m we assume near field coupling loss effects of 20dB between the victim receiver and the mains wiring. Field trial measurements at 1m from PLT devices were not available to confirm the near field effects of PLT devices. However, this coupling loss is in line with field strength measurements made for in home PLT devices by the Communications Research Centre Canada (CRC) at 3m which, translated to EIRP, are approximately 30dB down on the injected transmit PLT power [13].
- Filtering loss of a home consumer unit is 16dB based on measurements reported to ITU-R (see section 11.2).
- PLT device is a UPA device with a quasi peak transmit power level of -50dBm/Hz
- The attenuation of power cables is 0.4dB/m based on CISPR 22 discussions [14].

This shows that if any houses sharing the same mains circuit are within 62.5m of the victim system and using PLT then the victim system is likely to suffer interference. Similarly to the overhead power line case, if more than one household is using PLT and is connected to the same mains circuit the PLT interference level in the mains will increase and potentially the minimum required separation between the victim receiver and the PLT users will also increase.

Also similarly to the overhead power line case, the required loss between the PLT and shortwave listener's house of 25dB would largely be provided by the introduction of power control in PLT devices.

## 11.4 The probability of interference through indirect PLT powerline radiation via a shared power connection will become significant by 2020 if power control is not introduced

In sections 11.2 and 11.3 we have seen examples of the minimum cable length required between a typical victim receiver and the PLT user to avoid interference if they are sharing the same mains circuit. The overall likelihood of interference in both cases will depend on the probability that the victim receiver shares a mains circuit with a PLT user in the first place.

For sensitive aeronautical users we assume that the antenna would be more than 60 – 62.5m from residential areas and so would be unlikely to suffer interference via either of the two mechanisms described in sections 11.2 and 11.3.

For amateur radio and shortwave radio listeners we assume that these devices will be used in areas close to the user’s house and so interference from overhead powerlines will depend on the likelihood that the victim receiver’s location is supplied electricity via an overhead powerline and shares a mains circuit with a neighbouring house within 60m of cable length which is using PLT.

The number of adjacent houses within 60m of cable from the victim receiver will vary between house type from flats and terraced houses closely spaced at one extreme to farm houses at the other extreme. From Appendix M we assume that the average low voltage cable length per household is 20m and so on average a victim receiver will suffer interference if any of the six neighbouring houses around it (i.e. three at 20m each to the right and three at 20m each to the left) have a PLT device in use. It is worth noting that although the example link budgets worked through were specifically for a shortwave radio listener the difference for an amateur radio user at a similar frequency would be approximately 3dB due to the improved antenna gain but reduced bandwidth. This would give a difference in required cable length of 7.5m which based on our estimate of 20m would still mean that it would suffer interference if any of the 6 neighbouring houses (i.e. three either side of the amateur radio user) were using PLT devices as in the case of the shortwave listener. In addition, most new PLT devices apply at least a 30dB notch to amateur radio bands by default which should remove the risk of interference for amateur radio users.

We assume that the 6 neighbouring houses are on the same mains circuit as the victim receiver. This is based on Appendix M which shows 57 households on average share the same transformer giving 19 households on average sharing the same phase mains supply. It is therefore feasible that all six neighbouring houses could be sharing the same mains supply as the victim receiver.

Based on the medium uptake curve of our market model detailed in section 5.2, we anticipate that 21% of households will have PLT devices by 2020. Therefore the probability that at least one of its six neighbours uses PLT will be:

$1-(0.79)^6 = 0.76$ Equation 1[12]

Also based on Appendix M , we estimate that 22% of households in the UK have electricity supplied via an overhead cable. The probability of one of the victim receiver’s six neighbours using PLT and the victim receiver being supplied via an overhead cable would therefore be 17%.

This shows that based on the example scenario given in section 11.2, a significant proportion of victim receivers would experience interference from PLT via overhead cables by 2020 if the uptake of PLT continues to grow in line with our market forecast.

A similar logic can be followed for the likelihood of interference from the mechanism described in section 11.3. However, in this case interference will occur regardless of whether the victim receiver’s home is supplied electricity via an overhead or underground cable. The probability of interference to victim receivers in this case would therefore be much higher at 76%.

Table 13 summarises the resulting probability of interference when a similar logic is applied using the market forecasts for 2010 and 2015. These results illustrate the potential scale of interference via PLT emissions conducted via cabling external to the home and we recommend that consideration is given to filtering at the consumer unit to isolate in-home PLT networks from the remainder of the

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[12] (1 - probability that all six adjacent houses don't have PLT) gives the probability that at least one of the six adjacent houses has PLT

distribution network. Further measurements and research into these interference mechanisms are also recommended as we found a lack of previous studies in this area. In particular the filtering loss of consumer units and the average PLT signal transferred to external mains cables is relatively unknown.

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| **Interference from an overhead cable** | 6% | 14% | 17% |
| **Interference from victim receiver's own mains** | 26% | 65% | 76% |

**Table 13 - Probability of interference from indirect PLT powerline radiation to a SW radio via a shared mains connection over a 5 to 10 year timeline (based on baseline/medium takeup scenario)**

As mentioned earlier, interference via this route will be virtually eliminated if power control is introduced in line with the current roadmap for PLT devices. It is therefore recommended that power control is implemented in the forecast timescales.

# 12 Conclusions and recommendations

This study has examined the likelihood and extent of RF interference from in-home PLT devices over the next 5 to 10 years via two main routes; radiated emissions directly from the PLT user's home and interference from indirect PLT powerline radiation via a shared mains connection. In the case of both of these routes we have concluded that, provided uptake increases in line with our market forecasts, there will be a high probability of interference to HF users by 2020 if PLT device features do not change from those currently implemented. However, our results also indicate that interference mitigation techniques currently being developed by PLT device vendors and being discussed in international standards bodies will be sufficient to reduce this interference to negligible levels for most HF users. The exception to this is the safety critical aeronautical bands which will require notching by default.

In addition our study has considered the potential for interference from emerging PLT devices at VHF. While this is less of a concern than at HF due to reduced power levels, we have still found that action does need to be taken to protect VHF users including safety critical aeronautical systems.

Our conclusions across each of the interference mechanisms investigated can be summarised as follows:

- ***Cumulative effect of ground wave over very large areas*** - The likelihood of interference from PLT devices via this route is low. Instead the observed interference signal at the victim receiver is dominated by the closest PLT devices.
- ***Cumulative effect of sky wave over very large areas*** - Based on results from NATO, the likelihood of interference from PLT via the cumulative effect of sky wave is low. The exception to this is in quiet rural areas where interference is more noticeable.
- ***Cumulative effect of line of sight interference to airborne HF users*** - Based on results from the ITU, there is a significant chance of interference to these HF users. Both power control and notching combined with a maximum transmit power level of -63dBm/Hz are required to bring PLT signals below the interference threshold.
- ***Cumulative effect of radiated emissions to ground based HF users*** - The likelihood of interference via this route is similar across the three HF victim receiver types. The probability of interference is high with notching or power control alone but can be reduced to negligible if both techniques are used together. IARU bands are already notched by default in most PLT devices on sale today, but it is worth noting that earlier PLT devices did not include IARU notches and may need to be updated.
- ***Cumulative effect of line of sight interference to airborne VHF users*** - Based on our modelling of aeronautical instrument landing systems we have found that a small variability in PLT transmit power level or antenna gain of household wiring could dramatically change the probability of interference. This probability is borderline if VHF PLT devices are widely adopted in the near

future, rising to high in the longer term. We therefore recommend that these bands are notched by default.

- ***Cumulative effect of radiated emissions to ground based VHF users*** - Of the VHF victim receivers examined sensitive narrowband FM receivers and, to a lesser extent, FM broadcast receivers give most cause for concern and some bands may require notching. Nonetheless such receivers operating near the limit of their sensitivity may still have a low but measurable probability of interference.
- ***Interference from indirect PLT powerline radiation via a shared overhead cable*** - The likelihood of interference via this route is low to medium from now up to 2020 if PLT devices do not change. However, the introduction of power control is likely to reduce interference via this route to negligible levels. It should be noted that there is uncertainty over the filtering effects of UK consumer units which could affect this conclusion.
- ***Interference from indirect PLT powerline radiation via a shared mains connection close to the victim receiver*** - The likelihood of interference via this route is medium to high from now up to 2020 if PLT devices do not change. However, the introduction of power control is likely to reduce interference via this route to negligible levels. It should be noted that there is uncertainty over the filtering effects of UK consumer units which could affect this conclusion.

Based on these conclusions we recommend the following:

- ***The maximum transmit power of PLT devices should be harmonised***. Our conclusions are based on a quasi peak transmit power level of -50dBm/Hz which is the maximum transmit power level for UPA devices. However, currently PLT product manufacturers can vary the transmit power of PLT chipsets and the Homeplug AV standard operates at the lower level of -55dBm/Hz. This ambiguity makes future interference levels difficult to predict and levels will vary depending which devices become dominant. From our extension of ITU results for airborne HF users we note that a maximum PLT power level of -63dBm/Hz (in addition to notching and power control) is desirable to protect these safety critical services.
- ***Power control and smart notching should be implemented***. Power control and smart notching are anticipated to be available in Q2 and Q3 of 2010 respectively. Our results show that these features need to be introduced in these timescales to keep interference at manageable levels and recommend that these features are implemented in PLT devices in a timely manner.
- ***Notches in the IARU bands should be implemented***. Most PLT vendors already notch the HF IARU bands by default and our results show that this is an essential interference mitigation approach. However, we have not yet seen notching of amateur radio bands at VHF. We therefore recommend that notching of amateur radio and other similar sensitive narrowband receiver bands are implemented both at HF and VHF.
- ***Notches in the HF aeronautical bands should be implemented***. Our results show that notching and power control will be required to protect the HF aeronautical bands from PLT interference over the next 5-10 years. As the incoming signals are likely to be at low levels and of short duration we recommend that permanent notching rather than smart notching is applied. We have also

assumed a protection radius of 100m in our analysis and this should be discussed with the operators of aeronautical ground stations.

- ***Notches in the VHF aeronautical radionavigation bands should be mandated.*** Our results for ILS localiser receivers indicate that the probability of interference is likely to become high during the next 5-10 years. We therefore recommend that these safety critical bands are notched by default.

***Additional options include***:

- ***Interference between PLT and VDSL should be monitored***. There have been suggestions of interference between VDSL and PLT devices where the cables are installed next to each other. Our assessment is that this could lead to interference only in very specific installation situations, but we recommend that Ofcom monitor this situation with BT as VDSL is deployed in the UK.
- ***The filtering effects of UK consumer units should be measured***. Our results in relation to conducted interference are based on measurements that exist of PLT signal loss through consumer units, and lead us to recommend action on power control and notching. It would be prudent to test the filtering effects of a range of typical consumer units in the UK to ensure that consumer units with a lesser filtering effect are not present in large numbers.
- ***Measurements of radiated emissions from in-home PLT devices deployed in the UK.*** We found a lack of measurements of radiated emissions specifically from in-home PLT devices. One such study has been carried out recently in Canada measuring emissions outside a single PLT home. However, it would be useful to repeat this in the UK at distances covering the near field, far field and ground wave propagation to understand any dependency on UK-specific wiring practices and to examine the effect as the number of PLT homes increases.

# Appendix A Acknowledgement of stakeholder input

We have contacted the following people and organisations for input to this study and we thank them for their contributions:

| **Standards Groups** | |
|---|---|
| UPA (Universal Powerline Association) | Donald Pollock, Permanent Secretary |
| Homeplug Powerline Alliance | Rob Ranck, President |

| **PLT device vendors** | |
|---|---|
| Comtrend | Jonathan Lishawa<br>Marcos Ostman |
| DS2 | Jorge Marcos, Product manager for home networks<br>Chano Gomez, Standards<br>Santiago Vicent, Technical |
| Intellon (recently changed to Atheros) | Purva Rajokotia, Director of Standards |
| Gigle | David Sorensen<br>Jed Hurwitz |
| BT Vision | Trevor Morsman |

| **Victim Receiver Groups** | |
|---|---|
| UKQRM | Richard Yarnall |
| EMC Industries Association (EMCIA) | Keith Armstrong, President of the EMCIA |
| BBC | Cath Westcott, Senior Frequency Manager, Broadcast Networks at BBC World Service<br>John Endicott, Spectrum Manager |
| RSGB | Colin Richards, EMC Committee Secretary |
| CAA (Civil Aviation Authority) | John Mettrop |
| MCA (Maritime & Coastguard Agency) | Richard Rees, Spectrum & Technical Standards Unit |

| Victim Receiver Groups | |
|---|---|
| MOD (Ministry of Defence) | Ian Taft, Defence Spectrum Management |
| QinetiQ | Paul Arthur, Intelligence and Digital Security<br>Anil Shukla, Centre for Propagation and Atmospheric Research |
| Individual | Voi Piotrowski |

# Appendix B Abbreviations

| | |
|---|---|
| ADSL | Asymmetric Digital Subscriber Line |
| CAA | Civil Aviation Authority |
| CB | Citizen's Band |
| CISPR | Comité International Spécial des Perturbations Radioélectriques |
| | (Special international committee on radio interference) |
| CRC | Communications Research Centre Canada |
| DHS | Digital Home Standard |
| ECM | Electronic Counter Measures |
| EIRP | Equivalent Isotropically Radiated Power |
| EMC | Electromagnetic compatibility |
| ETSI | European Telecommunications Standards Institute |
| HD-PLC | High Definition Powerline Communications |
| HF | High Frequency |
| HomePNA | Existing wires home networking alliance |
| HPA | Homeplug Powerline Alliance |
| IARU | International Amateur Radio Union |
| ILS | Instrument Landing System |
| IP | Intellectual Property |
| ITU | International Telecommunications Union |
| MCA | Maritime and Coastguard Agency |
| MoCA | Multimedia over Coax Alliance |
| MOD | Ministry of Defence |
| NATO | North Atlantic Treaty Organisation |
| NTIA | National Telecommunications and Information Administration |

| | |
|---|---|
| OFDM | Orthogonal Frequency Division Multiplexing |
| PLT | Powerline Telecommunications |
| PMSE | Programme Making and Special Events |
| RF | Radio Frequency |
| RSGB | Radio Society of Great Britain |
| SCADA | Supervisory Control And Data Acquisition |
| SRD | Short Range Device |
| SSB | Single Sideband |
| SW | Short Wave |
| UKQRM | UK based group, QRM is the radio code for man-made interference |
| UPA | Universal Powerline Association |
| VDSL | Very high bit rate Digital Subscriber Line |
| VHF | Very High Frequency |
| VOR | VHF Omnidirectional Range |

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# Appendix D PA's structured approach to quantifying interference

PA's approach to the study is detailed in this section. Our approach drew on information from the PLT industry and existing interference analysis to avoid duplicating previous work. We developed and documented usage scenarios for in-home PLT and forecast likely future device densities. We then performed statistical modelling and sensitivity analysis to determine the likely extent of harmful interference to other licensed systems.

This approach was adopted to ensure that Ofcom has a comprehensive report on the likelihood and extent of interference, based on a clear evidence base and taking account of all relevant effects. The statistical model that we have developed will be made available to Ofcom to enable further sensitivity analysis to be performed as PLT device specifications develop and equipment volumes grow in the future.

## D.1 Overview of approach

PA's approach comprised four key stages.

- Conducting desk research and discussions with PLT industry bodies to confirm device characteristics and trends and gathering existing information on PLT interference to avoid duplicating previous work
- Defining usage scenarios and forecasting likely future densities for in-home PLT devices
- In parallel, examining the impact interference mechanisms between the PLT devices and victim systems in the relevant frequency band and perform statistical modelling to determine the likely extent of harmful interference based on forecast device density
- Finally conducting sensitivity analysis on the results by varying a number of assumptions and commenting on the viability of potential methods to mitigate against PLT interference.

Details of individual tasks follow.

