Environmental Effects of the widespread deployment of high speed Power Line Communication

Cumulative Effects on Signal/Noise ratio for Radio Systems

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1) Introduction

High speed Power Line Communication (hereinafter "HS-PLC", and elsewhere PLT or BPL) lays claim to a substantially higher allowance for radio interference emission than is permitted for other products, and many papers have been written pointing out the inevitability of serious interference to existing radio services in the High Frequency ("HF") spectrum should HS-PLC be widely deployed. We emphasise "High speed" because low speed PLC in the band below 150KHz poses no such problems. The HF band, covering 3 to 30MHz, is fully used by an overlapping mixture of broadcast transmissions and point-to-point services on land, sea and air. The band offers the special feature of ionospheric reflection that allows very long-distance transmission and reception with simple apparatus. Use of this spectrum becomes a matter for international regulation with strong implications for human rights.

The inevitability of interference can be proved beyond doubt by academic analysis, but demonstration of the problem is by definition difficult until the deployment of HS-PLC reaches such a scale that it is too late to take remedial action. The only direct proof of the cumulative interference phenomenon known to the present author is an anecdotal report that the frequencies used by analogue cordless phones in the 1990's were then clearly recognisable on a marine HF receiver in the North Sea as a series of noise bands of such strength as would hamper use of those frequencies.

The UK's official position on environmental effects of PLC was set out in a submission by the then DTI to an EC workshop [**ref.1**] as *"Many independent studies have been completed, but in the absence of validation, the application of any mathematical model will always be subject to debate, and no firm conclusions are possible on the likely impact of mass deployment of PLC on radio services"*

In the present paper we will briefly review the relevant fundamentals of radio communication. We will discuss some of the "many independent studies" in the light of the present situation, adding one new insight into the accumulation process that suggests a small but not crucial adjustment to some earlier predictions.

In the light of the present situation in the market place we will assess how long it will be before the belated validation sought by the DTI (now BIS) will occur.

Note that this paper does not discuss the issues of close-up interference from a single HS-PLC installation, or of the weaknesses in the problem-reporting process, or of the relation between problem reports and problem size. These are well covered by Williams and Marshall in **refs. 2 and 3**.

Almost all the work discussed below refers to frequencies below 30MHz. There are now proposals to extend PLC to higher frequencies, where, as may be seen from **figure 2**, the existing background noise levels are even lower.

2) Theoretical background

Radio signals always travel from a transmitter to a receiver via a transmitting antenna, an intervening path and a receiving antenna. These three sections may be intentional or unintentional, complex or simple, but the properties of each may be calculated according to the laws of physics as determined a hundred years ago. Very complex cases may be more easily explored experimentally with little risk thanks to this sound theoretical background. The whole process of propagation prediction has been routine since the 1930's.

Briefly, the antennas at each end of the path have directional characteristics and resistive losses that determine their "gain" in any specific direction. In the case of mains power wiring, and over the frequency range 3 to 30MHz used today for PLC, there is some agreement [**Refs. 4, 5, 12, 25**] that the transmission "gain" is actually a "loss" of about 20dB – that is mains wiring radiates about one-hundredth of the differential-mode radio-frequency power that is presented to it and the directional characteristics are on average largely independent of direction.

Propagation may be direct from transmitter to receiver by the so-called "space wave". In this case, if the path is unobstructed (eg. to an aircraft) – then the received power is precisely calculable: It falls as the inverse square of the distance. (To avoid confusion note now that the received *voltage* falls in inverse proportion to the distance, since the *power* is proportional to the *voltage squared*.) The basic inverse square law may alternatively be stated as 20dB fall for a ten-fold increase in distance, and is translated for EMC Standards work to the approximate equivalent of 10dB fall for every trebling of distance.

This rate of fall in the absence of any obstruction is shown by the black dashed line in **figure 1**, which shows the signal strength from a source of 100 mW effective radiated power over distances of 1 to 1,000km. The blue and orange lines in each chart show the more rapid attenuation of "ground wave" signals at 3 and 30MHz respectively when propagated across the English countryside. This chart is based on ITU-R P368-9, but with the transmitter power and field strength voltage scaled down to represent a background noise situation rather than an intended transmission.

For short distances buildings create even greater rates of fall-off; for an analysis of this and some examples of the pitfalls encountered in such calculations see Stott's paper [**ref. 4**]

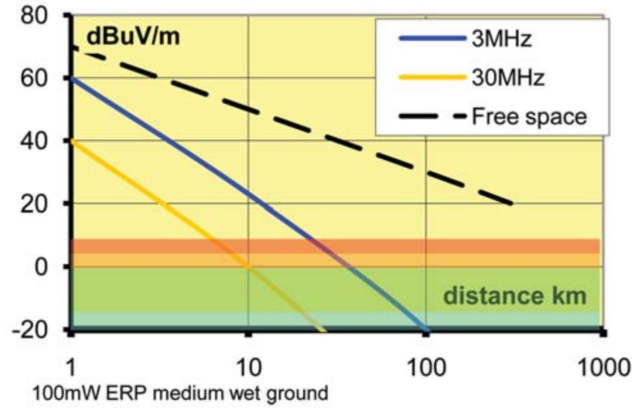

Figure 1 The signal strength of a 100mW source compared with the noise background. The red background corresponds to a "business" environment, the orange to "residential", the green to "Rural" and the blue to "quiet rural" at 10MHz

In **figure 1** the lower background is shaded to show the existing noise levels at 10MHz. Red = business areas, orange = residential, green = rural, blue = quiet rural. Useful signals must be above the relevant noise level, whether it is the existing one denoted by the coloured background or the enhanced one due to reception of the distant interference source as identified by the blue or orange lines. The shaded areas are based on data from ITU-R P372-9. Their edges are only approximate since these levels actually vary slightly with frequency as may be seen from the plot of **figure 2** that shows the ITU data after translation into field strength units. Some people believe that levels have risen since this data was compiled, but **ref. 27**, annex O, slide 6 (page 246) shows four professional plots of measurements in a UK residential area that are about 5dB *below* the ITU data. The orange triangles in **figure 2** show another set of recent measurements in a suburban UK location that also suggest that UK levels are *well below* the ITU figures.

