Copy No of 2

Autonomous Interference Monitoring System

Licence Exempt Spectrum Measurement Study
Volume 1 – Summary Report

Issue 2
February 2007

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Executive Summary

A measurement study of the licence exempt (LE) spectrum between 100 MHz and 10.6 GHz has been conducted by Mass Consultants Ltd (MASS) for Ofcom with the objective of assessing the current levels of utilisation of the LE bands across the UK.

The Autonomous Interference Monitoring System (AIMS) was deployed to 20 sites across the country and used to measure activity in the LE bands at each site. The results of this study are provided in two volumes. Volume 1, this document, describes the general methods used and summarises the results of the measurement campaign whilst Volume 2 provides in-depth analyses for each of the measurement sites.

The main finding of the study is that the LE bands are in general not heavily used. The band displaying the highest usage is the 458.5 – 459.5 MHz band, designated for use by industrial / commercial telemetry systems. Use of RF heating apparatus in the 886 – 906 MHz band is also widespread, although the energy is very low duty cycle.

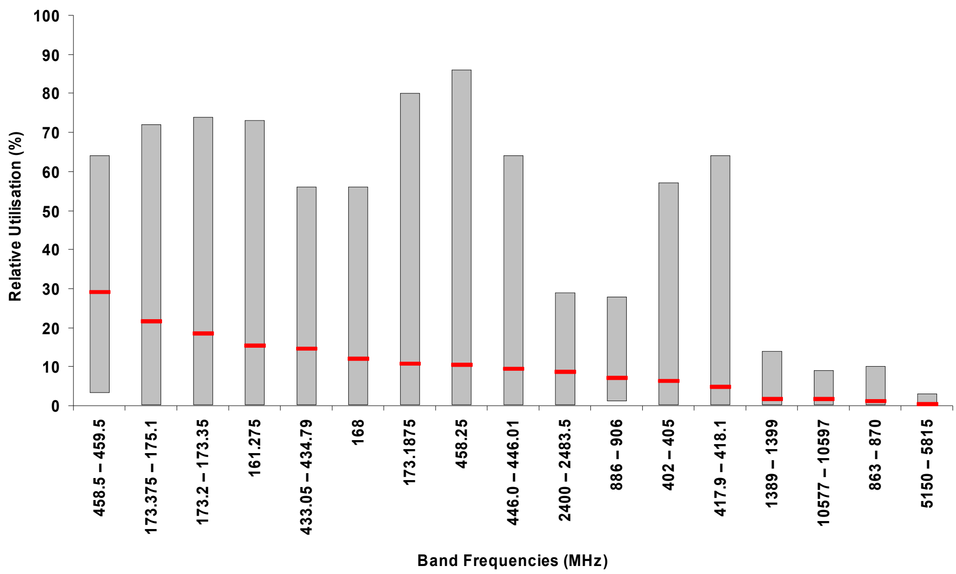

Figure 1. LE band relative utilisation – sorted by mean utilisation (Red line – mean; Grey box – min. and max. limits across all measurement sites).

A surprising result was the relative lack of Radio Local Area Network (RLAN) activity, especially in central London, possibly attributable to signal propagation effects and the low power output of the RLAN systems.

Comparisons are made with measurements of the 2.4 GHz band carried out in 2003 at three sites. Interestingly, all three sites display an increase in the level of activity since 2003, mainly attributable to recent deployment of RLAN systems. Despite these increases, the 2.4 GHz band is only heavily utilised at one of these sites.

Significant wideband interference effects were detected below 1 GHz, in particular due to malfunctioning fluorescent light tubes. This interference has a significant impact on the calculated utilisation metric. Utilisation with and without the interference component are presented. Utilisation is deemed to be low even with the effects of interference included.

CHANGE HISTORY

Version	Date	IR	Comments
1	24/01/07	-	First Formal Issue
2	15/02/07	-	Second issue addressing comments from Ofcom

This report was commissioned by Ofcom to provide an independent view on issues relevant to its duties as regulator for the UK communication industry, for example issues of future technology or efficient use of the radio spectrum in the United Kingdom. The assumptions, conclusions and recommendations expressed in this report are entirely those of the contractors and should not be attributed to Ofcom.