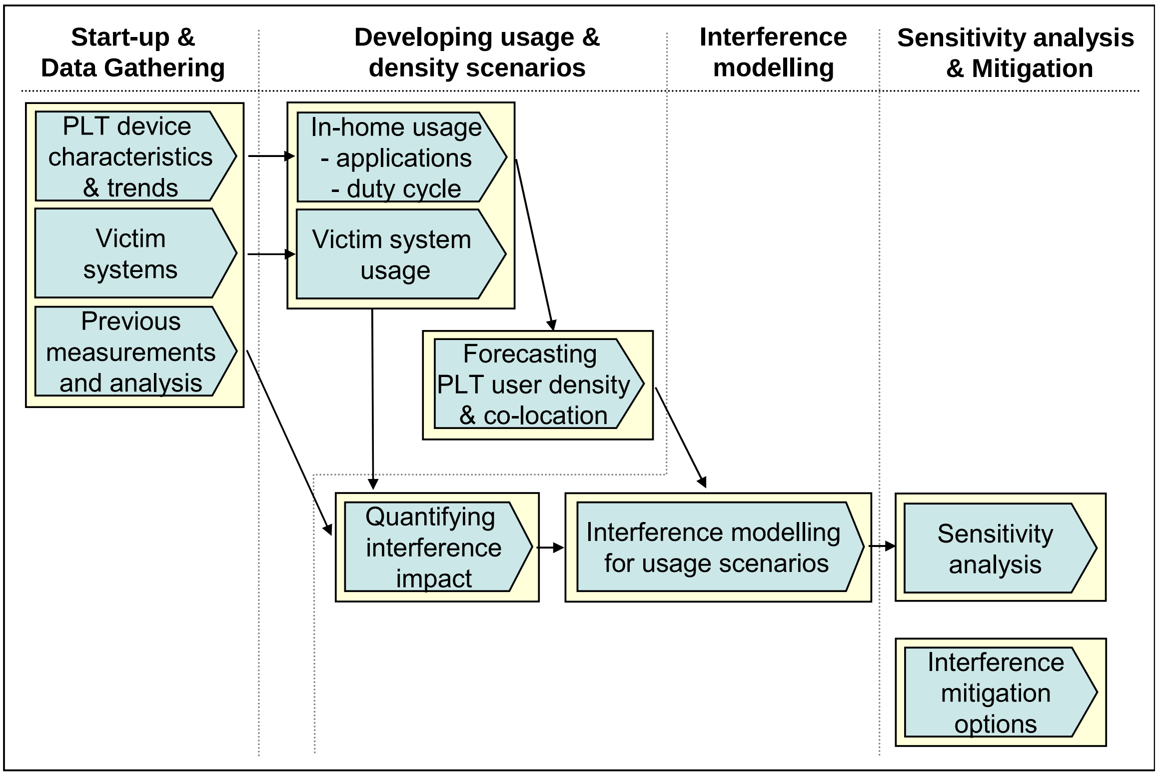


**Figure 33 - Overview of PA approach**

## D.2 Description of study stages

### D.2.1 Start-up and data gathering

The work began with a start-up meeting with Ofcom to confirm the approach to be taken to the study and to agree a number of key assumptions.

This included assumptions regarding the treatment of the different existing systems that could be subject to interference. The possible victims were derived from the list of users at the frequencies used by PLT.

We engaged with the PLT standardisation bodies and industry groups such as UPA and Homeplug to understand trends and likely roadmaps for PLT standards and devices. The study included a wider stakeholder consultation approach including PLT vendors and chipset providers, as well as bodies representing the potential victim systems. A list of all the stakeholders consulted is given in Section Appendix A .

We avoided 're-inventing the wheel' by conducting a desk research exercise to collate existing sources of material on models and measurements for PLT interference. Examples included reports by the ECC [16], NATO [5] and Ofcom [1, 2, 3]. A list of all the reference documents reviewed is given in Section Appendix C . Given the allowed scope for the study, this approach provided the necessary level of detail, without time-consuming activities such as widespread measurement of PLT devices or in-depth protocol level simulation of interference between PLT standards and the wide range of potential victim systems.

### D.2.2 Defining the usage scenarios

The first input required for the modelling is a definition of how PLT devices will be used in the home. A series of usage scenarios were generated. Product literature was used as a guide, not only as this highlights the possible applications, but also as it will tend to influence the buyers as to how to use the products.

Examples of the usage scenarios at which current devices are being targeted include:

- Home IT networks e.g. PC to printer
- Small office IT networks e.g. between multiple PCs
- Home entertainment networks e.g. re-directing satellite, Freeview or IPTV services to a TV screen.

These applications for PLT tend to be alternatives to dedicated wired networks or wireless devices such as WiFi or AV senders. Future scenarios could extend to smart metering and energy monitoring devices, home monitoring and device control systems.

Usage scenarios and characteristics were also derived for victim receivers. In order to keep the scale of the work to a manageable level, one standard implementation for each of the potential victim service types was selected. For example Amateur Radio uses a variety of signal standards, but SSB voice is the most common in the 2-30MHz range, so this mode alone was evaluated for scenarios where HF Amateur Radio is the victim receiver. Stakeholders confirmed that SSB is also the most common modulation in HF aviation communications.

### D.2.3 Forecasting PLT user density and co-location

Having identified the PLT and victim receiver usage scenarios, we then quantified their extent and likely density. The approach was forward looking as PLT is still at an early stage of adoption. The correlation between PLT users and victim receiver users was also considered because if they are usually co-located this will cause a greater RF interference impact than if their distribution is random. The degree of co-location was considered for different victim system types.

Our market predictions are based on demographics of the user groups identified in the usage scenarios, and on comparison with other markets in similar technologies and/or geographies. Two approaches to uptake forecasting have been used. A bottom-up approach, using statistical analysis of current data as the basis for future forecasts provides a detailed segmentation of user profiles as well as adoption rates. A top-down methodology is used to calibrate the bottom-up calculations and serves as a common sense check. Where possible the development of analogous markets is taken into account insofar as technology take-up curves tend to exhibit a similar shape across different markets, varying mainly in timescale. In carrying out our forecasting, we focussed on the drivers and influencers, be they technical, commercial, competitive or regulatory, in order to determine likely development of the PLT market.

While we recognise that there is considerable uncertainty in the potential market, we provide an evidence base for our estimates as far as possible by looking at the take-up of:

- devices that could utilise PLT - for example percentage of homes with more than 1 PC, homes with multiple TV sets, Sky+ homes etc.
- devices that perform a similar function to in-home PLT, such as Wifi routers and video senders.

Having established an estimate of the addressable market for PLT devices, we derived a number of high-level scenarios that cover the different possibilities, rather than trying to figure out a detailed 'answer' on PLT demand.  For example, the scenarios could be:

- very limited penetration, PLT achieves only a couple of percent of the market
- moderate penetration for use in WLAN-equivalent, competes with WiFi, but still only say 5-10% of market
- high penetration, used intensively by power monitoring, WLAN-equivalent, video senders etc.

### D.2.4 Quantifying the impact of interference on victim systems

The nature of RF interference is such that is rarely clear-cut as to whether interference will occur. Instead a more representative measure is the probability of successful reception or interference under particular conditions. This takes into account variability in factors such as propagation losses, antenna orientations, and the indeterminate nature of power wiring.

Determining whether interference is occurring is not only a matter of power levels however. Factors related to the standards and data rates such as the modulation scheme are also taken into account at this point. The question of what constitutes an acceptable level of interference will vary according to the application. For instance a Morse code signal can tolerate a much lower signal-to-noise ratio before it becomes unintelligible compared to a voice signal. The details of the signals of both the PLT system and the victim receiver have been considered in order to derive the extent of the RF interference.

The main PLT standards use OFDM modulation in which a large number of sub-carriers, each of narrow bandwidth relative to the whole signal, are modulated with data. This modulation is adapted to take account of channel conditions that vary with time and across the bandwidth of the transmission, and will typically vary from BPSK to multi-level QAM. The bandwidth of each sub-carrier is 20-24kHz compared to a typical bandwidth of 2-4kHz for the licensed radio systems in the HF range. It is therefore likely that the victim receiver will see part of one the PLT sub-carriers which will have a different interference effect to receiving the entire wideband PLT signal made up of many sub-carriers.  The impact of this effect has been examined in detail and our modelling approach for interference from PLT to the victim receiver takes account of the impact of this effect.

For each potential victim system we defined acceptable levels of interference based on the structure of the PLT interference.  The dominant PLT standards have been evaluated, although the similarities between them mean that a full analysis for one standard has been followed by a brief analysis of the effect of the differences in the other standard.

### D.2.5 A statistical approach to interference modelling

All the factors listed above formed the input to the statistical model driven by the assumed user densities. The statistical model built aggregates PLT interference according to the usage scenarios and determines the proportion of the time or of instances of use where RF interference is experienced sufficient to disrupt normal use of the victim receiver.

After considering a number of alternatives, the model was built using SEAMCAT, an interference analysis tool developed by the European Radiocommunications Office (ERO).

Full details of the modelling approach taken are given in Section 9.

### D.2.6 Sensitivity analysis

Our results expressed the interference impact as the probability of suffering RF interference for each of the scenarios identified. Subject to the details of the scenarios there may well be additional variables considered in the results such as changes in protection distances, market uptake and idle time. Variables such as these are explored in our sensitivity analysis.

The sensitivity of the results enable Ofcom to assess whether regulatory intervention is required, when and where, and the effectiveness of different possible forms of intervention.

### D.2.7 Interference mitigation

We commented on the viability of different interference mitigation methods to overcome interference.

Examples could include regulatory action on emissions masks, perhaps with notches at specific frequencies used by particularly sensitive victim systems. An alternative approach could be a technical solution in the in-home wiring, such as a wideband filter in the vicinity of the electricity meter to prevent interference leaking down the power lines - something that could perhaps be deployed in conjunction with future smart metering technology.

## D.3 Interaction with Ofcom

To deliver an effective outcome, PA secured the following contributions from Ofcom:

- Discussion and agreement of basic assumptions at the start of the project, including the relative focus to different victim system types
- Guidance on and access to previous Ofcom studies and a multitude of previous measurements and analysis that were helpful to the study
- Provision of contact details for key victim stakeholders.

# Appendix E In-Home PLT networking usage scenarios and competitive position

## E.1 PLT usage scenarios

The scenarios described here have been used throughout this study when considering:

- Market forecasts for PLT devices
- Proximity of PLT devices to victim receivers
- Duty cycles of PLT devices incorporating the correct split between the number of devices in idle mode compared to those transmitting data.

**PLT Home User Application 1**

| **Name** | **Broadband in every room** | **Source** |
|---|---|---|
| **Description** | Connecting the internet to one or more PCs that are not co-located with the modem. WiFi has it sown up at present but can PLT make inroads? | |
| **User demographic** | 50/50 male/female, average age 41.7, price sensitive | Forrester “2008 Global Internet And Broadband Landscape” |
| **Devices being networked** | 57% UK homes on broadband (2008)<br>68% EU-7 adults have a computer available at home, 9% of these have no desktops, 62% have 1, 22% have 2+<br>6% of those with a PC +7% of those without intend buying a PC in next 6 months (Q2 2008) | As “User demographic” plus Forrester “European Consumers And Their PCs” |
| **Data rates, duty cycles** | Home usage. 70% of PC owners use it for photos, 36% manage finances, 14% connect to employer’s network, 9% watch live TV + 4% record TV to HDD | Forrester “European Consumers And Their PCs” |

### PLT Home User Application 2

| **Name** | **Wired for sound and vision** | **Source** |
|---|---|---|
| **Description** | Networking the PC, TV, stereo etc. Content stored on or streamed to one device being played on a different device e.g. MP3 files on PC played on HiFi, or BBC iPlayer to TV | |
| **User demographic** | Average age 41, income $77,000 (US survey Q1 2007) | Forrester "Home Networks Begin To Shift To Entertainment" |
| **Devices being networked** | Sharing a broadband connection is still the main motivation for setting up the network<br>93% desktop, 71% laptop, 52% printer, 37% game console, 28% DVR, 20% Media PC, 11% media gateway | As above |
| **Data rates, duty cycles** | Share internet/printer/files/storage across PCs 82/61/57/31%, games console 37%, music to HiFi 29%, video to TV 24%, remote program DVR 15%, IPTV 11% | As above |

### PLT Home User Application 3

| **Name** | **The home teleworker** | **Source** |
|---|---|---|
| **Description** | A mini-LAN for the home office with PC, printer, modem etc. Non-work devices likely to be on same network | Forrester "Casual Home Workers Embrace The Digital Home" |
| **User demographic** | Forrester definition: bring work laptop home at least once a week | As above |
| **Devices being networked** | 95% desktop PC, 91% laptop, 52% printer, 32% game console, 18% media centre PC, 15% DVR, 10% network storage | As above |
| **Data rates, duty cycles** | Sharing across multiple PCs: 63% Internet connection, 39% printer, 32% files, 21% storage. 19% photos to TV, 15% music to HiFi | As above |

## E.2 Competing technologies

The main competing technology highlighted in our discussions with stakeholders from the PLT industry is WiFi. PLT aims to be more reliable, provide a longer range and have an easier set up than competing WiFi products. However with a typical price range of £20 - £125 PLT devices are slightly higher cost than the WiFi equivalent. Also at the moment PLT networks still require a network cable between the PLT adaptor at the mains socket and the end product requiring a network connection and so does not provide the mobility of WiFi.

Data networking over other wired media in the home such as coaxial and telephone cabling could also be seen as a competitor to PLT. However, from discussions with stakeholders there is a growing trend to provide a unified device that will support whichever in-home wired media is most readily available and provides the best performance. The emerging ITU G.hn standard for in-home networking provides a unified standard that will operate over telephone, coaxial or powerline cables and is an example of this trend.

Strengths and weaknesses of PLT against other in-home networking technologies can be summarised as follows:

- Strengths:
  - Easy setup. The setup of a PLT network aims to be as straightforward as plugging in the PLT adaptors and connecting a cable between them and the devices to be networked.
  - Longer range than wireless competitors particularly in older buildings with thick walls
  - Reliability. Although the mains network is not the most suitable wired medium for transmitting data and will suffer from changing loads and reflection of signals, PLT devices aim to be more reliable than a wireless solution such as WiFi which may suffer from interference and congestion from other users of the unlicensed band.
- Weaknesses:
  - Price. In-home networking PLT devices are slightly more expensive than equivalent WiFi products.
  - Lack of mobility. PLT devices still require a connection to the mains and so do not offer the same mobility as alternatives such as WiFi.
- Opportunities:
  - IPTV. Service providers are increasingly looking to provide triple play services to consumers consisting of voice, video and data. If IPTV is to be added to existing voice and video services a quick and easy method of sharing the broadband access point to other rooms in the home is attractive.
  - Smart metering. In a bid to be more environmentally friendly, enabling consumers to monitor their electricity consumption is becoming more topical and gaining interest with electricity suppliers.
- Threats:

- EMC testing.  There is much debate over suitable type approval and EMC testing for in-home PLT devices.   Changes to international standards in this area placing stricter limits on PLT devices could be a set back to the industry.
- Lack of a harmonised industry standard.  The WiFi industry has already converged on a single industry standard but within the PLT industry there are still multiple rival standards causing confusion amongst consumers.

# Appendix F Modelling future PLT uptake in the UK

In this section we describe the market modelling that has been performed to predict the future density of PLT devices nearby to victim systems. The approach, assumptions and principles of model operation to perform sensitivity analysis are described.

## F.1 The PLT device market model

PA has modelled the expected consumer market uptake of PLT devices in the home. The model provides Ofcom with a reasonable view of the speed and extent of domestic uptake during the next 10 years. This uptake is modelled on the basis of available data, the uptake of analogous technologies / the development of analogous markets, as well as based on PA's experience.