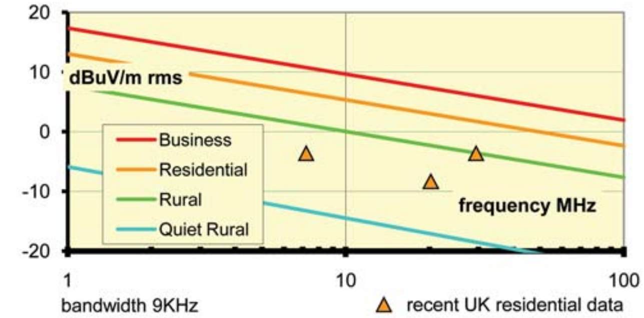

Figure 2 Man-made noise levels in various environments. This data is derived from ITU R372-9 figures for median external noise figure, assuming use of a half-wave dipole and 9kHz bandwidth. Note that above 10MHz galactic noise is some 5dB *above* the man-made "Quiet rural" level shown here.

Sky wave propagation involves one or more reflections from the ionosphere, which is a conducting layer of the upper atmosphere whose characteristics have been well researched since early measurements in 1924. [**ref. 6**]. **Figure 3** shows a section through the earth and the curved conducting layers of the ionosphere above it. The transmitter is shown near the lower left-hand corner. The "ground wave" is also shown hugging the earth's surface. This is a matter of diagrammatic convenience since as already mentioned there is a "space wave" propagating high into the atmosphere that may be received by aircraft.

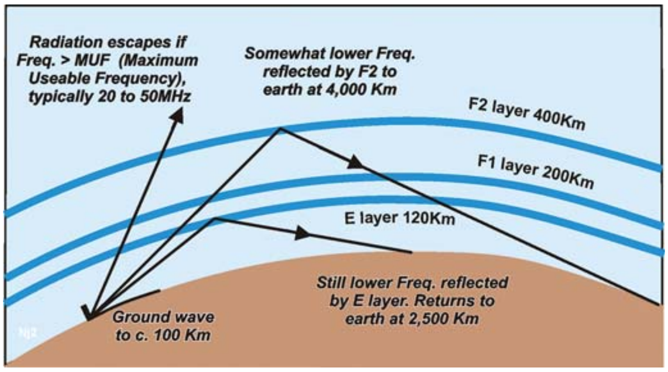

Figure 3 The geometry of radio wave propagation (not to scale)

Ionospheric reflection can be very low-loss, and is responsible for the enormous importance of the 3 to 30MHz "HF" radio frequency band for long-distance communication. Multiple reflections between ionosphere and earth, and continuous curving of radio waves around the planet within ionospheric "ducts" are also possible. With quite limited resources, it is possible under good conditions to send radio signals three times around the world before the signal sinks irretrievably below the noise floor. However, these ionospheric effects change according to the position of the sun and sunspot activity and suffer a good deal of statistical uncertainty.

For a radio transmission to be useful it has to be strong enough to overcome the noise and interference level existing at the receiving location. The required signal to noise ratio depends upon the modulation method. The ITU has recommendations for this too. In summary, the service area of an HF amplitude-modulated broadcast transmitter is defined in ITU-R BS.560-4 as that area of the globe in which the transmitter provides at least a 34dB margin of signal above the local noise level as plotted above in **figure 2**. Below we note that if the local noise level is increased, for example by additional man-made interference, then a larger transmitter power is required to maintain the intelligibility and reliability required for service area status.

3) Broadcaster victim; planet victim

A piecemeal erosion of the service area of broadcast and point-to-point HF radio is inevitable if HS-PLC spreads; it is only a matter of how much and how long it will take. Viewed locally this is the problem that has caused most anxiety, and it is exhaustively set out elsewhere.

However, there is a cumulative effect of local interference that has not received much attention. **Ref. 7,** prepared by Radio Netherlands World-wide, examined the effect of PLC installations near to the listeners to a Dutch broadcast transmitter beaming 500kW at 9.7MHz ESE across Europe and the Middle East. Today such a transmitter would service by a single ionospheric reflection an area covering Eastern Germany, Poland, Lithuania, European Russia, Kazakhstan, Iran, Saudi Arabia, Egypt, Libya and Sardinia. With two ionospheric reflections it would serve the Yemen and Oman. However, the widespread deployment of PLC in these countries that met the then-proposed NB30 limits (which are tighter than those current today) would limit the service area to Slovakia, Hungary, and parts of their immediate neighbours. To restore the original service area the transmitter power output would have to increase to 78 Megawatts! The well-argued calculations assume the use of domestic short wave radios with telescopic aerials only one metre from the nearest mains cable carrying PLC – but that is how it would be.