The comments in this report are, to the best of our knowledge, an accurate and unbiased interpretation of the measurement data. Whilst all due care and attention has been taken during the measurement and analysis processes and the subsequent production of this report, we cannot be held liable for any results or comments that later prove to be incorrect.

DISTRIBUTION

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VOLUME 1 – SUMMARY REPORT

VOLUME 2 – DETAILED SITE REPORTS

See separate volume for contents.

1 INTRODUCTION

The demand for licence exempt (LE) usage is on the increase and there is some anecdotal evidence that LE bands are getting more congested. However, few measurements have been undertaken to verify this hypothesis. Mass Consultants Ltd (MASS) was contracted to conduct a series of measurements to assess the current level of utilisation of the LE bands. The results of this LE study are provided in this report.

This study report forms one of several inputs to Ofcom's review of the LE bands, which will result in the production, by Ofcom, of a Consultation Document (ConDoc). This ConDoc will consider what action Ofcom should take to maximise the potential of the LE bands. Possible actions include opening further bands, changing the rules for band usage or publicising usage information to allow users to make informed decisions as to whether to invest in equipment.

MASS's LE study was conducted as part of the Autonomous Interference Monitoring System (AIMS) Phase 2 programme. LE measurements were conducted at 20 sites. In addition to the LE work, the wider AIMS programme includes measurement of man-made noise levels and measurements of interference and noise within licensed bands.

This study report is presented in two volumes. Volume 1, this document, describes the general methods used and summarises the results of the measurement campaign whilst Volume 2 provides in-depth analyses for each of the measurement sites

1.1 REFERENCES

[Volume 2]	Merricks, N. P., (2007), *Licence Exempt Spectrum Measurement Study, Volume 2 – Detailed Site Reports,* Mass Consultants Ltd. MC/SC0585/REP011/1
[2.4 GHz Study]	Day, S.W. and Merricks, N.P., (2003), *2.4 GHz Monitoring Exercise – Final Report,* Mass Consultants Ltd. MC/SC0390/REP010/1
[Spectrum Percentage Occupancy Study]	Hansell, P., Kirtay, S., Inglis, I., Pahl, J. and Munday, S., (2004), *Evaluating Spectrum Percentage Occupancy in Licence-Exempt Allocations,* Aegis & Transfinite Systems. 1606/LEM/R/3
[LE Economics Study]	Indepen, Aegis & Ovum, for Ofcom, (2006), *The Economic Value Of Licence-Exempt Spectrum – Final Report*.

2 MEASUREMENT CAMPAIGN

A measurement campaign was designed to give a representative view of utilisation levels in the LE bands between 100 MHz and 10.6 GHz across a geographical sample of 20 sites. The spectral and geographical considerations are detailed in sections 2.1 and 2.2.

2.1 MEASUREMENT BANDS

The LE bands of interest were specified by Ofcom. This baseline was used by all parties contributing to the LE ConDoc. For measurement purposes, contiguous or overlapping LE bands were combined into single 'measurement bands'. These are shown below in terms of their relative bandwidths:

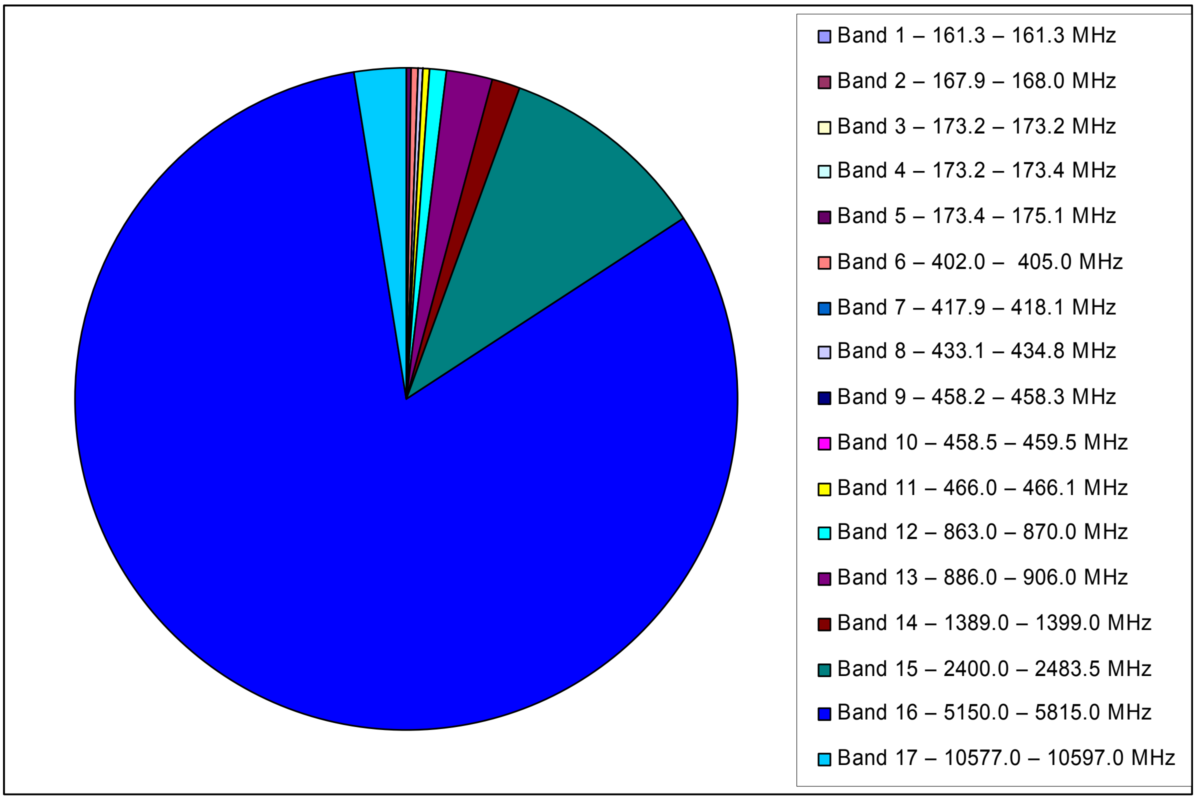


Figure 2. Bandwidths of the LE bands

Clearly, in terms of bandwidth, the LE bands are dominated by the 2.4 GHz (2,400 – 2,483.5 MHz) and the 5 GHz (5,150 – 5,815 MHz) bands.

Further details of the measurement bands, associated services and the selected frequency resolutions are provided in Appendix C. The frequency resolution for each band was chosen from consideration of the time required to complete a test and the bandwidth of the services that are likely to use the particular band.

2.2 MEASUREMENT SITES

The stated objective of the study was to assess the current level of utilisation of the LE bands in the UK. As such, it was agreed that the study should cover the major environment types (urban, suburban, rural and industrial) as well as both indoor and outdoor measurement locations. In addition, it was thought useful to revisit some of the sites used for the [2.4 GHz Study] by MASS in 2003 to enable analysis of changes in utilisation of this band over the last three years. As far as possible, within the constraints of a total of 20 sites, the study had to be geographically distributed to provide nationwide statistics.