We have employed our proprietary market / service model tool, which PA frequently deploys in such projects. This tool has been used to great effect for our clients in a variety of business and financial planning activities, technological deployments and regulatory activities such as in this case.

The market model is built in such a manner as to provide a market forecast output that feeds PA's in technical assessment of the likelihood of interference from PLT devices. This market forecast output is calibrated in terms of PLT device uptake density, relational to population. That is to say, the model determines the variation in the density of households that are likely to use PLT devices over the forecast period. The model forecasts a median scenario and in addition allows low- and high-scenario variations. The functioning of the model is explained in greater depth below. Input data is fully sourced and assumptions are fully documented.

## F.2 Model inputs and data sources

PA made use of a number of input data sets in its market model. Some of these inputs are directly consumed by the model, such as in the case of retail shipment volumes to date. Other inputs are used in aggregate to inform or shape the forecast, such as the historic and forecast values for the uptake speed of home networks deployments. Input data includes the following.

- Dept. for Communities and Local Governement (DCLG) planning guidance and housing statistics
- Business planning forecasts of the BT Vision service were taken into account, although PA applied its judgement in light of the large degree of variance between the previous iteration of the business plan and actual uptake to date.
- Equally, PA took into account both quantitative and qualitative statements by device manufacturers relating to current and expected sales forecasts, as well as expected product modifications and improvements.

- Numerous published primary and secondary market analysis studies, providing insight into the historic and forecast uptake of analogous technologies and markets. These include data on household PC, laptop and 2nd PC/laptop uptake, household broadband penetration, wired/wireless home-network uptake and household wLAN deployment as well as data on uptake of networked home audio-visual devices such as the ‘Squeezebox’.

## F.3 Model output – Density of households using PLT devices

PLT modems communicate between each other via the mains so it is reasonable to assume that any user will have a minimum of two such devices plugged in to form a network. Both UPA and Homeplug standards have protocols that allocate use of the channel between the modems in the network by means of time division. Put another way, no more than one modem in the network may transmit at any instant.

Considering the potential interference it is therefore not the number of PLT modems but the number of networks that they are organised into that will determine the number of active devices at one time.

The applications for PLT identified in Section 5.1 will in each case tend to have all the PLT modems in a household networked together. Different households’ networks will operate independently from each other. The number of households with PLT will determine the number of independent networks and hence the number of PLT devices transmitting (subject to activity factors) at a given time and frequency. Our market forecast has therefore been carried out to give the number of PLT equipped households in the UK.

One possible correction factor to this is that if market penetration of PLT reaches very high levels then supposedly independent networks may interact by means of reacting to each others’ emissions as a noisy channel. How the PLT devices’ self-organising protocols will react in this case is unknown at this time.

## F.4 Assumptions and variables

In the interpretation of third-party data, as well as in forecasting PLT device uptake, it is necessary and routine practice to make a number of assumptions. The main assumptions are explained below.

### F.4.1 Household density

Planning guidance [29] from DCLG gives a minimum housing density for new builds or redevelopments of 30 dwellings per hectare, equal to 3000 per $km^2$. This replaced previous planning policies from April 2007. Whilst developments since that date have on average exceeded this figure [30], there is also a stock of existing housing at both lower and higher densities. We have taken 3000 households per $km^2$ as a baseline for urban areas in 2007.

This density will then increase over time as new builds conform to the higher density level. With net new additions of around 1% of total households [30] we have estimated an annual growth rate in the density of 0.7%.

### F.4.2 Addressable market

PA determined an annual ceiling for the adoption of PLT devices. This ceiling was informed by the known and forecast deployments of broadband-enabled homes (suitable for IPTV services) and wired and wireless home-networks, both sourced from market analysis material.

### F.4.3 Rate of adoption

Whereas the uptake curve starting point is determined by the known market shipments to date, and PA forecasts the end point as a function of analogous markets, the rate of adoption (of curve pitch) is determined by parameters of the curve. PA's market forecast module contains existing scenario-based uptake curves for low, medium and high scenarios. The parameters are shaped using PA's interpretation of third party data and our experience.

## F.5 Methodology

PA extrapolated market data from BT Vision shipments as well as PLT device retail / resell shipments in order to determine the installed base of households with PLT devices as at 2009. From this point forward, PA benchmarked the rate of uptake against the proliferation of WLAN units as well as home wired/wireless networks.

The rate of adoption of devices can be varied, but is currently set to a 'medium' scenario. This rate of adoption is expected to be faster than the rate of wLAN adoptions. This is because the market is already familiar with the purpose of home networking technologies, and the fact that PLT networks are currently easier to set up than a wireless network.

The market penetration ceiling is also scenario-based and also set to 'medium'. Whereas market research against which PLT uptake is benchmarked will already include significant market events, the scenarios are predicated on the occurrence of certain situations as follows:

- ***Low Scenario*** - We assume that BT Vision has reached its maximum market share and continues to grow slowly allowing for the fact that the number of homes with broadband and therefore potential BT Vision customers will increase. In the home networking market PLT continues to struggle to differentiate itself against WiFi and takes a low share of this market.
- ***Medium Scenario*** - We assume that BT Vision continues to increase its market share slightly behind BT's own market forecast to allow for the below-forecast uptake that has been seen up until now. In the home networking market we assume that PLT devices slowly increase their market share but remain a minor player in this market due to the lack of convergence of standards and continuing dominance of WiFi.
- ***High Scenario*** - We assume that BT Vision reach their previous target of 2-3 million customers by 2011 and continue to grow at a similar rate over the subsequent years. In the home networking market we assume that PLT steadily increases its market share to 20%. Again, even in a high scenario, we do not anticipate PLT dominating the home networking market in the next 10 years due to absence of a single standard, no obvious cost advantage (especially as interference mitigation solutions are implemented) and the current dominance of WiFi.

The low, medium and high scenarios are driven by our assumptions on the proportion of UK broadband households that by 2020 will have IPTV and the proportion of the home networking market that PLT devices will have captured. These "forecast end point" assumptions for the low, medium and high scenarios are shown Table 14.

| | Low | Medium | High |
|---|---|---|---|
| **Proportion of broadband homes with PLT-distributed IPTV** | **10%** | **20%** | **30%** |
| **Proportion of home networking market using PLT** | **2%** | **10%** | **20%** |

**Table 14 - Assumptions on PLT uptake for 2020**

# Appendix G Characteristics of PLT devices currently deployed

This appendix discusses the technical characteristics of today's in-home networking PLT devices.

This chapter has particularly benefited from telephone interviews that we held with chipset vendors, PLT product manufacturers and standards organisations active in the PLT industry. We are grateful to the organisations who participated in these discussions.

## G.1 Industry standards - Homeplug vs UPA vs HD-PLC

There are three industry standards widely used in in-home PLT devices on the market; Homeplug, Universal Powerline Alliance (UPA) and High Definition Powerline Communication (HD-PLC).

The HomePlug Powerline Alliance (HPA) was founded in 2000 and was the first PLT industry standards group to be formed. The US semiconductor vendor Intellon (now Atheros) has always been heavily involved in the Homeplug standards but, unlike the other standards groups, is not the only semiconductor vendor in the HPA. Gigle produce Homeplug chipsets and STMicroelectronics and SPiDCom have both also announced that they plan to release Homeplug chipsets next year [17][18][19]. The alliance also has sponsors such as Intel, Motorola, Comcast, NEC and Cisco.

In November 2001 the HPA released Homeplug 1.0 with a peak data rate of 14Mbps. Alongside this the HomePlug logo was introduced so that consumers could readily identify interoperable products that had passed the alliance's certification program. This was followed by the high end Homeplug AV standard in 2005 which delivers 200Mbps and is aimed at high quality video and audio distribution.

Confusingly, there are PLT devices on the market that are marked with the Homeplug logo but provide 85Mbps rather than 14 or 200 Mbps. These devices are sometimes described as "Homeplug with Turbo" but this isn't an official standard published by the HPA. Homeplug with Turbo is instead an Intellon proprietary technology and extends Homeplug 1.0 by adding Turbo coding and a higher order modulation to give the increased data rate.

The second of the PLT industry standards groups, the Universal Powerline Alliance, was announced in 2005. This group was set up by the Spanish semiconductor vendor DS2 who originally participated in the Homeplug standards. The aim of UPA was to develop a global universal PLT standard, equally accessible to all semiconductor vendors. Although DS2 are currently the only semiconductor vendor in the UPA, the alliance is working to get other semiconductor vendors involved.

The UPA originally aimed to develop standards covering both in-home and access PLT devices. However, as the Open PLC European Research Alliance (OPERA) was also working towards a standard for access PLT devices around the same time, the UPA has focused more on PLT for in-home networking and interoperability between in-home and access PLT devices. The UPA Digital Home Standard (DHS) was approved in February 2006 and with data rates of 200Mbps is comparable to Homeplug AV.

UPA certified PLT devices dominate the UK market as DS2 chipsets are used in the Comtrend powerline adapters included in the BT Vision package. At September 2009, we understand that there were 750,000 pairs of these devices deployed in the UK.

The third industry standards group is based around Panasonic's High Definition Powerline communications technology (HD-PLC) which is a registered trademark of Panasonic. HD-PLC delivers 210Mbps and is comparable to Homeplug AV and UPA DHS. The HD-PLC alliance who promotes this standard, is based in Japan and was founded in September 2007.

The HD-PLC alliance claim in their description of HD-PLC that using a wavelet OFDM waveform, as opposed to FFT OFDM waveform, means that HD-PLC compliant devices have sharper roll off and deeper notches than other in-home PLT standards to minimise interference to other users.

Table 15 compares the technical characteristics of the various in-home PLT standards. Unfortunately, we were unable to obtain detailed technical specifications for HD-PLC. We are unaware of HD-PLC devices on sale in the UK and so have focused on Homeplug and UPA as these are the most important to understand from a UK perspective. ITU G.hn is included on Table 15 for comparison and will be discussed in section Appendix H under future trends.

All in-home PLT standards use OFDM for the Physical layer. Both UPA and Homeplug operate over similar frequency ranges of 2-28MHz and 2-32MHz respectively. Interestingly, 30MHz is a breakpoint in EMC regulations and DS2 must reduce transmit power above 30MHz by 30dB to be compliant.

| | **HomePlug V1.0** | **HomePlug 1.0 with Turbo (Intellon proprietary)** | **HomePlug AV** | **UPA Digital Home Standard** | **ITU G.hn** |
|---|---|---|---|---|---|
| **Frequency range** | 4.5 -21 MHz | 4.5 – 21 MHz | 2 – 28 MHz | 2 – 32 MHz | 2-50MHz,<br>2-100MHz or<br>100-200MHz |
| **Number of usable sub-carriers** | 84 | 84 | Between 275 and 1155 carriers are used. | 1536 | 1966<br>4014 or<br>4096 |
| **Sub-carrier spacing** | 200kHz | 200kHz | 24.41kHz | 19.53kHz | 24.41kHz |
| **Max. bitrate** | 14 Mbps | 85 Mbps | 200 Mbps | 200 Mbps | 1 Gbps |

| | **HomePlug V1.0** | **HomePlug 1.0 with Turbo (Intellon proprietary)** | **HomePlug AV** | **UPA Digital Home Standard** | **ITU G.hn** |
|---|---|---|---|---|---|
| **Modulation scheme** | DBPSK or DQPSK | 16 QAM, 64 QAM, 256 QAM | BPSK to 1024 QAM | BPSK to 1024 QAM | Up to 4096 QAM |
| **Forward error correction** | Concatenated Viterbi and Reed Solomon | Turbo | Turbo convolutional code (TCC) | Reed-Solomon adapted for powerline | Low density parity check (LDPC) |
| **Adaptive modulation and coding?** | Yes | Yes | Yes | Yes | |
| **Notching?** | Notches at fixed frequencies to protect amateur radio bands | Notches at fixed frequencies to protect amateur radio bands | Notches at fixed frequencies to protect amateur radio bands | Programmable notches up to 40dB deep. | Notches at fixed frequencies to protect amateur radio bands. Smart notching also required |
| **MAC scheme** | Prioritised CSMA/CA | Prioritised CSMA/CA | TDMA and CSMA | Token ring prioritised TDMA | |
| **Central controller?** | No | No | Yes | Yes | |
| **Security** | 56 bit DES | 56 bit DES | 128 bit AES | 168 bit Triple DES | |
| **Range** | Approx 200m | Approx 200m | Up to 700m | 300m | |
| Quasi peak **transmit power** | -50dBm/Hz | -50dBm/Hz | -50dBm/Hz for US<br>-55dBm/Hz for Europe | -50dBm/Hz below 30MHz<br>-80dBm/Hz above 30MHz | -50dBm/Hz below 30MHz<br>-80dBm/Hz above 30MHz |

**Table 15 – Technical Characteristics across PLT device standards**

The MAC is quite different between Homeplug and UPA. Homeplug AV uses a combination of Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) for its MAC. All nodes in the network are synchronised to two cycles of the mains signal or 40ms. At the start of each frame a central node announces the allocated time slots for the next frame which will include contended and non-contended periods. In idle times, where no data is being transmitted, this schedule announcement or beacon signal from the central controller is the only transmission seen. The MAC in UPA is different and is based on a token passing TDMA scheme. Each node in the network can only transmit when it holds the token. However, this means that in idle times there are still a high number of transmissions on the network as the token gets passed from node to node. The result is that UPA devices are more likely to cause more interference in idle mode than Homeplug devices. In our lab tests, the difference in MAC between UPA and Homeplug was audible on a SW radio as an additional tone of approximately 1kHz (see appendix I.4).

Adaptive coding and modulation is facilitated by both standards to maximise data rates for a given cable or channel quality between two PLT devices.

It should be noted that these standards are technical specifications that have been agreed amongst vendors to ensure interoperability between PLT devices rather than conformance with EMC regulations. For example, the relevant alliances for both UPA and Homeplug have test facilities for performing Plugtests and supporting their certification programmes. However, EMC testing is outside the scope of Homeplug or UPA certification and is instead expected to be covered by the product manufacturer to obtain CE marking.

Recently 1Gbps PLT devices have been entering the UK market in Belkin products based on a Gigle chipset. This chipset combines Homeplug AV with a proprietary technology that uses spectrum as high as 300MHz. While these devices do not represent an official extension of the Homeplug or UPA standards it is worth noting their characteristics as these devices are available for use in the UK and so may potentially cause interference. We understand that the Gigle chipset uses a dual band modem which operates Homeplug AV from 2-28MHz and a Gigle proprietary technology from 50-300MHz. Above 30MHz the transmit power level is dropped considerably to -80dBm/Hz.

## G.2 Interference mitigation in current PLT devices

Both UPA and Homeplug have worked with the American Radio Relay League (ARRL) at various stages to ensure that interference to amateur radio users is minimised. The Homeplug standards include 30dB notches for the International Amateur Radio Union (IARU) bands and an additional amateur radio band at 5MHz. The UPA DHS specifies that programmable notches up to 40dB in depth must be provided and in practice most UPA manufacturers notch out the IARU bands by default. We have observed these notches in our own lab testing of PLT devices as shown in Figure 34 with further details given in Appendix I.2.

In terms of dealing with complaints outside these default notches PLT device manufacturers are given the following options:

- Amplitude mapping or power reduction
- Programmable notches

Both DS2 and Intellon allow PLT device manufacturers to customise the spectral mask of their chipsets by reducing the transmit power for particular group of sub-carriers via an amplitude map or masking out sub-carriers completely to generate a notch. Notably the DS2 chipset can be programmed once installed in the end-user's premise via a web based interface and this approach has been used to resolve a number of complaints in the UK.