The economic consequences to broadcasters of a *gradual* increase in HS-PLC usage may be scoped as follows. A recent analysis [**ref. 8**] estimates that the worldwide average daily transmitted broadcast radio power in the HF band amounts to 2,666MWh. Suppose that HS-PLC deployment grows only slowly taking the world as a whole, so that the average background noise rises by 0.5dB per annum. This would equate to a 12% annual interference power increase. To maintain the signal to noise ratio in their service area (and their commercial/ political viability) the short wave broadcasters would have to invest in more powerful transmitters to match the growth of interference. Assuming that these additions are of 85% efficiency their power consumption would increase by 2666 x 365 x 0.012 / .85 =137,300 MWh/annum. Each year this would require the installation of a further electrical generation resource equivalent to some 30,000 wind turbines!

What evidence is there that this assumption of 0.5dB/annum worldwide increase of background noise is reasonable? Early estimates were based on *access* PLC. Fortunately this has proved economically unattractive, though present interest on "Smart Metering" may offer a replacement mass market. Recent developments have been of in-home systems, for which there is no shortage of buoyant marketing claims. In the UK, the BT Vision service has installed large numbers of in-home systems and has plans to grow its field population 7 fold **[ref. 28].** This project is discussed later under the heading "Today's worst case spelt out".

4) The mains as an antenna

An early measurement of the antenna gain of an in-house network [**ref. 25**] made measurements of the horizontally polarised field from a two-storey house whose wiring was energised *in common-mode* against ground. The results were;

MHz	3.6	7.05	10.1	14.1
dB loss	26	11	21	19

The 50 ohm source was not matched to the house wiring – but the minimal 11 dB loss figure at 7.05MHz suggests that matching was good at that frequency. If we add 6dB to these numbers to correct for the common-mode energisation then the result is a good match to more recent *differential mode* measurements.

Direct measurements of the sky wave antenna gain of mains networks (both access and in-house) have been conducted in Switzerland [**ref. 5**]. The measurement method used the mains wiring as a *receiving* antenna and compared the received signal from remote broadcast transmitters with that obtained from a reference antenna near to the PLC installation. A sufficient number of transmitters were monitored to allow the determination of the average gain and the polar diagram in elevation across the relevant range of frequencies. A sample of this work is reproduced in **figure 4.** The plotted points are the averages of 66 measurements. The trend line is that deduced by the present author. The figure shows somewhat lower "gain" than has been assumed elsewhere, but it is of course representative of Swiss wiring practice and the wiring was given a balanced 50 ohm termination rather than 100 ohms as has been assumed in some other work. This might have given up to 4dB extra attenuation.

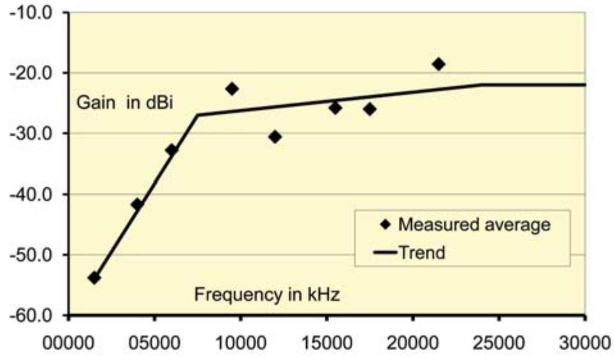

Figure 4 Average sky wave antenna "gain" for indoor sockets.
Data from ***ref.5****. courtesy H Widmer, ASCOM Switzerland; trend line by present author.*

The differential-mode impedance of mains wiring varies, and with it varies the power transfer from HF-PLC modem to that wiring. This variable is generally absorbed into the "antenna gain".

The conversion of differential-mode power into common-mode power that can be radiated has been the subject of bitter debate for the last 15 years since it is a vital part of the arguments about the effect of PLC on *nearby* radio reception. In that context a part of the argument relates to whether the worst-case or the average conversion factor is relevant. However, for the long-distance effects discussed here there can be no dispute: We are concerned with the rms average factor. It must be said that the UK's "protective multiple earthing" power distribution system adds an extra degree of unbalance and so must lead to a greater degree of radiation than most other configurations. However, no measurements of this have ever been published.

All authors have absorbed these variables into the "antenna gain".

The "antenna gain" measurements discussed above appear to be the only credible published sources of data. The considerably reduced gain observed in **figure 4** and in **ref. 25** and **ref. 5** at lower frequencies has important implications and further verification is needed.

The German NB30 specification sensibly transferred responsibility for determining antenna gain onto the PLC system owner by specifying not the culprit launch power but instead the resultant magnetic field strength at 3 metres distance from the installation. However such a specification does lead to regulatory difficulty when the PLC modem and the cable network are in different ownership – and 3 metres is too close to allow meaningful measurement.

5) Prior work and its contemporary relevance

Here we concentrate on the likely magnitude of the cumulative effects of very large numbers of PLC installations at a considerable distance from a victim radio *receiver*. Several studies have been published over the last twelve years – but they have all had to "shoot at a moving target" by making assumptions about the scale of a *future* emission threat. This target was initially "access" PLC. Today it is "In house" PLC. Soon the target may have to encompass "Smart Metering" and wireless power transfer.

The principal source of complaints about "In house" PLC emission in the UK today is the BTVision product. The technical characteristics and field population of this are set out and analysed in "Today's worst Case" later in this paper. First, we will use these present-day figures as a part of the following review of earlier studies to scale their conclusions to the emission level in the UK today.