The sites used are listed below in chronological order of their measurement dates:

ID	Description	Outdoor				Indoor		
		Urban	Suburban	Rural	Industrial	Office	School	Industrial
14	IET Savoy Place, London					X		
41	Wraysbury, nr. Heathrow (RMDF*)			X				
27	ETS, nr. Stansted			X				
20	Wilkinson’s Distribution, Worksop							X
12	Sheffield University Arts tower roof	X						
42	Sheffield University Arts tower 1st Floor					X		
18	Willis & Gambier (Indoor), Saffron Walden							X
9	Ninestiles School, Birmingham						X	
22	Perkins Engines, Peterborough				X			
18	Willis & Gambier (Outdoor), Saffron Walden				X			
2	Cambridge University Wireless Society			X				
16	Addenbrookes Hospital, Cambridge							X
6	Silicon Valley, Lightwater					X		
7	SCS, Henley-on-Thames		X					
5	MASS, St Neots		X					
28	Baldock satellite site (RMDF*)			X				
23	Audionics Practice Rooms, Rotherham							X
26	Woodall Services, M1				X			
24	Moto Services M18				X			
40	Daniels Residence		X					
	Total	1	3	4	4	3	1	4

*Remote Monitoring Direction Finding (RMDF) systems are operated by Ofcom at various sites across the UK.

Sites 9 (Ninestiles School), 14 (IET Savoy Place) and 16 (Addenbrookes Hospital) were used previously on the [2.4 GHz Study].

Figure 3 shows the geographical distribution of the measurement locations.