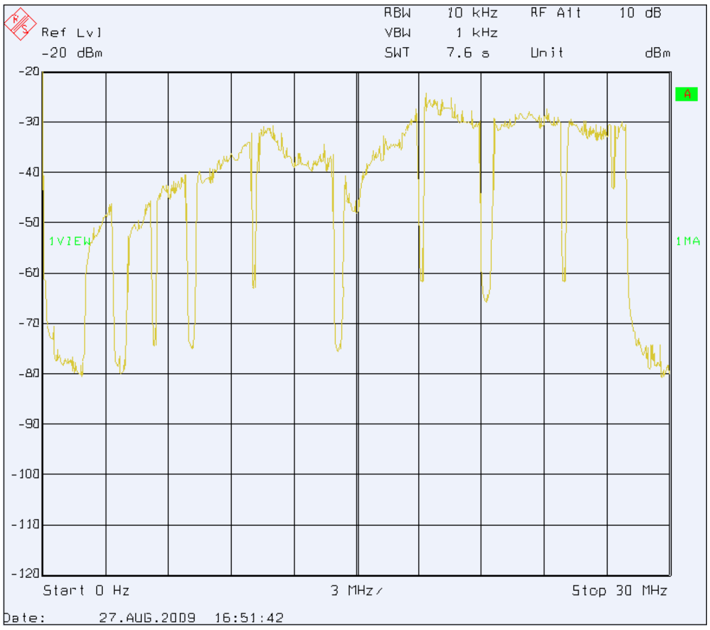


**Figure 34 – Observed spectrum of a Belkin Homeplug AV PLT device**

There are plans to improve the current approach to interference with smarter device features that automatically reduce power or add notches as interference is detected rather than relying on manual intervention by the regulator, service provider or user. These are discussed further in Section Appendix H .

## G.3 International regulation of PLT devices

There is much debate and concern around EMC testing for PLT devices. While it is not in the remit of this study to comment on this subject, it is useful to be aware of the relevant standards and differences between countries as these affect the characteristics of PLT devices.

In the US FCC part 15 applies to PLT devices [20]. This specifies radiated emissions limits for unintentional radiators below 30MHz. Conducted emission limits are not applicable to this category of devices. For in-home PLT devices these radiated emission limits equate to a power spectral density of -50dBm/Hz below 30MHz, which is used by the Homeplug standards. However, above 30MHz the radiated emission limits are much stricter and equate to a drop in power spectral density to -80dB/Hz.

The FCC has added a subsection to part 15 to cover access PLT. Extra requirements include:

- Interference mitigation techniques such as power control and smart notching
- Notching of aeronautical and maritime bands
- Exclusion zones around aeronautical and maritime receiver stations such as coast guard stations

Currently, in-house PLT is classified separately and these extra measures do not yet apply to it.

In Canada, Interference-Causing Equipment Standard 0006 (IECS-006) applies to PLT devices and has recently been updated to specify radiated emission limits from 1.705 – 960 MHz in line with FCC Part 15 equivalent limits, to clarify that in-home PLT devices are subject to IECS-0006 and to add in-situ testing [21]. No conducted emission limits are set above 1705kHz as this requires further study.

CISPR 22 gives international guidelines for Information Technology Equipment (ITE) but is based on conducted emissions for unintentional radiators below 30MHz rather than the US approach of radiated emissions. CISPR22 translates into European EMC directive as EN55022. There is debate over how conducted emissions of PLT devices should be tested but as yet there have been no PLT-specific changes to these standards. This has left standards with some ambiguity which has caused considerable debate around EMC compliance of PLT devices currently on the market [15].

In 2001, the European Commission (EC) requested that work should start on a harmonised European standard for PLT devices. European regulators have been working towards setting specific limits and example suggested limits include the German NB30 and UK MPT1570 levels [5]. The general guidance from the EC in this area is based on recommendation 2005/292/EC from April 2005 which recommends removing unjustified regulatory obstacles to deploying and operating electronic communications networks over powerlines [22]. However, as yet there has been no agreement on a harmonised standard in Europe.

This general confusion and uncertainty over harmonised international regulations for PLT devices is potentially slowing the uptake of PLT devices. Service providers will not want to commit to including PLT devices in their service offerings while regulatory changes are still being debated that could demand the recall of deployed PLT devices and be a major set back to the PLT industry.

# Appendix H Future trends in PLT devices

This section discusses how the PLT landscape is likely to change in the next 5 to 10 years as a key area for the study is the future likelihood of interference as both devices change and devices may become more widespread in the market.

## H.1 Industry standards

### H.1.1 Convergence on a single standard for in-home PLT devices

As discussed in section G.1, there are currently 3 industry standards for in-home PLT devices. In the past we have seen that the uptake of technologies usually accelerates once the industry has converged on one standard due to the clarity amongst consumers and economies of scale that this brings. The WLAN industry converging on the IEEE 802.11 series of standards is an example of this. There have been similar efforts in the in-home PLT industry with two main future standards emerging; IEEE P1901 and ITU G.hn.

The main difference between ITU G.hn and IEEE P1901 is that ITU G.hn is a completely new PHY and MAC for in-home devices using telephone, power or coaxial cables whereas IEEE P1901 specifies mechanisms to ensure co-existence of existing in-home PLT industry standards.

The exact transmit power for ITU G.hn is still under consideration but for PLT devices will likely be -55dBm/Hz below 30MHz and -80dBm/Hz above 30MHz. The frequency range of ITU G.hn varies with medium and mode. For PLT devices 3 bands have been suggested as 2-50MHz, 2-100MHz or 100-200MHz. It is also likely to include improved interference mitigation features such as quieter idle times, smart notching and dynamic power control. Other technical characteristics of ITU G.hn are compared against existing standards in Table 15. It is worth noting while there are significant similarities between ITU G.hn and Homeplug AV the two standards are not compatible.

As shown in Figure 35, there is a split amongst the current in-home PLT industry standards groups between IEEE P1901 and ITU G.hn. It is difficult to see how this standards battle will play out. The HPA claim that 75% of in-home networking devices worldwide are Homeplug based and introducing a new PLT standard that is not backwards compatible with these doesn’t make sense. However, UPA claim that at 200Mbps they dominate the market and are promising ITU G.hn chipsets by mid 2010. The UK is skewed towards UPA because of the BT Vision deployments but interestingly Freesat are HPA members and could significantly address this imbalance if Homeplug was used in Freesat set top boxes for interactive TV.

While this division in the in-home PLT industry still exists it is unlikely that PLT devices will enjoy the high uptake seen by competitors like WiFi.

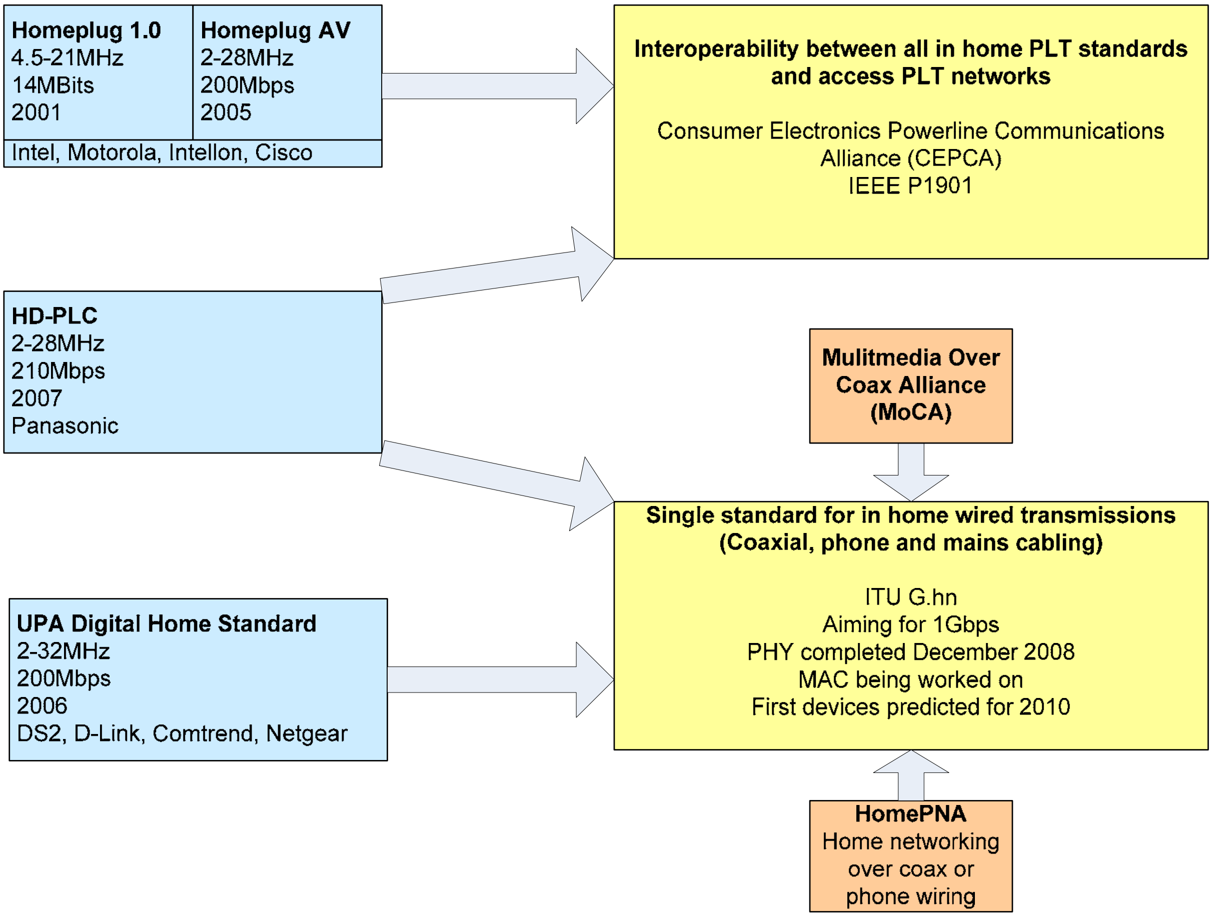


**Figure 35 – Future direction of in-home PLT standards**

### H.1.2 The future of the Homeplug standards

The current roadmap for the UPA standard is very much to adopt ITU G.hn and so it is likely that any future UPA standards will look similar to ITU G.hn. The HPA support interoperability amongst multiple standards via IEEE P1901.

Current Homeplug standards efforts beyond those already deployed include:

***Homeplug Command and control***. This was released in October 2007 and is a low cost, low data rate (7.5kbps) variant of Homeplug that uses the CENELEC frequencies. This targets applications like control of heating, lighting, air conditioning and remote monitoring around the home. It also covers advanced metering applications and is linked to Smart Grid initiatives.

***Homeplug BPL.*** This is for last mile broadband access to the home and so not in the remit of this study.

***Homeplug GP or Green PHY***. This takes Homeplug Command and Control further to cover more Smart Grid applications and uses higher data rates of 1-3.8Mbps. HPA is working with utility companies to understand the information they need from homes and how this fits with monitoring in the rest of their infrastructure. Homeplug GP will be interoperable with Homeplug AV and operates in a similar frequency range. This takes PLT networking outside the home which is something to track as it extends the range of interference.

***Homeplug AV2***. This will go higher in frequency to give data rates to fit a 600Mbps use case. Most HD steams require 20Mbps so the current Homeplug AV real data rate of around 30Mbps starts to get tight for use cases with multiple HD streams around the home. Homeplug AV2 will be compatible with IEEE P1901 and has the same MAC as Homeplug AV. The PHY is changing to use a higher frequency range and the HPA is examining the characteristics of transmitting at these higher frequencies at the moment. Transmit power is reduced by 30dB above 30MHz due to FCC part 15 limits.

## H.2 Interference mitigation techniques in the pipeline

From discussions with stakeholders the two main features on PLT device manufacturers' roadmaps are:

- Dynamic power control estimated to be available Q2 2010. This will adjust the power between two PLT devices to the minimum level to get the required data rate and will provide an overall reduction from the current situation where maximum transmit powers are used constantly.
- Smart notching estimated to be available Q3 2010. This will detect the presence of victim systems that PLT devices may cause interference to and applies a notch as appropriate. For example, an ETSI working group has been studying detection of SW radio signals based on pick of the SW broadcast in the mains wiring. There is some concern over the feasibility of detecting victim signals using mains wiring due to sensitivity limits and the ability to detect non continuous signals outside of broadcast signals. This route also has cost barriers for vendors as the main IP is owned by Sony. Other approaches include using a database of victim receiver systems and applying notches based on knowledge of the PLT device's location.

Transmissions during idle time are also a concern and ITU G.hn are currently looking at power saving solutions which will reduce transmissions and interference particularly in idle mode. In particular, the ITU G.hn standard includes a synchronous MAC and scheduled hibernation for several cycles to reduce interference.

The synchronous MAC allocates timeslots to each user via a frame which each PLT device listens for. Devices only transmit in their timeslot if they have data to transmit which is an improvement on UPA where a token is constantly passed between devices even if there is no data to transmit. Also if a device has no data to transmit it can inform the network master that it is going into hibernation mode. Whilst in this mode no data will be sent to this device. Data destined for the hibernating node will be buffered until the device wakes up.

## H.3 Future international regulation of PLT devices

There have been multiple draft changes to CISPR 22 proposed to define limits specific to PLT devices but none of these have as yet been agreed upon.

The general theme of suggested changes are to:

- Mandate notching of IARU bands
- Specify maximum PSD around -55dBm/Hz below 30MHz and -85dBm/Hz above 30MHz.
- Mandate interference mitigation features in PLT devices such as automatic power control and smart notching.
- Mandate lower transmissions by PLT devices in idle time

While most PLT devices currently notch IARU bands by default, we are not aware of any devices on the market which apply dynamic power control or smart notching.

# Appendix I PA observations of PLT devices

## I.1 Lab test configuration

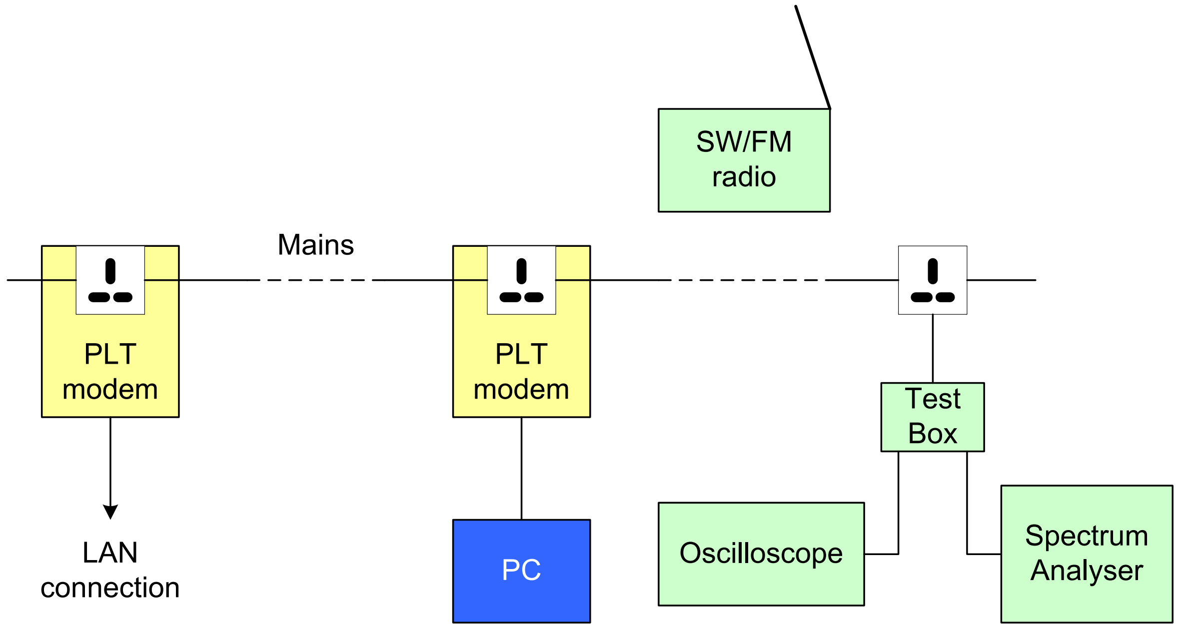


**Figure 36 - Lab test setup**

Initial test were carried out in the PA electronics laboratory. The test set up comprised the following main items:

- A pair of PLT modems
- A PC and LAN connection to provide traffic over the PLT modems
- A spectrum analyser and test box for sampling the high frequencies from the mains, with an oscilloscope for observation in the time domain
- A portable shortwave radio receiver
- A portable FM radio receiver (VHF tests only)

The spectrum analyser and oscilloscope monitored the conducted emissions carried on the mains wiring. The test box attenuated the 50Hz mains to a level that did not affect the sensitivity of the spectrum analyser. The radio monitored (qualitatively) the radiated emissions.