Exclusion zones and aircraft communications

The victim status of receiver users was analysed in a pioneering contribution [**ref. 4**] to the work of a group meeting under the aegis of the UK's Radiocommunications Agency. In this Stott analysed the requirements for the protection of "sensitive receiving sites". (These might include commercial, marine, aviation, diplomatic, security, and radio astronomy installations. Today the "LOFAR" and "Square Kilometer Array" radio astronomy projects would be prime examples.) Stott's calculations were intended to define the necessary size of an exclusion zone around such a site assuming a uniform distribution of PLT sources across the entire region beyond that zone. Stott analysed the effect of ground wave and sky wave propagation, and introduced the concept of "effective radiated power per square kilometer". The paper set out a method for computing the effects of sky-wave propagation from distant rings of uniformly distributed interferers, noting that interference from such sources "may not always be negligible". He based his conclusion on access PLC, with 3.5 installations/km² across large conurbations, each installation generating a differential-mode power of 500µW in 10KHz bandwidth, and subject to a wiring antenna power gain of x 0.01. These figures correspond to 101 dBµV rms conducted emission per wire and –20dB antenna gain. He calculated that this would equate to an effective isotropic radiated power (EIRP) of 17.5µW per km² and provided a table of exclusion distances that would be required to protect a sensitive site from ground wave interference from such a PLC scenario. It was noted that nothing could protect such sites from distant interference coupled via sky wave.

Whilst it is conceivable that "sensitive sites" might be protected from access PLC whose deployment was in the hands of a single entity such as an electricity supplier, it would be both politically and legally very difficult to exclude consumer electronic devices such as indoor PLC as deployed today from any specific zone.

Aircraft communications were identified as being at particular risk of interference from PLC. The received noise would be largely independent of aircraft height, since the higher the aircraft the more PLC systems would be in view. The paper concluded that a noise field strength of the order of 40 to 43dbµV/m might be expected with the assumed source power density. This is about the same level as would be expected for an active, reliable communications signal and so suggested a significant threat that needed further consideration. A later paper by Stott [**ref. 14**] generalised the mathematics of his earlier note and covered a wider variety of cases – including interference to aircraft from a non-isotropic ground source. There was no change to the basic conclusions.

In comparable terms to Stott's work the most recent figures of EIRP in the UK may be estimated by applying a little arithmetic to the figures in **ref. 3**, where it was noted that there were 300,000 installations of BTVision in the UK. Since 7.51 million of the UK's 60 million population live in greater London, we can estimate that there were 300,000 x 7.51/60 = 37,550 BTVision installations there. The land area is 1,579km², so there were about 37,550/1,579 = 24 installations per square kilometer. Given the recent clarification of the 4µW average *conducted* power delivered by a BTVision modem, the conducted power must be 4 x 24 = 96µW/km². The *radiated* power will be less by the antenna gain; taking Stott's figure of –20dB, that is one-hundredth in power terms, the radiated power density for Greater London was 0.96µW/km². So Greater London's PLC interference emission in March 2009 was about one-twentieth (0.96/17.5) of the basis figure calculated by Stott ten years earlier. In decibel notation it was 12.5dB less.

Stott's reasoning regarding interference to aircraft communications can be scaled in the same way, changing his field strength estimate from 43 to 30.5dBµV. This figure is still well above the ITU "business" noise field as reproduced in our **figure 2** above, and strongly suggests that HF-PLC is already reducing the safety margin of HF aeronautical communication. Recently the work gathered into the annexes of **ref. 18** has confirmed the reality of this threat. This ITU-R Study Group report is a very comprehensive document. Although the main report provides no summary and minimal conclusions there are 128 pages of annexes detailing measurements of excessive emissions from PLT systems world wide. For example Annex 2.6 describes measurements in Germany of the noise level recorded in an aircraft (presumably over an area without existing PLC deployment). Using the known characteristics of a reference PLT installation replicated across the ground at a density of 250 culprits/km², this annex calculates the degree of reduction of PLT transmission level that would be needed to reduce the risk to safety-critical aeronautical radio to an acceptable level. It is concluded that a 50dB reduction is required, and that with today's technology *"Compatibility is not given even when using power management and dynamic notching"*.

Ground wave and sky wave

The work of York University [**refs 10 & 11**] covered HF-PLC and the telephone-line technologies ADSL and VDSL. The following comments relate only to PLC. At the time it was written PLC was seeking to use spectrum "chimneys" from 2.2 to 3.5 and from 4.2 to 5.8MHz. The proposed power within these bands was very high: The authors assumed 100% adoption of access PLC and hence calculated a conducted power density of 3.57mW/km² - about 37 times (+15.7dB) the power density actually reached in greater London by 2009.

The discussion of ground wave effects is based on Stott's paper that we have just discussed. [**ref 4**]. The York paper takes Stott's figure of 14.2 dBµV/m in 10KHz for the field strength at the centre of a 10km radius exclusion zone and uses this as representative of ground-wave effects in the more general case. One could criticise this selection of data on the grounds that a major conurbation is of well over 10km diameter and rarely has sharp edges. It would have been better to quote Stott's figure of 3.25 dBµV/m for a 30km zone and then further correct it downwards for a situation where the culprit area did not completely surround the victim.

Sky wave effects were analysed by assuming a uniform distribution of access PLC systems within each of the 15 major conurbations of the UK together with the Ruhr treated as a single entity. No account was taken of other overseas contributions. The PLC antenna radiation pattern is derived from a street model, but the antenna efficiency is assumed to be –15dB after reference to Stott's earlier work. The received powers were summed and it was concluded that the result would be a more-or-less uniform interference field across the UK of some 7.5dBμV/m. Interestingly, the contribution of the Ruhr to this figure was greater than that of London. From **ref. 5** we can now judge that this estimate of antenna efficiency was about 7dB too high. Since the source power assumption was 15dB above that actually reached in 2009, this work allows an updated prediction of 7.5 – 15 –7 = -14.5dBμV/m for the UK in 2009. It is clear from our **figure 2** that such a level would be difficult to detect – but the task will get easier year by year.