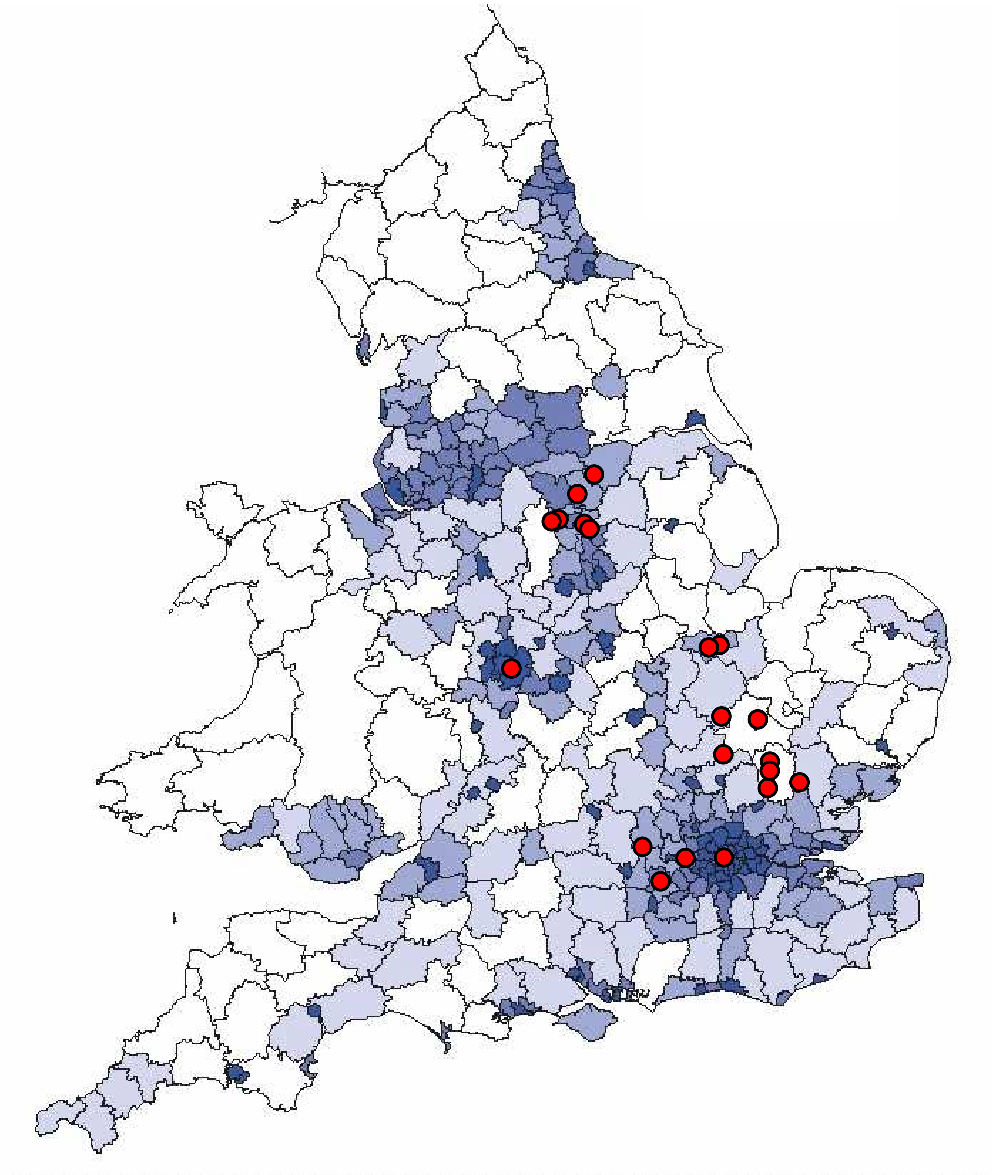


Figure 3. Measurement site locations (shading indicates population density).

3 MEASUREMENT & ANALYSIS METHODS

It was agreed that this LE study should concentrate on real-world measurements as opposed to modelling activities. Further, it was agreed that the most practical approach was to conduct a survey of LE spectral utilisation, rather than measurements of percentage occupancy against a known band capacity.

To achieve those goals, a measurement method for characterising the utilisation of the LE bands was developed, based on hardware and software developed in conjunction with the AIMS programme of work. (Further details of the AIMS hardware are provided in Appendix B.) The AIMS was then deployed to perform measurements at each of the 20 sites and left to gather data for a period of time ranging from a few hours to a few days.

To provide an objective measure of band utilisation, a Relative Time & Frequency Utilisation (RTFU) metric was developed. This is discussed further in Section 3.1 below.

3.1 RTFU METRIC

Previous work based on modelling (see the [Spectrum Percentage Occupancy Study]) used an occupancy metric that determined what constituted 100% occupancy of a radio channel in an area and then referenced other results to that reference point. The same approach is not immediately transferable to the current AIMS measurements as each set of measurements relate to a very specific location (and a limited area round about) rather than the more extensive areas considered in the previous modelling[1]. Nonetheless, it is possible to gauge some measure of spectrum use around the measurement location without necessarily being able to determine whether a particular frequency band is full. In order to achieve this in an objective fashion, a utilisation (as opposed to occupancy) metric has been used.

The ITU-R SM.1046-1 specification defines a Spectrum Utilisation Efficiency (SUE) as:

$$SUE = \frac{Information}{Bandwidth \cdot Space \cdot Time}$$

This may be compared to a standard reference SUE to provide a relative spectrum efficiency (RSE) thus:

$$RSE = \frac{SUE}{SUE_{\text{Standard}}}$$

This approach is modified slightly to make it more suitable for use across the LE bands. A Relative Time Utilisation (RTU) metric is calculated by combining the cumulative distribution functions (CDFs) of all iterations[2] within a channel and measures the probability of exceeding an adaptive noise threshold (see subsequent paragraphs for an explanation of this term). By combining CDFs across all iterations *and* all channels in a band, a Relative Time & Frequency Utilisation (RTFU) metric can be derived.

Of critical importance to the utility of this metric is the estimation of an exceedance threshold. In practice, a fixed threshold does not give a meaningful result, because the environmental noise across different sites and bands is too variable. So, for each band the minimum received power is assumed to represent the noise floor. An additional 3dB is added to this to give the overall RTFU threshold which is then applied to the band to find the proportion of time and frequency above the threshold. This number is expressed as a percentage of the total time / frequency.

A disadvantage of this method is that it is not always possible to measure the true environmental noise floor, for example when the band is fully utilised. In these cases, the RTFU will show a value close to 0%, when the true value is 100%. In practice, these cases occur rarely (the algorithm only has to have a single ‘look-through’ to the noise floor, either in

[1] The nearest equivalent would be to repeat the measurements across a grid of points covering a much wider area and then aggregate the results to obtain a measure of occupancy.