## I.2 Spectral mask of Homeplug V UPA

The spectra of a pair of Belkin Homeplug AV PLT modems and a pair of BT Vision Comtrend 902 PLT modems were observed. The results are shown in Figure 37 and Figure 38 respectively.

The red traces are the spectra observed from the mains Live connection with the modems active. The blue and green traces in Figure 38 are the background mains noise with the modems off and the spectrum analyser noise floor respectively.

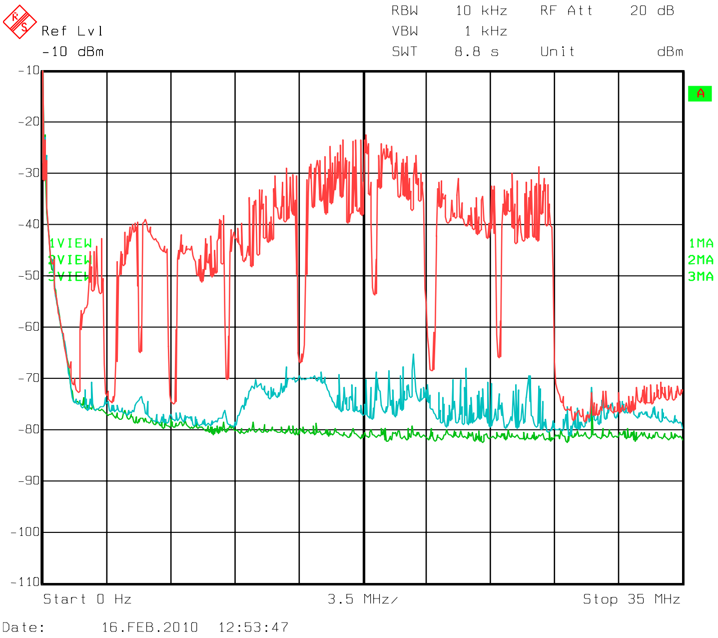


**Figure 37 -Frequency response of Belkin Homeplug AV modem**

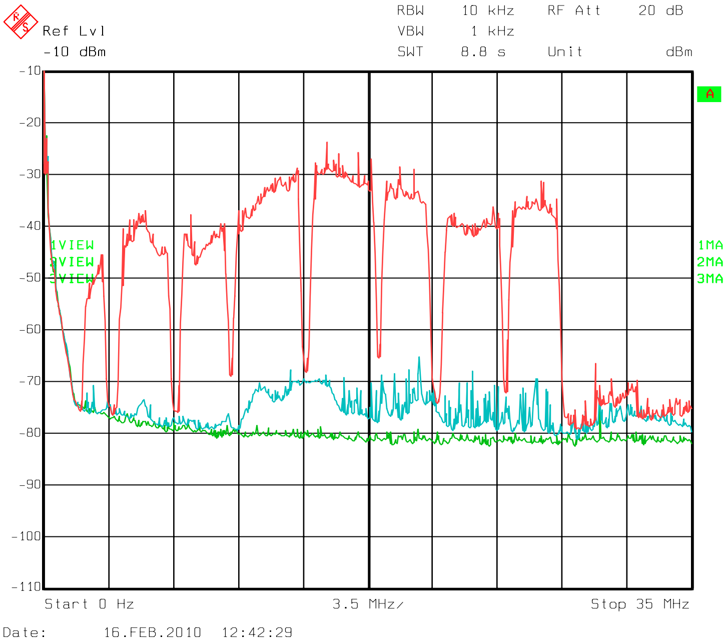


**Figure 38 – Frequency response of the Comtrend 902 modem**

The variability with frequency can be attributed to two factors:

- The mains wiring is designed to distribute power at 50Hz and is not optimum for signal transmission at MHz frequencies. There will be various resonances due to stubs and impedance discontinuities as a result
- The filtering effect of the test box that is used to remove the 230V 50Hz component will also attenuate the low frequency end of the PLT band

Both devices have default notches at the IARU bands. The Belkin device has an extra notch at 5.3MHz which the Comtrend device is missing. The extra band is also used by amateur radio groups and but is not an official IARU band. We understand that some of the complaints about interference from Comtrend devices that Ofcom has received are in relation to this band. In these cases complaints have been resolved by adding the extra notch which is a straightforward procedure.

The notch at 21MHz was examined more closely on both modems as shown in Figure 39 and Figure 40.

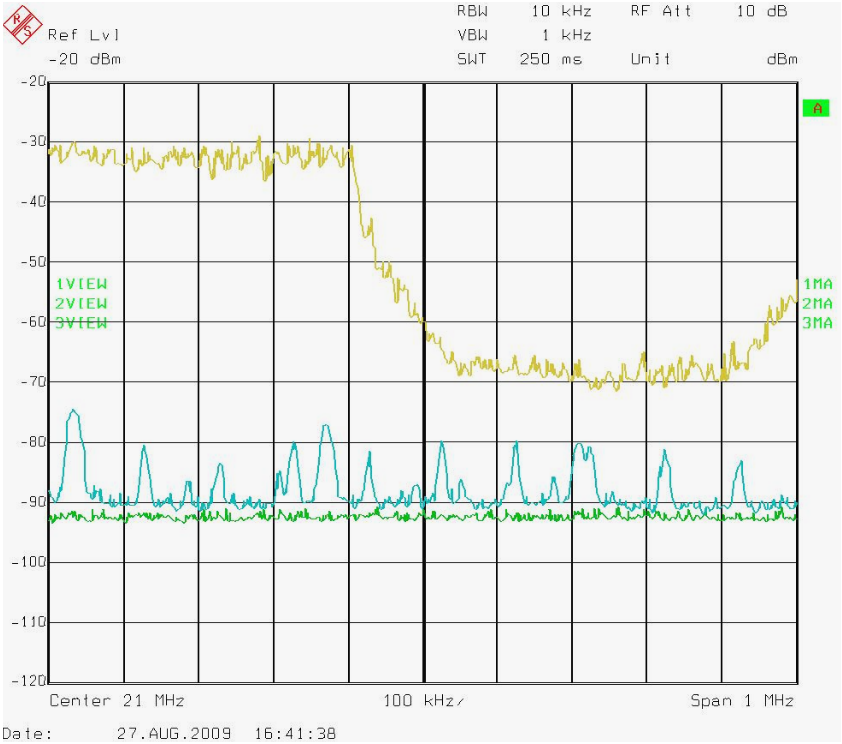


Figure 39. 21MHz notch on Belkin Homeplug AV modem

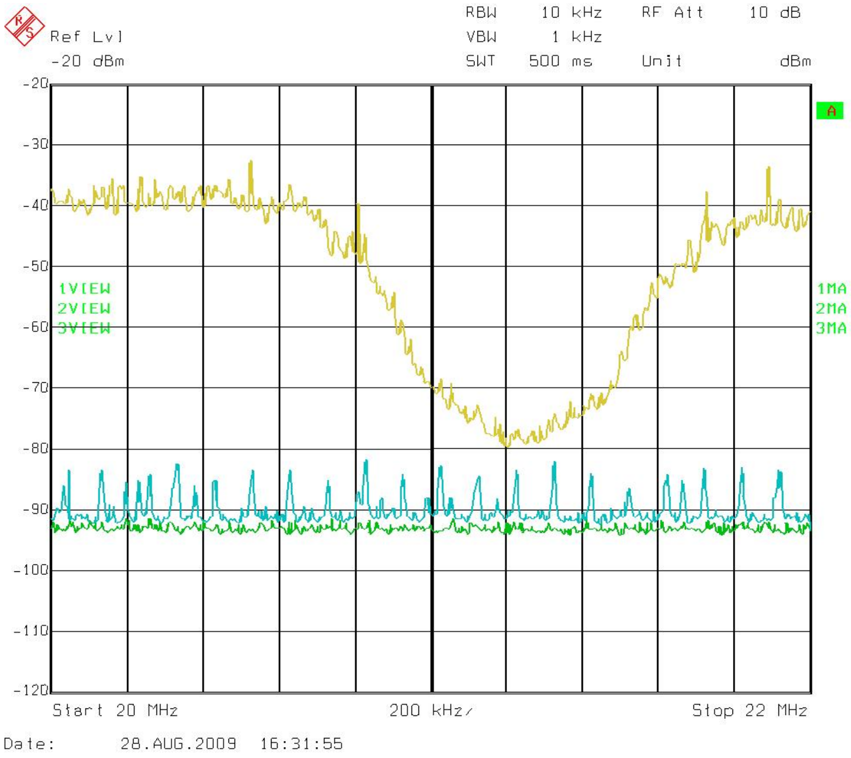


**Figure 40. 21MHz notch on Comtrend 902 modem**

The Homeplug modem had a noticeably sharper rolloff and broader bandwidth of the notch than the UPA (Comtrend) modem.

Both modems achieved a similar notch depth of 35-40dB. The limiting factor was not identified. Intermodulation in the mains wiring can cause the PLT spectrum to spread at a reduced level into the notches and to frequencies outside the intended frequency band. These tests were carried out in a building that had been professionally rewired a few years earlier so the wiring was assumed to be in good condition.

We also checked for differences in the spectra of the UPA and Homeplug devices when they were transmitting data compared to idle mode.  No difference in the measured power spectra were observed between the two modes indicating that the transmit power level remains the same for PLT devices whether they are in idle mode or transmitting data.

## I.3 Spectrum of PLT devices operating at HF and VHF

For comparison we also captured the spectrum of the Belkin 1Gbps powerline adapter which has recently been introduced to the UK market.  This uses a chipset from Gigle which applies Homeplug AV at HF and a Gigle proprietary technology at VHF.  As can be seen from the traces the transmit power level is reduced by approximately 30dB above 30MHz.

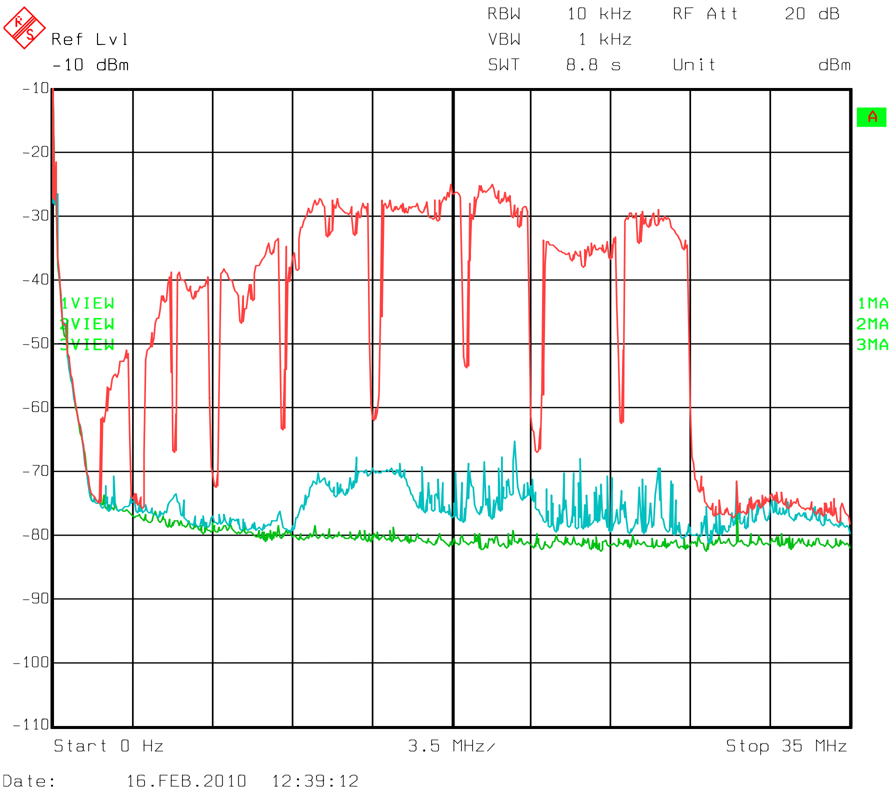


Figure 41 - HF spectrum from Belkin 1Gbps PLT adapters

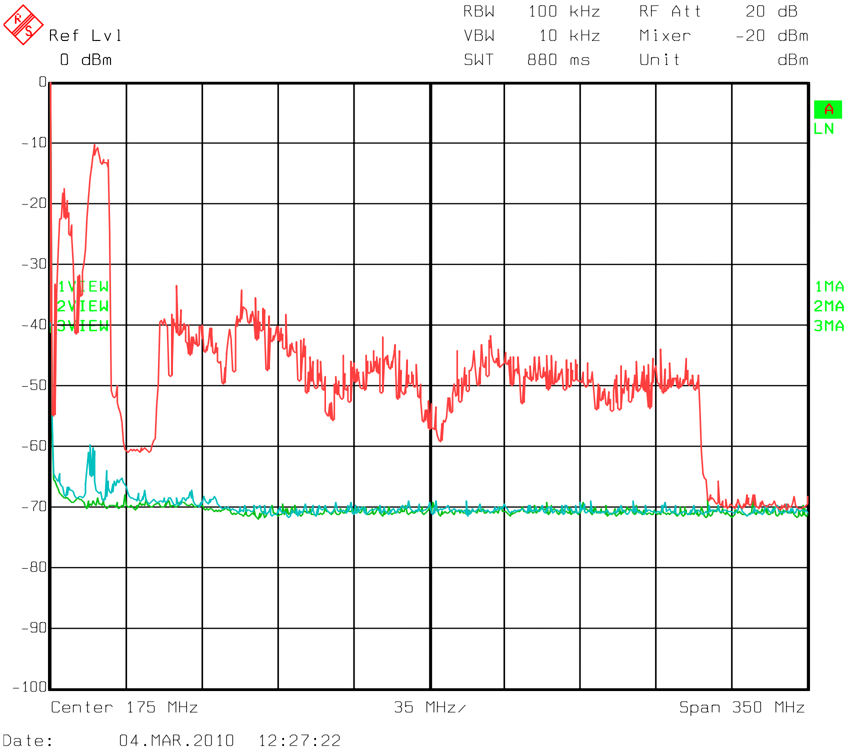


Figure 42 - Spectrum capture including VHF for Belkin 1Gbps PLT adapters

## I.4 Interference from Homeplug V UPA

To observe interference from PLT devices, a shortwave radio was placed on the laboratory bench where a UPA device was plugged in but not switched on. The radio was tuned to a channel with no audible radio signal before the UPA modem was switched on.

The UPA device was switched on and left in idle mode. A continuous tone of around 1kHz was audible on the SW radio. In addition a regular “click” could be heard at a rate of around 2 per second.

Observations of the UPA device in idle mode via an oscilloscope showed a regular burst of energy at a period of 972µs corresponding to a frequency of 1029Hz. These bursts were of duration 297µs giving a duty cycle of 31%. There were periodic longer bursts also observed.

A Homeplug PLT device was tested in a similar way and a “clicking” was also heard on the SW radio although not with the same underlying 1kHz tone as the UPA case. Observations via the oscilloscope showed that a beacon signal was transmitted in idle mode approximately every 40ms for a duration of 500µs. This duty cycle of 1.25% is much lower than UPA and may account for some of the difference in audible interference between the two PLT device types.