The York paper noted that the sky wave field would be about 7dB lower than the ground-wave field at 10km from "Greater London". We have already cast doubt upon this ground wave figure and so are equally unhappy with the author's conclusion that "Ground wave propagation is the mechanism that is likely to lead to the largest increases in the established noise floor". Stott's statement "When there can be nearby interferers … ground-wave propagation provides the dominant part of the received interference" is much better since it allows the important conclusion that for rural and sensitive sites sky wave interference will certainly establish an inescapable man-made noise floor.

Skywave Studies

A study at the University of Karlsruhe [**ref. 12**] concluded that there would be no cumulative problem if all the PLC sources met the requirements of NB30. However, today's PLC systems do not meet the requirements of NB30. The authors noted that their conclusion differed from that of the York study discussed above, but calculated that their results would have been closely similar to that sky wave analysis had they made the same assumptions for PLC source power.

A Swiss analysis [**ref. 13**] concluded that "the present natural noise levels in electromagnetically quiet areas will not change significantly with … deployment of …(access PLC) if the maximum psd (power spectral density) per cell … is below -40dBm/Hz". This figure was based upon measurements of the magnetic field near to a buried low-voltage distribution network carrying PLT signals at a rather higher level. An antenna model was then chosen to match this magnetic field, and its radiation used as input for a proprietary computer program developed for military HF radio system design purposes. This was then used to compute the disturbance field strength produced by unwanted emissions of PLC users located in distances ranging up to a few thousand kilometres from a victim receiver. The input to this program was based on 0.35 access PLC cells/km² averaged across the whole of Germany, each energised for only one tenth of the time to allow for typical power control and traffic levels. Plots of the resulting field strength covered a variety of ionospheric situations, and it was by inspecting these that it was determined that the source power would have to be reduced to -40dBm/Hz (100nW/Hz) to achieve the desired result. This figure is equivalent to 0dBm in 10KHz bandwidth – the same figure as used for skywave emission in the York study discussed above.

Surprisingly this analysis did not consider the additional world-wide interference that might reach remote areas from countries other than Germany. It was the first to recognise that PLC sources might not be emitting at their maximum level all the time – an important truth. It has been criticised in **ref. 10** for the obscurity of its ionospheric calculation and summation.

The authors specifically excluded *indoor* PLC from their scope, presumably because an indoor power circuit would radiate much more than a buried access cable. If however we ignore this factor we can compare the authors case with BTVision in the UK today as follows:

UK/Germany = (relative % "on" time) x (rel. culprits/km²) x (rel. power in nW/Hz)
=100/10 x 1.24/0.35 x 0.4/100 = 1/7 or –17dB.

However, bearing in mind the issue of increased indoor cable emission, the UK must now be near the limit determined by this Swiss author.

Radio astronomy

A Japanese contribution [**ref.15**] calculated that because of the extreme averaging time applied to space signals a *single* access PLC installation (launching –50dBm/Hz and assuming -20dBi antenna gain) would need to be at least 424 km distant to avoid disturbance to any of the country's four radio astronomy laboratories. These establishments investigate HF emissions from the Sun, Jupiter and other large gaseous planets. The solar studies are essential for the prediction of ionospheric disturbances that may have a serious effect upon communication and power distribution here on earth. The sensitivity of all such measurements in the HF radio band is limited by the laboratory's radio noise environment.

The contribution assumed free space propagation; presumably it was felt that a more sophisticated approach was unnecessary given the revealed magnitude of the problem. The 424km figure underlines the fact that a single PLC system emits an interference power equal to many thousands of CISPR22-conformant products – and has correspondingly greater long-distance effects. This can be seen as an indication of the inevitable international implications of PLC emissions.

The assumed –50dBm/Hz per installation has to be compared with the 2009 UK figure of –64dBm/Hz per installation. Accordingly a group of just 25 installations of BTVision should produce the same calculated trouble distance as has been determined by these authors.

A Military View

Ref. 26 is the final report of a NATO task force that considered the impact of ADSL and PLC upon COMINT - Communications and Intelligence. Its 101 references include the most comprehensive bibliography of PLC. Original work includes consideration of ground reflection (which appears to have a substantial effect upon measurements within 200 yards of the PLC site). A further comment is that measurement of CMRR/LCL at the injection point may not be representative with respect to radiation since impedance mismatches can cause large variations in common-mode current along the line – a factor disputed in PLT standardisation work.

On the basis of the bibliography different assumptions were made for Indoor and access PLC;

	d/m modem power	mains antenna gain	modem duty cycle
Indoor	-50dBm/Hz	-30dBi	30%
Overhead Access	-50dBm/Hz	-15dBi	15%
Buried Access	-50dBm/Hz	-30dBi	15%

Market growth figures from Germany in 2006 suggested that Indoor PLT was the greatest contributor to interference emission. Future emission from this source alone was modelled using the above assumptions and the rather extreme prediction of 0.5 modems per capita – a market presence some 20dB higher than the contemporary situation. Today we can postulate a contribution from "Smart Grid" that would make the NATO prediction a modest one.

The calculation method and an example of the results is set out in the box **"The NATO sky wave analysis".**

It was noted that the ITU-R noise levels were median values and might not be acceptable metrics for NATO purposes. An Absolute Protection Requirement of –15dBµV/m in 9kHz was postulated with the comment that the probability of this being exceeded was large for all the frequencies and receiver locations investigated.