[2] An iteration is the fundamental AIMS data unit, representing the shortest time slice of AIMS data.

time or in frequency, to return an accurate value), are fairly easy to identify and so can be manually adjusted if required.

Note that the total power of an emission is not important for the RTFU, except that it must be above the threshold. If power above the threshold is received in a particular time / frequency slice, then that slice is deemed to be utilised.

An example is provided in Figure 4. This figure shows a band comprising 10 measurement channels, 3 of which are continuously active throughout the measurement period. Therefore the RTFU is 30%. If the activity on all channels stopped halfway through the measurement period then the RTFU would be 15%.

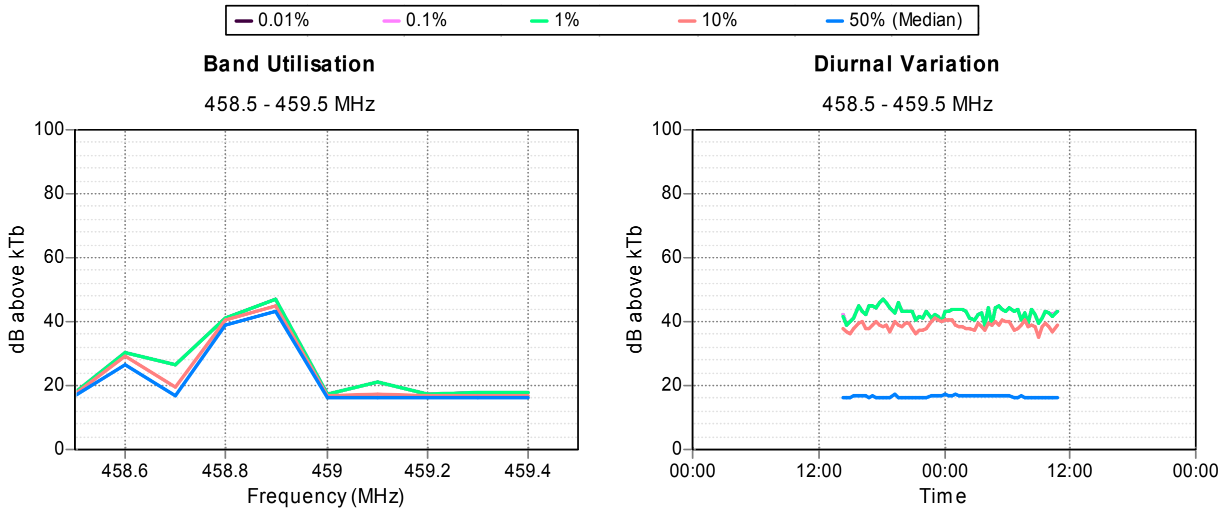


Figure 4. RTFU estimation example

Figure 4 shows two types of analysis plot generated by AIMS, the Band Utilisation Plot (BUP) and the Band Diurnal Variation (BDV) plot. The features of these plots are explained in the box below with full details provided in Appendix A.

Band Utilisation Plot (BUP)

The BUP shows the variation of the measured power across the entire band as a function of frequency. Five traces show the spectral utilisation at different probability levels in time. The coloured lines show the signal power level that is exceeded for the specified proportion of *time* (Blue = 50%; Red = 10%; Green = 1%; Magenta = 0.1%; Black = 0.01%). The degree of temporal activity can be gauged by considering which curves are *raised*. For example, if the 10% line remains at the noise level but the 1% line is lifted, then the proportion of the time over which this signal is active must lie between 1% and 10%.

Band Diurnal Variation (BDV)

The BDV plot shows the variation of the measured power across the entire band as a function of time. Five traces show the temporal utilisation at different probability levels in frequency. The different curves show the signal power level that is exceeded for the specified proportion of *frequency* (Blue = 50%; Red = 10%; Green = 1%; Magenta = 0.1%; Black = 0.01%).