Our observations match the 40ms beacon rate used by Homeplug AV where the start of a beacon period is synchronised to the AC mains power signal and has a duration of two AC cycles. In a Homeplug AV network one device will always act as the central coordinator and produce a beacon signal at the start of each beacon period to announce the schedule for that beacon period to the other PLT devices in the network. This short beacon signal occurs regardless of whether data is being transmitted or not.

The difference in duty cycle between Homeplug and UPA can be explained by the difference in MAC schemes used. As mentioned, Homeplug uses a short regular beacon signal to announce scheduling. UPA instead operates on a token passing arrangement and so the token is continuously passed from one PLT device to the next even when there is no data to be sent.

## I.5 VHF Interference

To observe interference at VHF we placed a FM radio next to a pair of transmitting Belkin 1Gbps PLT devices. A faint audible "clicking" was heard on the FM radio although it was at a much reduced level compared to the SW radio test at HF. It is also worth noting that when the test was repeated with a second FM radio the interference wasn't audible which we assume is due to a difference in quality across the FM radios used.

Using a spectrum analyser, the PLT interference pulses were observed to be approximately 10-20dB *above* the level of the wanted signal, yet still only caused minor interference. Our conclusion is that portable FM receivers are much less sensitive to this type of interference than theory would suggest – the nominal value of interference at -32dB for a high quality FM receiver to degrade audio signal:noise is not representative of most FM radios is the market.

In addition a portable aeronautical receiver was used close to the Belkin 1Gbps devices when they were transmitting. A faint clicking was audible in some locations but not others.

## I.6 Effect of PLT sub-carrier offset from victim receiver centre frequency

As discussed in section 9.1.3, the interference effect of an OFDM signal from a PLT device cannot be assumed to be the same as AWGN in a narrowband victim receiver. Nasri and Lampe [23] have examined a similar effect between MB-OFDM as used in UWB and narrowband receivers. Based on their conclusions the interference effect will depend on:

- Ratio of the sub-carrier spacing to the victim receiver bandwidth.
- Offset of the dominant OFDM sub-carriers from the centre frequency of the victim receiver.

In our lab tests we were unable to change the bandwidth of the PLT devices or the SW radio to verify the first conclusion. However, we did observe the cycle between least audible interference and most audible interference as the SW radio was tuned across half a the sub-carrier spacing of the PLT device as predicted by Nasri and Lampe.

| Frequency on the SW radio (Tuning resolution of 5kHz) | Relative audible interference level | Homeplug sub-carrier number corresponding to tuned frequency |
|---|---|---|
| 15.47 MHz | Low | 633.7 |
| 15.48 MHz | High | 634.1 |
| 15.495 MHz | Low | 634.7 |
| | | |
| 6.555 MHz | Low | 268.5 |
| 6.57 MHz | High | 269.1 |
| 6.58 MHz | Low | 269.5 |

**Table 16 - Observations of interference with offset of sub-carriers and victim receiver centre frequency**

## I.7 Observations of PLT devices in home scenarios

A pair of Belkin Homeplug AV PLT devices were tested at three residential locations; two with underground cabling to the mains and one with overhead mains cables.

In the case with underground cabling:

- Interference 2m from the houses was not a problem when listening to a SW radio station
- On a clear channel, i.e. just listening for interference, PLT interference was observed up to 20m from the houses
- At one of the houses a low level of PLT interference was observed near the consumer unit of a neighbouring house on a clear channel indicating that the PLT signal was being passed from house to house

In the case with overhead cables:

- PLT interference was observed up to 75m from the house
- In particular interference was observed when walking underneath the overhead cable indicating that it was spreading interference from the PLT to the rest of the street.

# Appendix J Propagation model for In-Home PLT devices

## J.1 Near field

The near/far field boundary is at a distance of:

$$d = \frac{\lambda}{2\pi}$$

Thus d varies across the PLT band from approximately 24m at 2MHz to 1.6m at 30MHz. A variation with distance of approximately 20dB/decade down to 3m has been observed in a number of measurements as described in section 9.1.2, so these measurements vary from near to far field across the band. Thus the near field model is in practice an extension of the far field model used at shorter ranges than it normally quoted validity

Continuing this extrapolation to shorter distances than 3m is still valid at higher frequencies but may break down at the lower frequencies involved. In practice with these very short ranges it is likely that the mains wiring can no longer be considered a homogenous item but that individual cable runs closest to the receiver will start to dominate.

There is a human factor involved here also. If a radio is placed in a location where it suffers interference, many users will attempt to move the radio a small distance to see if they can get better reception. If there is a rapid change in interference level, it is unlikely that the radio would be left in an area of high interference i.e. close to the relevant wiring.

We have therefore included the above extrapolation in the model, with the caveat that it may not apply at very short ranges.

## J.2 Far field

Friis' equation describes mathematically the propagation of an electromagnetic wave in free space in terms of the power loss from the transmitter to the receiver. Excluding the antenna gains and expressing the remaining factors in logarithmic terms gives:

Path Loss = 32.5 + 20 log10(f) + 20 log10 (d) dB

Where f is the frequency in MHz and d is the distance between antennas in km. This is already included in Seamcat as a standalone propagation model, and has been included in the custom model for the far field mode.

## J.3 Ground wave

The ground wave propagation mode is modelled by the GRWAVE program [24]. It returns field strength values and transmission losses. The input values used for this study are:

- Atmospheric Constants: Refractivity =315; Scale height 7.35km (fixed values)
- Transmitter power = 1kW EIRP (fixed value)
- Ground Constants: Rel. permittivity = 33, Conductivity = 0.014mS/m. According to ITU-R R.832 [25] this is the upper end of the range of ground conductivities in the UK, which will give the strongest propagation conditions. It occurs over a large area of the Midlands extending to Lancashire, Somerset and Lincolnshire.
- Vertically polarised E-field
- Distances and frequency to suit individual simulation
- Transmitter and receiver height = 5m each. This represents the upper levels of mains wiring in a typical two-storey house and an external radio amateur's antenna at the level of the house eaves.

The effect of ground wave propagation with distance is illustrated in Figure 11.

The attenuation of 40dB per decade of distance is consistent but the overall level of attenuation varies with the above input factors. The transition between far field and ground wave is described in ERO Report 069 [26] section 4. In order to assess the range at which this transition occurs, GRWAVE was run for a series of frequencies across the range 2-30MHz. This created the Easymptote values for the ground wave mode which could then be used to calculate the range at which it would intersect the free space propagation characteristic. The results are shown in Table 17 and Figure 43.

| **Frequency** | 2 | 3 | 6 | 8 | 10 | 15 | 20 | 25 | 30 | MHz |
|---|---|---|---|---|---|---|---|---|---|---|
| **E asymptote** | 107.9 | 106.3 | 100.8 | 97.7 | 95.1 | 90.9 | 88.3 | 86.7 | 85.6 | dBuV/m |

**Table 17. Field strength asymptote values**

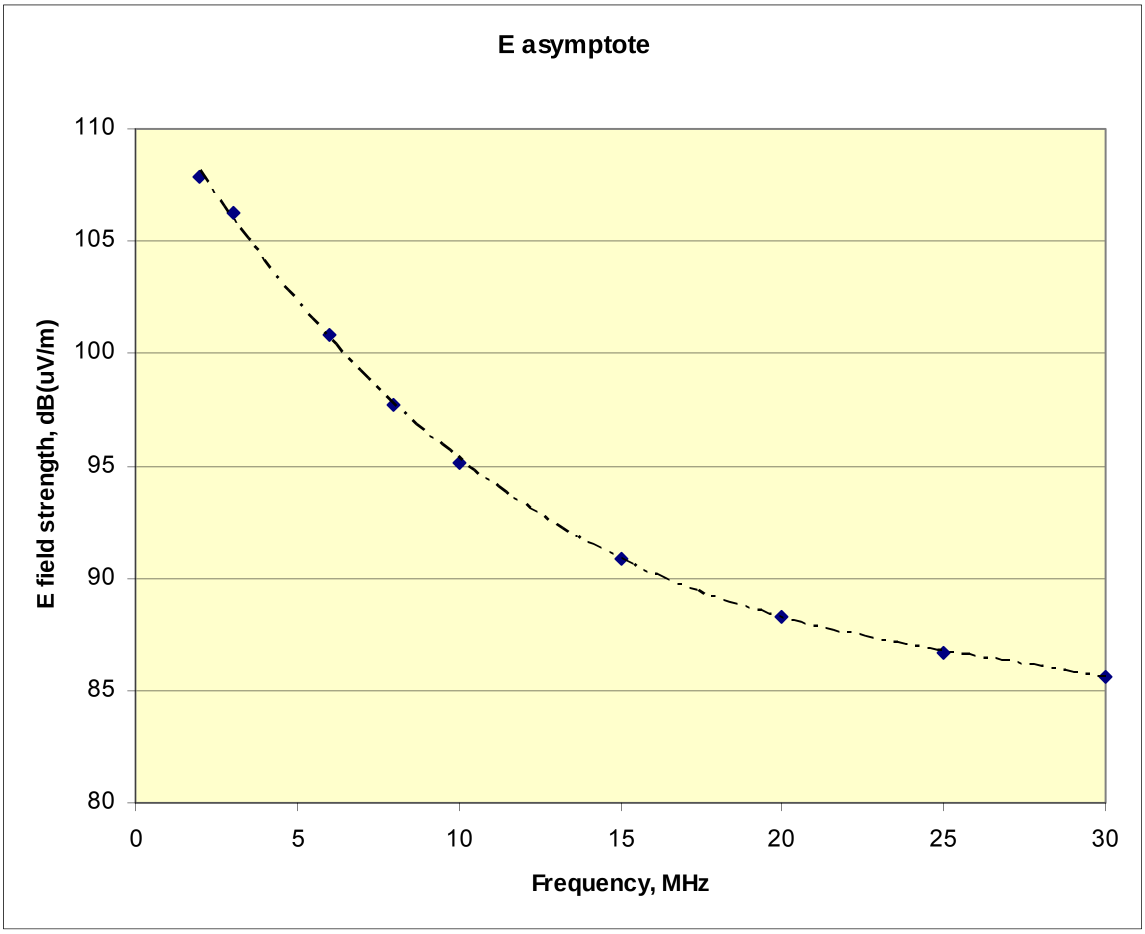


**Figure 43. Field strength asymptote values**

## J.4 Sky wave propagation

Sky wave propagation is far more complex to model than the other propagation modes involved at HF due to the number of variables. A widely recognised software implementation of the relevant ITU recommendation 533 has been developed and released by the NTIA for predicting coverage of the Voice of America radio network. There are several variants, the ICEPAC Inverse model has been used here to illustrate the effects.

Figure 44 and Figure 45 show the difference between daytime and night-time propagation at 7.1MHz to a receiver in Lerwick, Shetland Isles. The location was chosen to best illustrate the propagation from the South. The minimum path loss is similar in both cases, 123dB and 125dB. However the geographical distribution is very different. During the day the minimum path loss is to be found in a belt across the UK, Ireland and Scandinavia. At night the reduction in solar radiation causes the ionosphere to become less active and the height of reflection of the sky wave rises, causing the lowest path loss to appear at a greater range. In this instance it moves down to Spain, Portugal and Southern Italy.

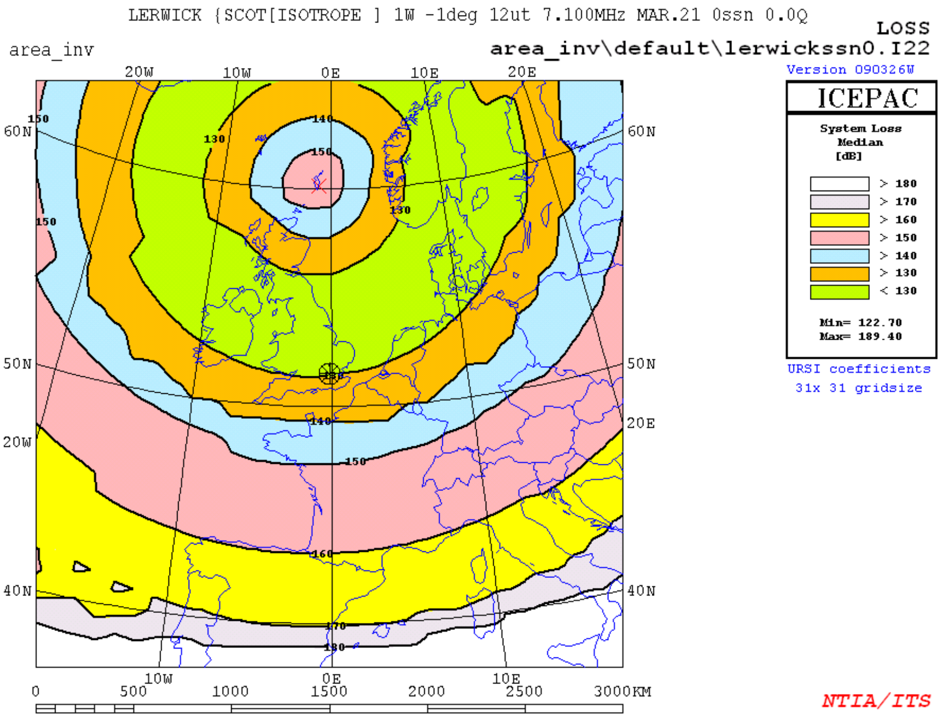


Figure 44 - Path Loss at Midday

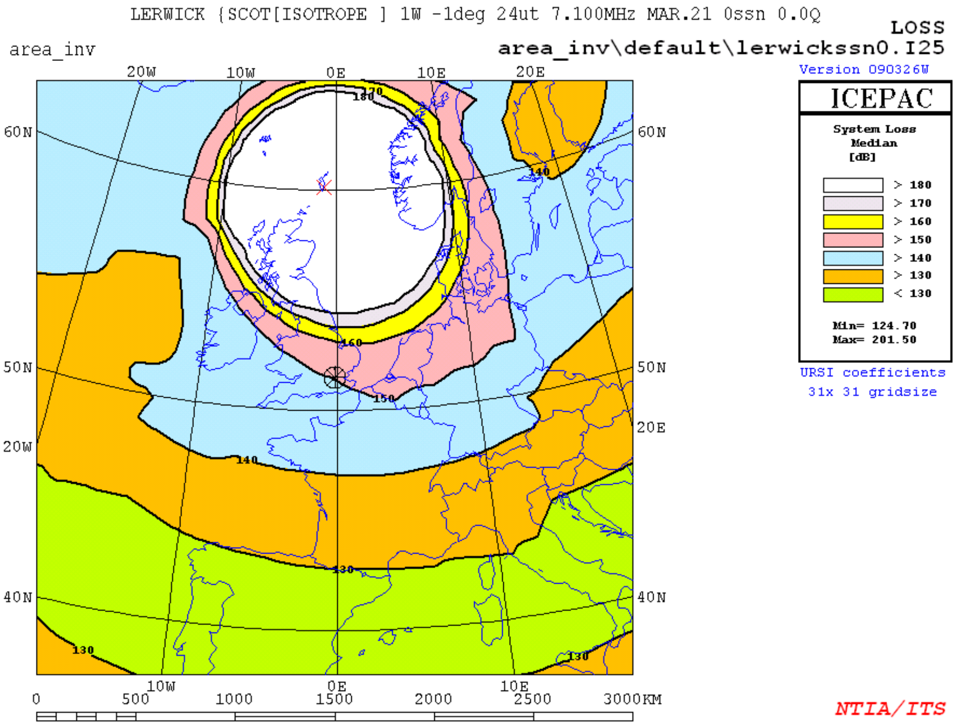


Figure 45. Path Loss at Midnight

The implication of this is that the received power via sky wave depends not only on the loss via the sky wave but the PLT density over a continent-sized area. Only a small part of that area will contribute significantly to the received power at any given time, frequency and receiver location.