Conclusions included;
* There is a high probability that PLT will cause increased noise levels at sensitive receiver sites given the projected market penetration.
* NATO should seek to support harmonised regulatory limits by working with national and international authorities.

Summary of the above prior work
Each of these documents state that there is, or soon will be, a problem. Each of them has been ignored by the Standards makers and the regulatory authorities. Each of them has been ignored by the designers, manufacturers and marketeers of PLC equipment.

6) Uncertainties in calculations

In the following analysis we expand the path from culprit to victim that was identified earlier. It is necessary to start with the summation process, in which large numbers of unwanted signals arrive at a receiver. We can assume that they are independent of each other, though they may share some subtle characteristics (such as being of reduced power in notched bands). The correct parameter to add is therefore the received *power* from each individual source. This is awkward, because power is rarely measured directly in EMC practice: It is inferred from voltage whilst making assumptions about bandwidth, waveform and time-profile. EMC measuring receivers generally measure average, quasi-peak, or peak voltage. Very recent measurements of the real launch power from a PLC modem on Standby (to be described in section 8)) gave an answer *well above* that which would be calculated from the *average* conducted voltage and only 10dB below that corresponding to the quasi-peak figure.

The NATO Sky Wave analysis

Analysis was restricted to Sky Wave propagation. This was treated thoroughly – not just by picking a few key areas as in the other work reviewed. The authors developed a Cumulative PLT Tool as a front-end for the IONCAP ionospheric propagation tool. For each chosen victim site their CPLT tool accepted data for population per "square" of 0.25° x 0.25° within a grid of latitude and longitude co-ordinates over an appropriate region of the globe. IONCAP was then called for each transmitter "square" and the received powers at the victim were summed by CPLT.

The results for one European site are presented here in figure 6.

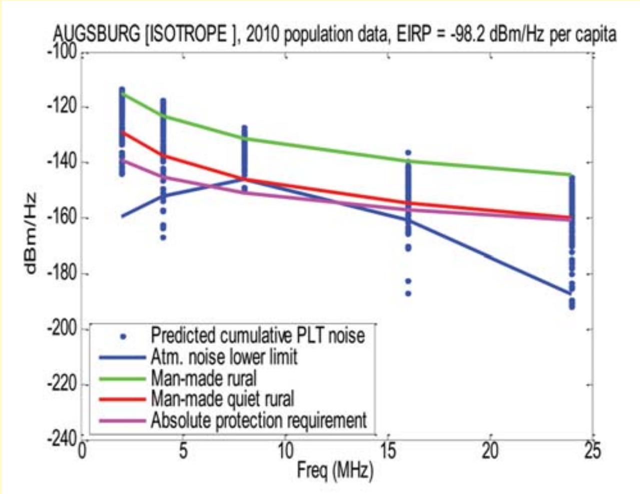

Figure 6 Predicted cumulative PLT noise parameters for example with receiver in Augsburg, compared to established background noise levels.
The original version of this material was published by the Research and Technology Organization, North Atlantic Treaty Organization (RTO/NATO) in Technical Report, RTO-TR-IST-050 - "HF Interference, Procedures and Tools", in June 2007. See ref. [26]

The columns of partially-overlapping blue dots represent the predicted summation of PLC noise at Augsburg by sky-wave *only*, excluding the larger contribution to be expected by ground wave. The source area covered Europe, N Africa, the middle east and part of Russia. Within this area radiated interference power was calculated from an estimated emission *per capita* of –98.2dBm/Hz . This figure was based upon a substantial market penetration of Homeplug devices *only*. Each blue dot represents a particular assumption about reception frequency, time of day and season, sunspot number and geomagnetic activity.

There will be relatively few different designs and protocols for PLC devices, so the statistical benefits of averaging will not remove systematic errors in source power measurement.

The variation of interference power with data rate is also important. In this respect Williams **[ref. 9]** has shown that at least one implementation of the UPA standard is very unsatisfactory. Some of the work described earlier assumed that the effective culprit power would be that specified for the technology. That by Widmer **[ref. 13]** assumed that it would be one-tenth of this. Accordingly we have to be aware of the assumptions made in previous work when transposing their results to present and future situations.

The propagation of radio waves has been well-studied as it is a vital factor for planning radio systems, and most authors have followed the ITU guidelines. Propagation is affected by absorption by the terrain. UK authors **[refs. 4, 10, 11]** assumed "wet ground" (conductivity 10^{-2} S/m) whereas **ref. 12** assumed that Germany was "land" (conductivity 3 x 10^{-3} S/m). At 3MHz and 100km the latter results in 7dB lower field strength, so the assumption is of some importance.

The ITU data of course assumes deliberate transmission from an antenna intentionally raised above the surrounding terrain. Whilst installations in a tower block will be like this, most PLC will be at or near ground level. In this situation we have to consider the possibility of extra attenuation beyond the "one-hundredth power (-20dB) at ten times distance" theoretical rule.