4 MEASUREMENT RESULTS

Band utilisation, expressed in terms of the RTFU metric (see Section 3.1) is provided in Section 4.1. This is followed, in Section 4.2, by a discussion of features of interest in each of the LE bands. Section 4.3 compares current measurements of the 2.4GHz band with those from the earlier [2.4 GHz Study], conducted by MASS in 2003.

4.1 BAND UTILISATION

By compiling RTFU figures for each band at each site, it is possible to display a graph of band versus RTFU for the entire measurement campaign. Figure 5 shows the mean RTFU of all sites as a red line, with the minimum and maximum limits represented by the grey box. This gives an estimate of LE band utilisation across all 20 sites.

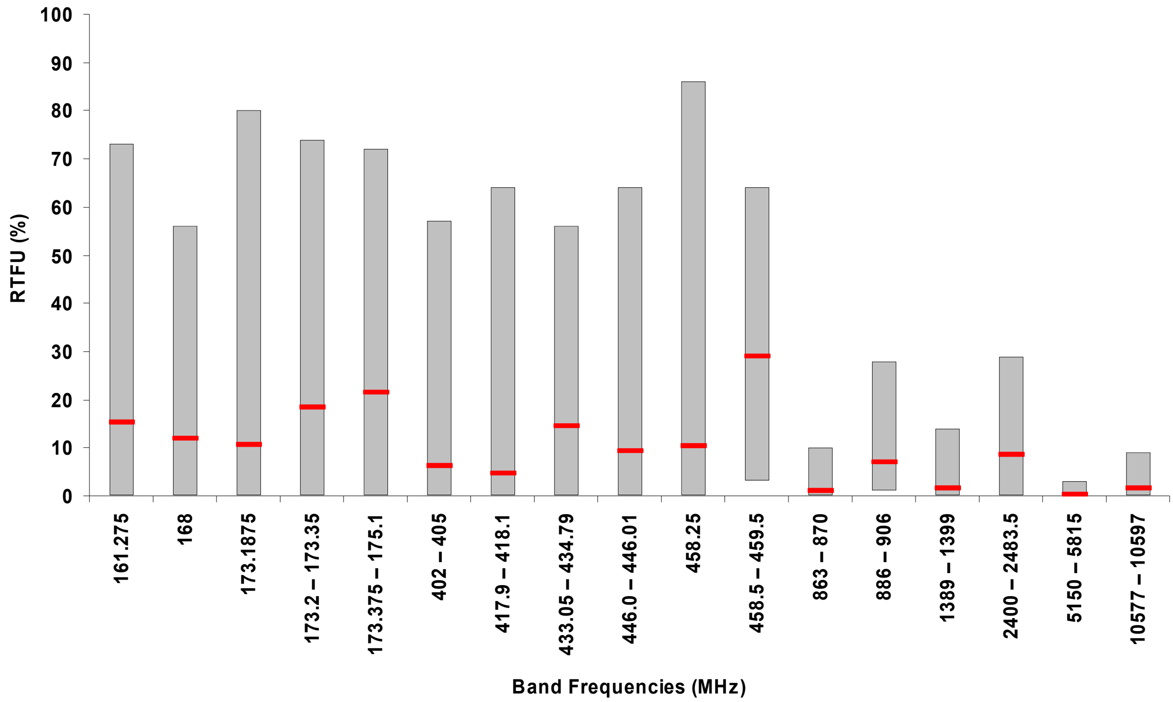


Figure 5. LE band utilisation averaged across all sites.

The following observations are made concerning this result:

- Overall, utilisation is low. The highest RTFU figure, showing a mean of 29% across all measurement sites, was for the 458.5 MHz industrial telemetry band. Applications in use here include Electronic Point Of Sale (EPOS) systems, security, data-loggers, environmental monitoring, automated meter reading (AMR) and automotive electronics;

- The second and third most utilised bands are also allocated to industrial telemetry, in the 173 MHz region of the spectrum. It is therefore likely that these industrial services are the heaviest users of the LE bands;

- The RTFU metric includes the effects of interference in the utilisation figure. This may not always be appropriate, for example if the equipment using the band is not susceptible to the interference. Therefore Figure 6 shows the RTFU for the campaign with the effects of interference removed[3];