# Appendix K Overview of Seamcat model

## K.1 Introduction to Seamcat

Seamcat was developed by the European Radiocommunications Office (ERO) as a generic radio interference modelling tool. It takes as inputs some basic parameters about the transmitter and receiver such as power and sensitivity, and information about the spatial distribution of both. Many of these parameters can be given statistical distributions. Various propagation models can be chosen or custom models can be written. The threshold of what constitutes interference can be defined in several ways such as signal to noise ratio or increase in noise floor.

Having set the parameters the program executes a Monte-Carlo analysis on the parameters defined as distributions rather than fixed values. The power from the interfering source(s) and if relevant from the wanted source are calculated for each case and the percentage of cases where interference occurs is calculated. A post-processing function allows the input power to be varied and the impact on probability of interference is shown as a cumulative distribution function.

## K.2 Seamcat model structure

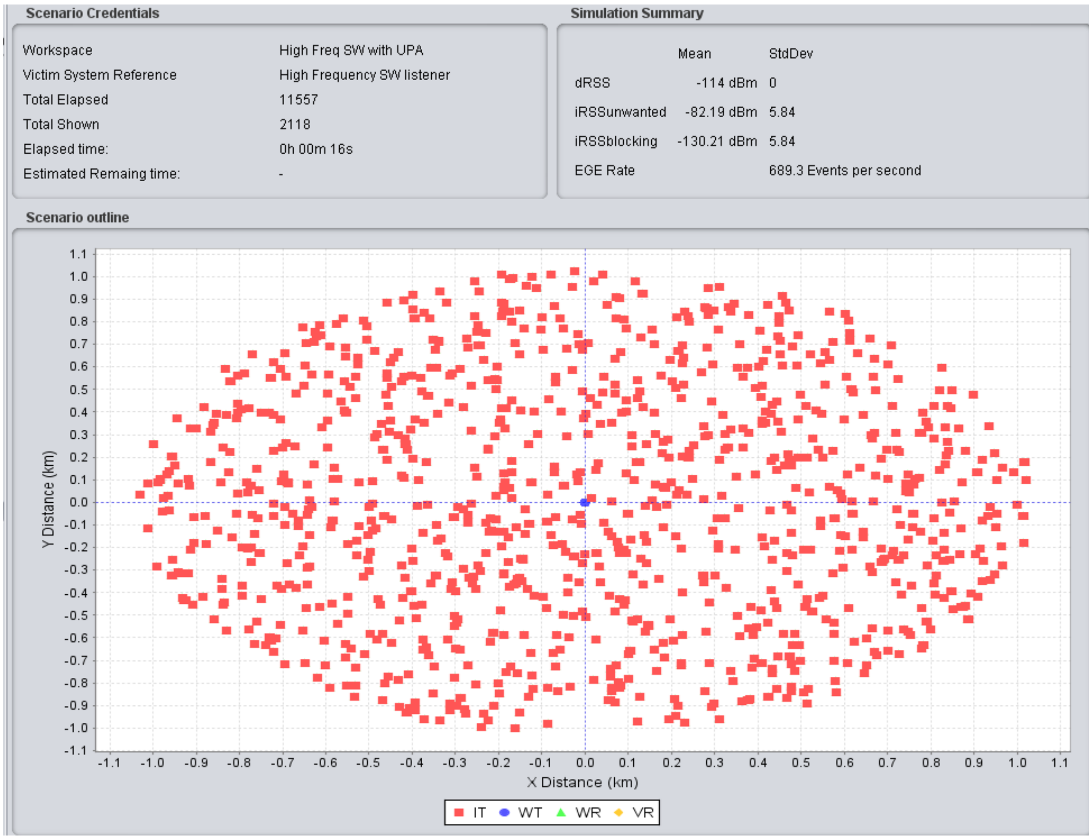
For this study we have built up a Seamcat workspace to represent a low, medium and high frequency band in range of 2-30MHz for each of the three HF victim receiver types:

- Shortwave radio
- Amateur radio
- Aeronautical ground station representing professional users

Seamcat workspaces were also developed for the following victim receivers at VHF:

- FM radio listener
- Narrowband FM user
- Aeronautical radionavigation

For each simulation a victim receiver is placed at the centre of the simulation area and a number of PLT devices are then scattered around this victim receiver as per the density of PLT devices that has been forecast in our market analysis described in section 5.2. A link budget calculation is performed between each PLT device and the victim receiver and these are then summed to give the received interference signal, termed the iRSSunwanted, at the victim receiver. A typical screenshot of the setup we have used is shown in Figure 46 with the blue dot at the centre representing the victim receiver and the red dots representing PLT devices.



**Scenario Credentials**

| | |
|---|---|
| Workspace | High Freq SW with UPA |
| Victim System Reference | High Frequency SW listener |
| Total Elapsed | 11557 |
| Total Shown | 2118 |
| Elapsed time: | 0h 00m 16s |
| Estimated Remaing time: | - |

**Simulation Summary**

| | Mean | StdDev |
|---|---|---|
| dRSS | -114 dBm | 0 |
| iRSSunwanted | -82.19 dBm | 5.84 |
| iRSSblocking | -130.21 dBm | 5.84 |
| EGE Rate | | 689.3 Events per second |

**Scenario outline**

**Figure 46– Typical screenshot from Seamcat**

We have also used Seamcat to perform interference probability assessments based on the received interference signal at the victim receiver and the rise in background noise floor that this would create at the receiver.

## K.3 The effect of increasing the number of active PLT devices in the model

In the simulation model, we can vary the distance between interfering transmitters and the victim receiver using two parameters:

- Number of active transmitters per simulation run
- Density of interfering transmitters given in devices per km²

The density of interfering transmitters or PLT devices is taken from our market analysis, detailed in section 5.2, for each of the environment types that the victim receivers will be operating in. The area that the simulation is run over is therefore set by the total number of active receivers. As illustrated in Figure 47 and Figure 48, Seamcat is forced to distribute the interfering transmitters over a larger area as the number of interfering transmitters increases but the density of PLT devices stays the same.

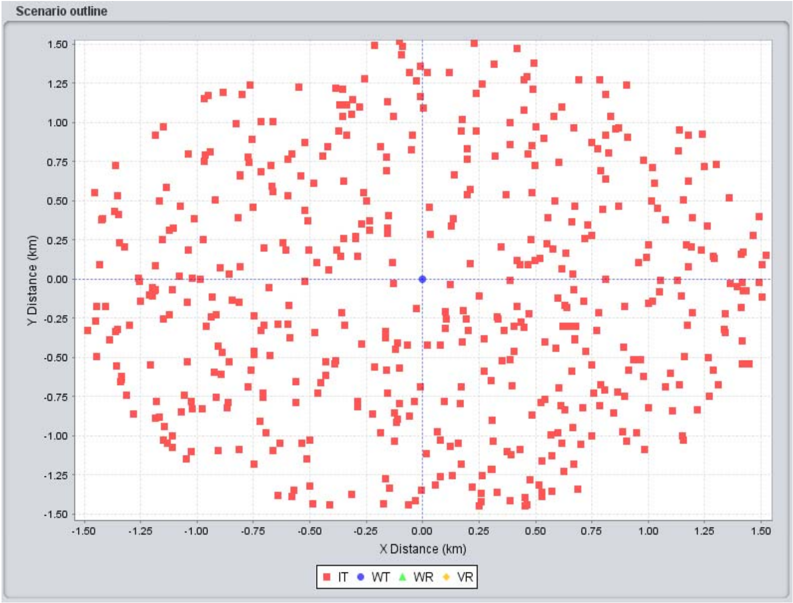


**Figure 47 - Interference with 100m protection radius, and 500 active devices per simulation run.**

In Figure 47 there are 500 PLT devices, indicated by the red squares, per simulation run. The radius of the area covered is approximately 1.5km with a protection radius (meaning no PLT devices within that radius) of 100m around the receiver represented by the blue dot.

In Figure 48 the parameters are the same except for the number of PLT devices being 100 per run. With the same density of PLT devices, the area covered has now been reduced to a radius of 750m.

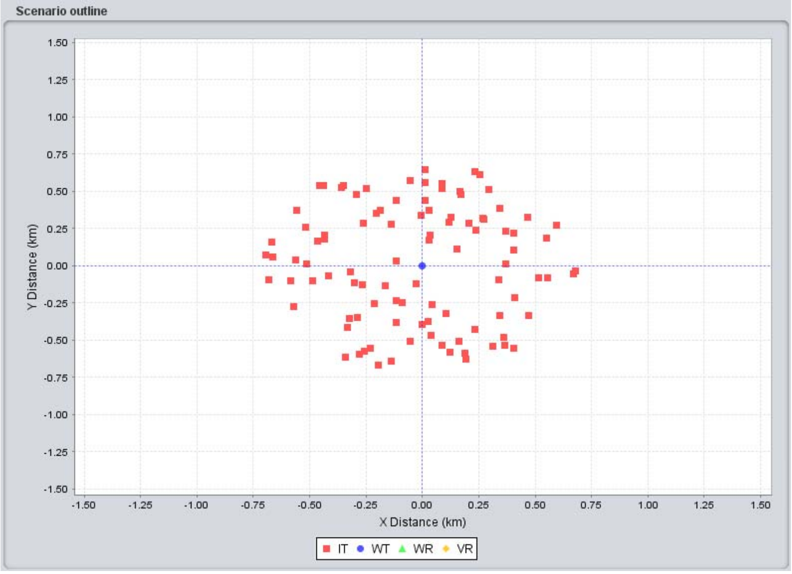


**Figure 48- Interference with 100m protection radius and 100 active devices per simulation run**

By monitoring the total received interference for different numbers of active PLTs we can see if it is dominated by a few devices at close range or if it continues to increase as more interference sources are added and the simulation is run over a wider area i.e. if the cumulative effect is significant.

# Appendix L Assumptions on technical characteristics of PLT devices

## L.1 Typical quasi peak transmit power level for UPA devices

The various industry standards for in home PLT devices provide recommended maximum quasi peak transmit power levels for PLT chipset vendors to implement. For UPA this level is -50dBm/Hz and we have assumed this level throughout this study. However, it should be noted that PLT manufacturers may in practice inject power into household wiring at a lower level than this.

For example, measurements of UPA PLT devices by CRC [13] showed peak conducted emissions in a 9kHz measurement bandwidth of approximately 95dBµV/m (Figure 3-5 of 13]). Using conversion factors provided by CRC in the same report this equates to a quasi peak PSD of -57.3 dBm/Hz.

- Our sensitivity analysis therefore includes the possibility that PLT devices may transmit at a lower level than the maximum specified in the industry standards.

## L.2 Average antenna gain for household wiring

We have based our antenna gain for PLT devices on measurements reported. A NATO study into PLT summarised a number of PLT emission level measurements and recommended an antenna gain of -30dBi for in home PLT devices with a variation of ±5dB to ±10dB due to variations in the wiring [5].

As a cross check we have applied this assumed antenna gain to recent field measurements of PLT devices made in Canada as shown in Table 18. As can be seen the field strength arrived at by applying a -30dBi antenna gain as used in our simulation model predicts a very similar field strength to those measured proving this assumption matches well with observations of real PLT devices.

| **Expected V Measured PLT emissions in a 9kHz measurement bandwidth** | **Value** |
|---|---|
| Quasi peak PLT transmit power (-57.3dBm/Hz in 9kHz as per the UPA devices used in the Canadian field trials) | -17.8 dBm |
| Assumed household wiring antenna gain | -30dBi |
| Convert quasi peak to peak (to match Canadian measurement technique) | -5.8 |
| *Expected peak EIRP at PLT house* | *-42dBm* |

| Expected V Measured PLT emissions in a 9kHz measurement bandwidth | Value |
|---|---|
| **Expected peak field strength at 3m (EIRP converted using ITU-R P368.7 for isotropic radiator)** | **53.2 dBµV/m** |
| **Expected peak field strength at 10m (EIRP converted using ITU-R P368.7 for isotropic radiator)** | **42.8 dBµV/m** |
| | |
| **Measured peak field strength at 3m [13]** | **53 dBµV/m** |
| **Measured peak field strength at 10m [13]** | **41 dBµV/m** |

**Table 18 - Comparison of expected PLT radiated emissions with those measured in Canadian field trials**

## L.3 The effect of wideband OFDM on a narrowband receiver

There is little literature around the interference impact of radiated emissions from PLT devices on narrowband receivers. However, Nasri and Lampe [23] have examined a similar effect between MB-OFDM, as used in UWB, and narrowband receivers. As well as being an OFDM based signal the “bursty” time domain nature of MB-OFDM creating by hopping the signal across multiple bands can be likened to the short bursts in idle mode from PLT devices. Nasri and Lampe have concluded that the interference effect will depend on:

- Ratio of the sub-carrier spacing to the victim receiver bandwidth.
- Offset of the dominant OFDM sub-carriers from the centre frequency of the victim receiver.

Their results show that in that in the worst case scenario the victim receiver performance can be likened to operating with interference from an impulsive noise source. However, in some cases the performance with the MB-OFDM interferer is better than performance with an AWGN interference source at the same level.

The bandwidth of the victim receivers being modelled are 2.2kHz, 3kHz and 4kHz and so compared to a UPA sub-carrier spacing of 19.5kHz will receive 0.11, 0.15 and 0.2 sub-carriers. Based on Nasri and Lampe’s results, for the variation in performance for different ratios of sub-carrier spacing to victim receiver bandwidth, these scenarios should perform close to if not slightly better than AWGN interference at the same level.

Nasri and Lampe have also modelled the effect of the offset between the dominant OFDM sub-carriers from the centre frequency of the narrow band victim receiver. However, the performance curves produced indicate that performance varies equally either side of the AWGN performance as the offset varies from 0 to +/- 0.5 of a sub-carrier. This cycle of a slight increase and decrease in performance in steps of 0.5 of a sub-carrier spacing is an effect we have also seen in our lab tests (see appendix I.6). As the centre frequencies of the victim receivers are spread throughout the HF band, the victim receiver centre frequency will be a random offset from the sub-carriers in the OFDM signal from the PLT device. Therefore in some cases the performance will be worse, in others it will be better and on average will be approximately AWGN.

From Nasri and Lampe's results in a worst case scenario the performance of a victim receiver suffering interference from a MB-OFDM signal will converge on the performance of the same victim receiver in the presence of an impulsive noise source. Their results show an approximate difference in BER performance that would translate to a reduction in SNR of 2dB between the AWGN and impulsive noise case if performance in AWGN is taken as a reference level. Throughout this study we have assumed this worst case scenario that the effect of PLT radiated emissions is similar to an impulsive noise source of interference.

Our baseline interference criteria assume that interference will occur if the noise floor is increased by 3dB. The PLT device can therefore produce interference equal to an AWGN signal at the same level as the noise floor. Given the effect of OFDM on a narrowband receiver, the PLT device will produce this equivalent AWGN interference level when it is 2dB below the background noise floor.

This gives our final interference criterion: $\frac{I}{N} = -2dB$.

## L.4 Weighted duty cycle assumed in our simulation model

Our Seamcat model requires a duty cycle for the simulated PLT devices to model the effect that not all deployed PLT will be transmitting at the same instant. Our baseline model assumes usage of UPA PLT devices which, from our observations in the lab (see Appendix I ), transmit 30% of the time when in idle mode and close to 100% of the time when transmitting data.

To calculate a weighted average duty cycle for PLT devices we need to understand the average split between the number of devices in idle mode and transmitting data at any instant in time. This will depend on the time of day and application of the PLT device.

As the dominant deployment of PLT devices in the UK is for IPTV applications we have based this average split between the number of devices in idle mode and those transmitting data on TV viewing figures as follows:

- Viewing figures for 9pm on 7th October 2009 (from www.broadcastnow.co.uk) show a popular show capturing 2.3 million viewers representing 10% of the total audience at that time. This gives a total TV audience for this time of 23 million viewers.
- The UK population at mid 2008 was 61.4 million (from www.statistics.gov.uk).
- Therefore at 9pm on an evening approximately 40% of the population are watching TV.
- We therefore assume that at peak times 40% of PLT devices will be in transmit mode and 60% will be in idle mode.