In **Ref.4** Stott reported measurements in the UK by the electricity distributor Norweb of 25dB, but it is not specified over what distances this figure applied. Recent attempts in the USA to table a figure of 40dB have lead to a comprehensive rebuttal by the ARRL [**ref 16**]. A recent Canadian study [**ref.17**] claims statistical confidence in an 18.2dB figure – but only by extrapolation from measurements at 3m and 10m. Both these figures are questionable because they do not take proper account of "near field" effects. The near field is the region close to an antenna where the amplitude and phase relationship between the electric and magnetic fields is not properly established, and so there is an ebb and flow of energy between the antenna and its surroundings, and simple maths does not apply. For a half-wave dipole the near field ends at a distance from the antenna approximately equal to $\lambda/(2*\pi)$ – that is one sixth of a wavelength or 1.6 metres at 30MHz. However, for complex antennas such as the multiplicity of cables in an indoor mains network, both theory and modelling by the present writer [**ref.19]** has shown that far field conditions are only established at a greater distance where the contributions of the various antenna elements approach the phase relationships that they would have at infinity. This "Rayleigh Distance" is given by $2*D^2/\lambda$ where D is the largest dimension of the antenna aperture, and is equal to 13 metres at 30MHz. So PLC emission measurements at 10 metres or less will be of poor repeatability and give limited indication of the far-field effect. However, for cumulative effects, the averaging will substantially reduce the impact of such errors. The NATO report [r**ef. 26]** provides data and analysis of this near-field problem. It is concluded that a universal model is not possible and that it is best to use the measurement results obtained by the referenced groups. These results depend on frequency and distance and range from 10 to 40 dB per ten times distance.

The NATO authors have also modelled the effect of ground reflections; - a factor ignored by other writers but well known to EMC test engineers.

All cumulative assessments must make assumptions about the culprit population size and usage. EMC Standards do not explicitly consider these factors – but because of cumulative effects such consideration is vitally important for exceptional mass-market products. For access PLC market penetration may yet become 100% if the technology is adopted for smart metering. For in-house population size we are reliant on marketeer's numbers. The various studies reported above assumed 15% to 100% usage. For in-house PLC 100% usage factor is already commonplace because of poor protocol design **[ref. 9].**

Calculation errors relating to the mains as an antenna and to propagation will be minimised by averaging across the large population – but this does open up the possibilities of "hot spots" of more serious trouble such as were encountered following estimates of the average level of radioactive fall-out from the atom bomb tests of the 1950s **[ref. 20].**

All these studies make assumptions about culprit population that are as-yet unfulfilled. If allowance is made for differing assumptions they all agree substantially. However there is no reason for complacency. Whatever population there is, we can safely assume that in the developed world it is growing at 25% pa (15% sales and new product introductions, 10% increasing data throughput) which equates to 1dB/annum increase in cumulative interference. If the calculated figures are a 10dB overstatement this only delays the rise of spectrum pollution by 10 years. For access PLC and for smart metering the ultimate market size is equal to the number of electricity meters!

7) So why has nobody noticed - YET?

The measurement of one noise source in the presence of others is only possible if one can identify some unique non-noise characteristic. For example, man-made noise from business activities is almost completely turned off on Christmas day, so the reduction of background noise then compared with that on a normal business day gives a useful measure of business emission. Again, under certain ionospheric conditions distant sources of noise are absent and so their normal magnitude may be estimated by the effect of their absence.

PLC data transmissions are designed to be noise-like because that maximises the communication efficiency. So far no one has published any method of identification applicable to HF-PLC, other than switching it off – which is hardly possible when cumulative effects of multiple sources are involved. Nevertheless, there are some characteristics that might help identification;-

a) Most PLC systems are notched to minimise interference to amateur radio. Accordingly a comparison of noise measurements inside and outside of each amateur band should help. There appear to be ten notched band edges for HF-PLC that could be measured and the results averaged.

b) Where a single transmission format is predominant, as is currently the situation in the UK, it may be possible to identify some more detailed structure. The UPA specification [**Ref. 21]** specifies sub-carriers spaced at 156.25KHz ±100ppm. In **Ref.22** Bigwood shows an instantaneous spectral plot of some of these sub-carriers. This reveals regions of 10dB lower emission between them. However these regions disappear in a time-averaged plot.

c) A single installation using the UPA protocol may be identified by the 1.3KHz tone demodulated by an am receiver. However, this tone is not locked to mains frequency. It will be of unpredictable phase and so not detectable in a cumulative situation.

Further work is needed to evaluate these methods of source identification.

To plan a demonstration the situation offering the highest PLC/background ratio must be chosen. One aspect of this choice is the behaviour of the ionosphere at different times of day. At frequencies below a few MHz we may look for a minimum of sky wave interference at about noon, because the "D" layer, which is predominately an absorber, will then be at its thickest. At higher frequencies the maximum useable frequency ("MUF") is the controlling factor and night time may be the best choice for ground-wave measurement.

8) Today's worst case spelt out

Given the complexity of the models used previously and the greater detail that is now available about the culprits it is worthwhile to review what appears to be today's worst-case scenario. This is the rise in HF noise level that might interfere with communications to an aircraft overflying London, England.

In **Ref. 3** it was noted that in March 2009 there were about 300,000 active BTVision installations using Comtrend Power Line Adaptors in the UK, and that from UK population statistics we can expect 300,000 x 7.513/60 = 38,000 of these to be in the greater London area. This equates to 24 installations per km². These modems employ the UPA protocol **[ref. 21]** which results in the very unfortunate feature of emitting as much interference when idle as when carrying data. The protocol designers clearly did not appreciate the EMC responsibilities of the writers of communications software. In **ref. 9** Williams stated that the quasi-peak level in 9KHz bandwidth on each wire of such an adaptor is about 90dBµV. (We may ignore the 0.41dB correction between 9KHz and 10KHz bandwidth.) As discussed in the previous section, the rms voltage is the appropriate parameter for the necessary power summation. This is difficult to determine for PLC because of the high crest factor and wide bandwidth, but two independent tests of Comtrend modems have recently given values of 80±1dBµV rms on standby, and we have one measurement of a 2dB increase in rms voltage when active.