This gives a weighted duty cycle of:

(0.3 x 0.6) + (1 x 0.4) = 0.58

# Appendix M Electricity distribution in the UK

This appendix supports the calculation of the probability that victim receivers share a mains circuit with a PLT user within a particular distance.

The area of interest is the low voltage (LV) distribution network[13]. Transformers act as an effective block to the high frequencies used by PLT and so consumers are considered as connected together for PLT purposes if they are on the same transformer and phase.

The term ‘consumers’ here refers to an electricity supply connection, not the number of persons who use that supply. It includes both business and residential users.

| Country | Area | Total number of consumers | Consumer density per sq.km | LV overhead line km | LV underground cable km | Transformers per 1000 consumers |
|---|---|---|---|---|---|---|
| England | North | 5600000 | 157 | 31780 | 87690 | 13.2 |
| | Midlands | 8100000 | 164 | 41275 | 110189 | 20 |
| | South | 6250000 | 170 | 32518 | 91775 | 18.7 |
| | London | 2100000 | 300 | 0 | 26458 | 6.6 |
| Wales | | 2500000 | 99 | 10498 | 33439 | 48.8 |
| Scotland | Hydro | 600000 | 12 | 4833 | 17500 | 80.8 |
| | Power | 1600000 | 79 | 7854 | 21853 | 21.4 |
| N.Ireland | | 700000 | 52 | 3433 | 9526 | 21.4 |
| Totals | | 27450000 | | 132191 | 398430 | |

**Table 19 – UK Electricity distribution statistics from Mott MacDonald, “The Carbon Trust & DTI Renewables Network Impact Study Annex 3: Distribution Network Topography Analysis” [27]**

Based on Table 19, the average length of LV cabling per household is 20m.

This is substantially smaller than the median value derived in Table 20 as a single cable from the transformer will supply multiple consumers.

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[13] LV in mains electricity terms refers to the 230V single phase / 400V three phase network.

| Country | Area | Consumers per transformer | Distance to farthest consumer, m | Median distance to consumer, m | % of line length overhead | % overhead line weighted by number of consumers |
|---|---|---|---|---|---|---|
| England | North | 76 | 392 | 277 | 27% | 0.0543 |
| | Midlands | 50 | 312 | 220 | 27% | 0.0804 |
| | South | 53 | 316 | 224 | 26% | 0.0596 |
| | London | 152 | 401 | 284 | 0% | 0.0000 |
| Wales | | 20 | 257 | 182 | 24% | 0.0218 |
| Scotland | Hydro | 12 | 573 | 405 | 22% | 0.0047 |
| | Power | 47 | 434 | 307 | 26% | 0.0154 |
| N.Ireland | | 47 | 535 | 378 | 26% | 0.0068 |
| | | | | | | |
| | Averages: | 57 | 402 | 285 | 22% | 24% |

**Table 20 – PA analysis of statistics in Table 19**

# Appendix N ILS description and modelling assumptions

## N.1 ILS Localiser

The Instrument Landing System (ILS) is a radio based system for guiding aircraft down to land on a chosen runway. It is used at all major airports and a number of minor ones as it provides the major benefit of being able to guide the aircraft to a safe landing even when the runway is not visible to the pilot due to low cloud or fog.

The principle of operation is that there is a ground based transmitter and an airborne receiver, the latter linked to a cockpit display or autopilot. There are two components to the ILS radio transmission, localiser and glideslope. The localiser provides horizontal guidance as described below and uses a carrier frequency in the range 108.0 to 112.0MHz. The glideslope provides vertical guidance using the same method as the localiser but uses a carrier frequency around 330MHz. The localiser is therefore of interest when studying PLT devices but the glideslope is out of this frequency range.

The localiser signal consists of two narrow beams transmitted from the far end of the runway towards the approaching aircraft, one aimed slightly left of the centreline and the other an equal angle to the right. The beam to the right (as seen from the approaching aircraft) is amplitude modulated at 150Hz, the beam to the left with 90Hz. By comparing the amplitude of the 90Hz and 150Hz components of the modulation the receiver can determine whether the aircraft is on the runway centreline or to the left or right of it, and by how much. This is illustrated in Figure 49.

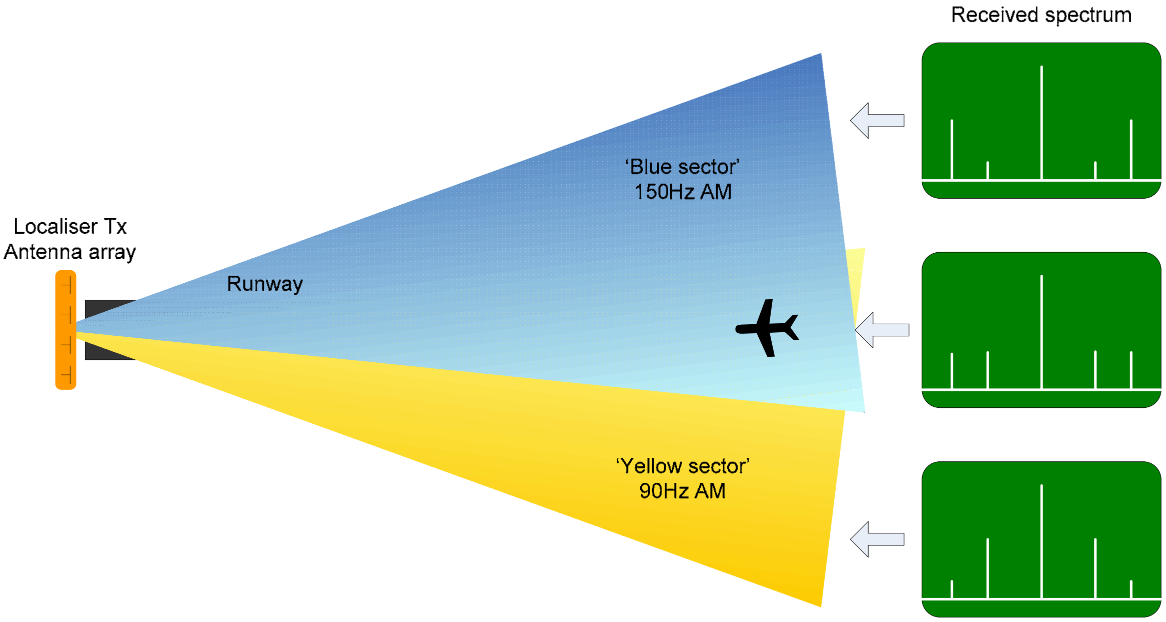

**Figure 49 - The ILS Localiser**

The ILS signal is intended to be received many miles from the runway – the exact coverage varies depending on the angle from the centreline but may be up to 25 nautical miles (46km). In addition the antenna is beyond the far end of the runway, which at Heathrow for example is nearly 4km long, making the Tx-Rx distance up to 50km. By contrast the relatively shallow angle of the glideslope (typically 3°) means that the aircraft will be much closer to the ground than the distance from the ILS transmitter, as illustrated in Figure 50. In many instances the aircraft will pass over urban areas where PLT use is likely whilst following the ILS signal. If this PLT is generating emissions at the ILS frequency, there is potential for interference.

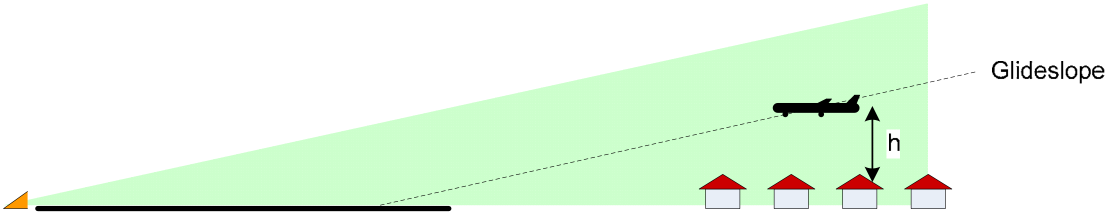

**Figure 50 - Height of ILS receiver above PLT**

## N.2 Effect of aircraft height on interfering signal

It was has been suggested by J.Stott of the BBC [12] that the height of an aircraft has little effect on the level of PLT emissions received. This is due to two effects that occur differently compared with ground based receivers. Firstly there is free space propagation (or close to it) from all the PLT devices to the aircraft, meaning that the PLT signal reduces according to the square of the aircraft height. Secondly the distance to the horizon increases in proportion to the aircraft height, so the area visible increases according to the square of the height. Assuming a constant PLT deployment density this means the number of PLT devices visible to the aircraft increases with the square of its height, which cancels out the propagation loss and leaves a constant received signal level regardless of aircraft height.

Both these effects are approximations to the square law and a detailed analysis shows there are other terms. The height effect was examined by using Seamcat to statistically model the received signal level, and to determine the number of PLT devices needed to represent a wide area deployment in this scenario. The following parameters were used:

| Parameter | Value | Unit |
|---|---|---|
| PLT emission level | -80 | dBm/Hz |
| Mains wiring effective antenna gain | -30 | dBi |
| PLT user density | 126 | per km2 |

| Parameter | Value | Unit |
|---|---|---|
| Total number of users | Variable | |
| Frequency | 110 | MHz |
| Rx bandwidth | 32 | kHz |
| Rx antenna height | Variable | |
| Rx antenna gain | 0 | dBi |

**Table 21 - Parameters for VHF airborne victim receiver simulation to understand effect of height on cumulative interference signal**

Simulations were performed for aircraft heights (i.e. Rx antenna height) of 100, 200, 500 and 1000m. For each of these the total number of PLT users was set at $10^5$, $3x10^5$ and $10^6$, meaning PLT devices were simulated up to 20.9km, 36.2km and 66km respectively from the point directly below the aircraft. For comparison a fourth set of simulations was run with just 100 interferers, giving a deployment radius of 795m. This shows the effect of modelling only a small scale deployment where much of the area visible to the aircraft is not populated with PLT.

The amount of power received by the aircraft from the PLT devices was recorded and is shown in the graph below.

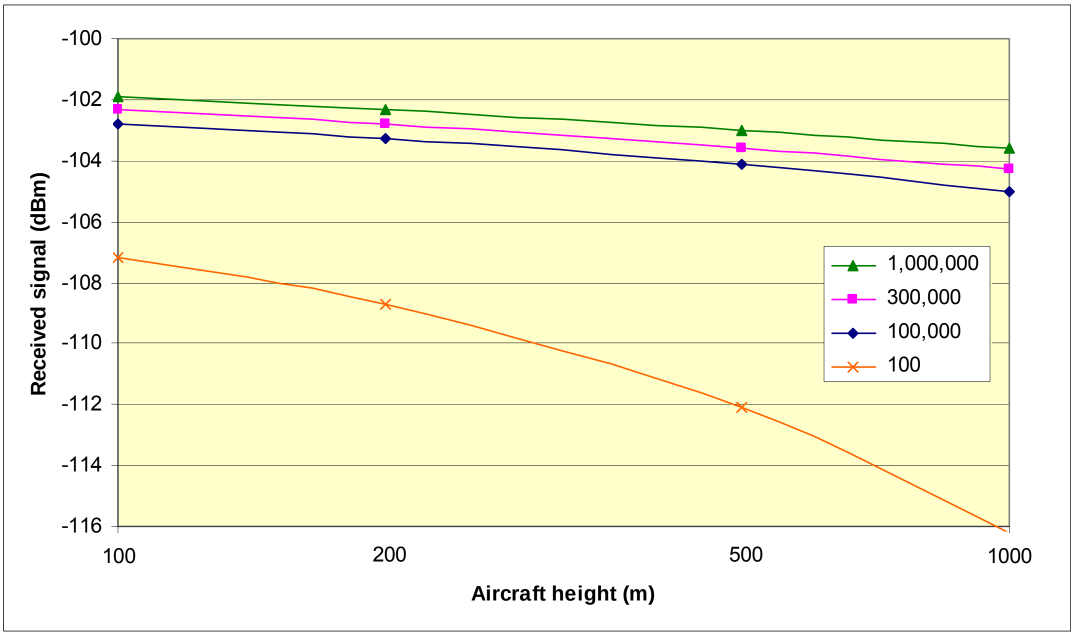

**Figure 51 - Effect of aircraft height on cumulative interference signal observed**

Under simple point-to point free space conditions, a variation of distance by a factor of 10:1 would produce a change in path loss of 20dB; in this case it produces a change of around 2dB. This demonstrates that, whilst the received signal power is not totally independent of the aircraft's height, it is relatively insensitive.

Similarly an increase of 10:1 in the number of transmitters would produce an increase of 10dB in the emitted and received signal powers; in this case it is around 1-1.5dB for large numbers of PLT devices. The simulation of 100 devices not only gives a significant drop in power but increases the sensitivity to aircraft height. The conclusion is that the received power is relatively insensitive to the exact number of PLT devices, provided a sufficiently large number is used.

In conclusion we consider that an aircraft height of 200m with a deployment of 100,000 PLT users is an appropriate reference case for the effect on an aircraft of passing over a wide area deployment of PLT.

# Appendix O FM radio broadcast

## O.1 C/I ratio for FM broadcasting

ITU-R BS.641 gives a requirement for a 50dB audio frequency signal to interference ratio (S/(I+N)) as the threshold for determining the RF protection ratio, assuming a receiver that is capable of at least 56dB audio frequency signal to interference ratio without the interfering signal (S/N).

The relationship between the audio frequency signal to interference ratio (S/(I+N)) and the RF carrier to interference ratio (C/(I+N)) for a wideband FM demodulator is given by:

$$\frac{S}{(I+N)} = 3\beta^2\left(\frac{C}{(I+N)}\right) \qquad [28]$$

where β is the modulation index, which is 5 for FM radio broadcasts with ±75kHz peak deviation and a maximum audio frequency of 15kHz. This gives a 19dB conversion factor between the audio frequency and RF signal to interference ratios for FM radio.

Applying this conversion factor to the ITU-R BS.641 ratios gives:

$$\frac{C}{(I+N)} = 31dB$$

$$\frac{C}{(N)} = 37dB$$

Solving for C/I from these two equations gives a ratio of 32dB.

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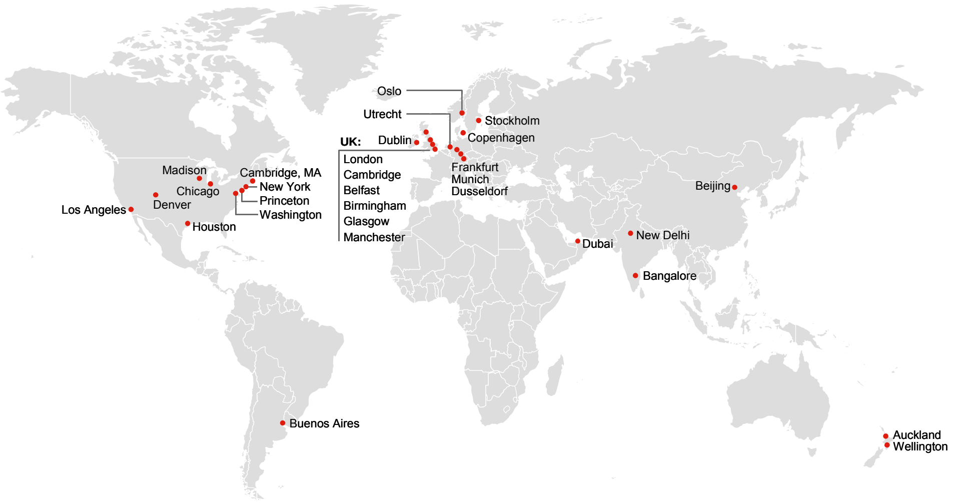

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