Accordingly we can assume a power output equivalent to 80dBµV on each wire, which translates into a two-wire power of -24dBmW total, or 4µW. For some comparisons it is useful to translate this into 0.4nW/Hz or -64dBm/Hz by subtracting 40dB to correct for the reduced bandwidth. Given the limited database on mains antenna gain we have to accept a typical PLC far-field antenna gain figure of –22dB, (that is a power reduction of 1/158) and limit consideration to the frequency range of 10 to 30MHz because of the uncertain antenna efficiency at lower frequencies. Therefore the *radiated* power *density* across the greater London area is estimated to be 24 x 4 x 1/158 = 0.6µW/km², or –32.3dBm/km².

Echoing the approach used by York **[refs 10, 11]**, it follows that the total radiated power from BTVision installations in Greater London in May 2009 was about 38,000 x 4x10^-6 x 1/158 x 10^3 = 0.96mW (0dBmW) measured in *any* 9kHz bandwidth within the adaptor's spectral emission range of 10 to 28MHz excluding the notches. The field strength/distance curves of **figure 1** were plotted for 100mW (20dBmW) radiated transmitter power: With Greater London as the source the plotted lines need to be corrected for today's worst case by lowering by 20dB. **Figure 5** shows the effect of this adjustment. On the ground, the interference drops into the rural noise at about 11km distance even at 3MHz, but in the air, where the dotted line plot of the pure inverse square law applies, there appears to be a 20dB excess of PLA interference above likely other sources.

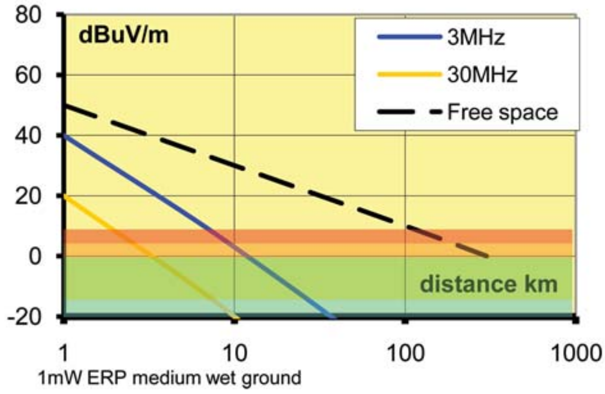

Figure 5 Field strength resulting from a 1mW transmitter. As in Fig 1 the red background corresponds to a "business" environment, the orange to "residential", the green to "Rural" and the blue to "quiet rural"

The 1mW EIRP estimate used to prepare this chart is subject to most of the uncertainties discussed earlier. Maybe these amount to 10 or 15dB in total. Also the spectrum will be filled with much stronger wanted signals that will make measurement problematical at most frequencies, but there is a reasonable chance that a measurement at an elevated site or from an aircraft would be possible today – and it will certainly be possible within the next few years unless something is done to make PLC more environmentally friendly. Note that the ambitions of Marks **[ref. 28]** for BTVision were for 3 million subscribers by 2010. If this ever becomes a reality it will raise their cumulative emission by 10dB.

9) Future Prospects

There is no doubt that HF radio communication at any distance - from wireless mice to intercontinental broadcasting - will suffer directly from the continuing marketing of PLC equipment with today's emission characteristics. Fixed and dynamic notching and power management as currently being discussed would help but not solve the long-distance problem if they were rigorously applied, but such rigor is unlikely given the present regulatory inertia and the steady growth in demand for the transport of data. It is noteworthy that the global demand for data transmission bandwidth continues to grow unabated, according to a leading optical components manufacturer [**ref. 24**].

We have to be concerned also about the example set by these high levels of emission, and the prospect of other products (eg Wireless power transmission) playing catch-up.

If the installed base of these "greedy" technologies continues to grow at 25% per annum, which corresponds to 1dB in engineering terms, then any errors in the calculations made by the experts referenced in this paper only amount to a delay of 5, or at most 10, years before the situation becomes so serious that radio interests have to respond. They have few options.

10) Conclusions and Recommendations

There is strong evidence that the wide deployment of high-speed PLT will seriously impact radio communication. If we allow this to happen we sacrifice a proven long-distance universally accessible technology of considerable commercial and social importance for what can only be described as a short-term gain in convenience for local data networks.

There are several things that could be done to minimise this problem;

First, we must make sure that EMC Standards are preserved from any relaxation that legitimises environmentally unacceptable emission. However, there is little point in doing this without a parallel campaign to increase awareness of the value of these Standards. We need to reverse the trend of the EU to discount Standards, and instead to encourage national governmental and quasi-governmental institutions to support them. It ought to be simple; Standards make people's jobs easier and establish a genuine level playing field.

The key area where awareness is needed is the market place. Today, almost no retail sales literature or product reviews make any mention of EMC specification or performance.

Identification of these noise-like interferers is very difficult. It would be much easier if all such sources were required to embody, and publish, some feature that would be recognisable for both a single source and an aggregation of similar sources. This should be a simple matter for the Standards Committees, but they may claim that it is a regulatory matter and so outside their jurisdiction. In this case, who can make it happen?

The "polluter pays" principle ought to apply to electromagnetic pollution just as it does to atmospheric pollution by CO_2. At present the victim pays in the short-term by inconvenience and in the long-term by the loss of development options and by increased energy cost. "Polluter pays" could be achieved by a tax on all products that do not conform to the internationally adopted EMC Standards.

Of course *local* interference is already being caused by *individual* PLC installations. The case for reduced HS-PLC emission to avoid these problems involves less extrapolation. Let us hope that Standards and Regulations will soon be put in place that will solve both sets of problems. Time is running out.

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