- It is notable that the mean RTFU for the 2.4 GHz band is only 10%. In one sense this is surprising given the prevalence of WLAN and other devices that are known to make use of this band. On the other hand, the propagation in the microwave frequencies leads to much more localised utilisation. This result is also consistent with the [2.4 GHz Study] results of 2003, which found that this band was not heavily utilised;

- Almost no utilisation was detected in the 5 GHz and 10 GHz bands. This is consistent with the propagation behaviour at these frequencies and in any event it is known that 5 GHz WLANs are only just coming to market;

- There is considerable variation of RTFU across sites. Many bands show very high utilisation at some sites. This is especially the case for sites that exhibit significant levels of interference, as may be verified by comparing Figure 5 and Figure 6. Nearly all bands show zero utilisation at some sites.

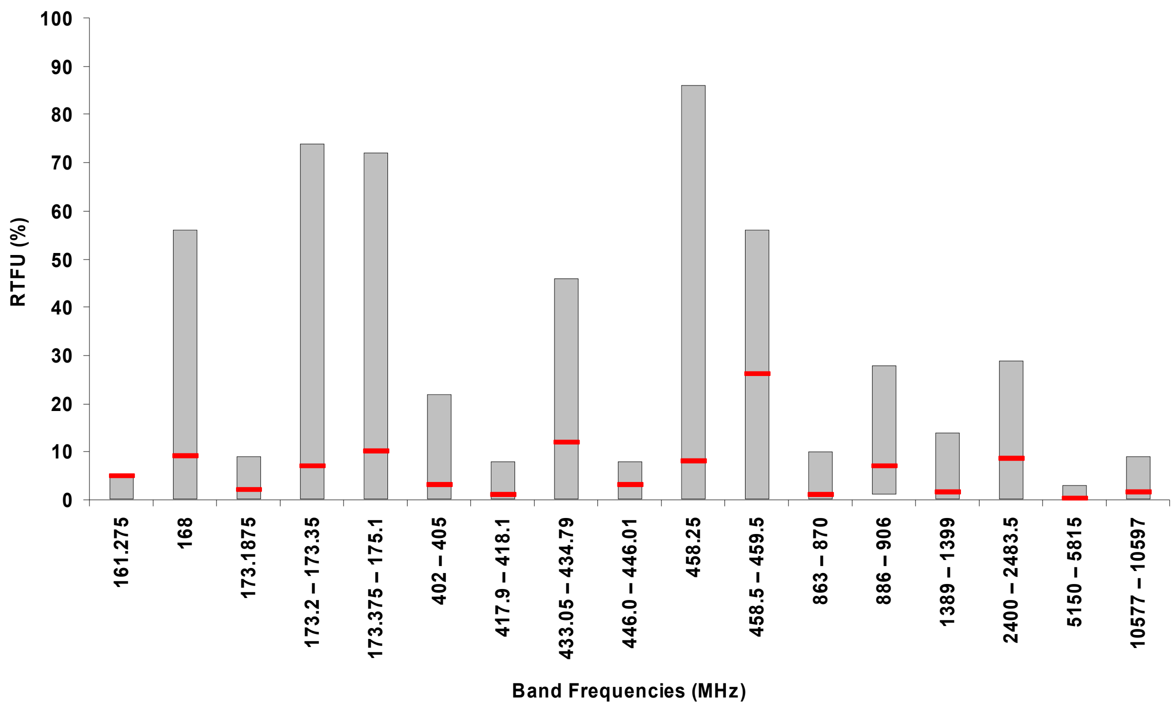


Figure 6. LE band utilisation averaged across all sites (effects of interference removed).

[3] Interference was detected by manually analysing the data and looking for consistent patterns of activity across multiple bands. Measurements displaying interference characteristics were then removed from the analysis.

Figure 7 and Figure 8 show the LE band utilisation results sorted by mean RTFU to enable easy comparison across bands.

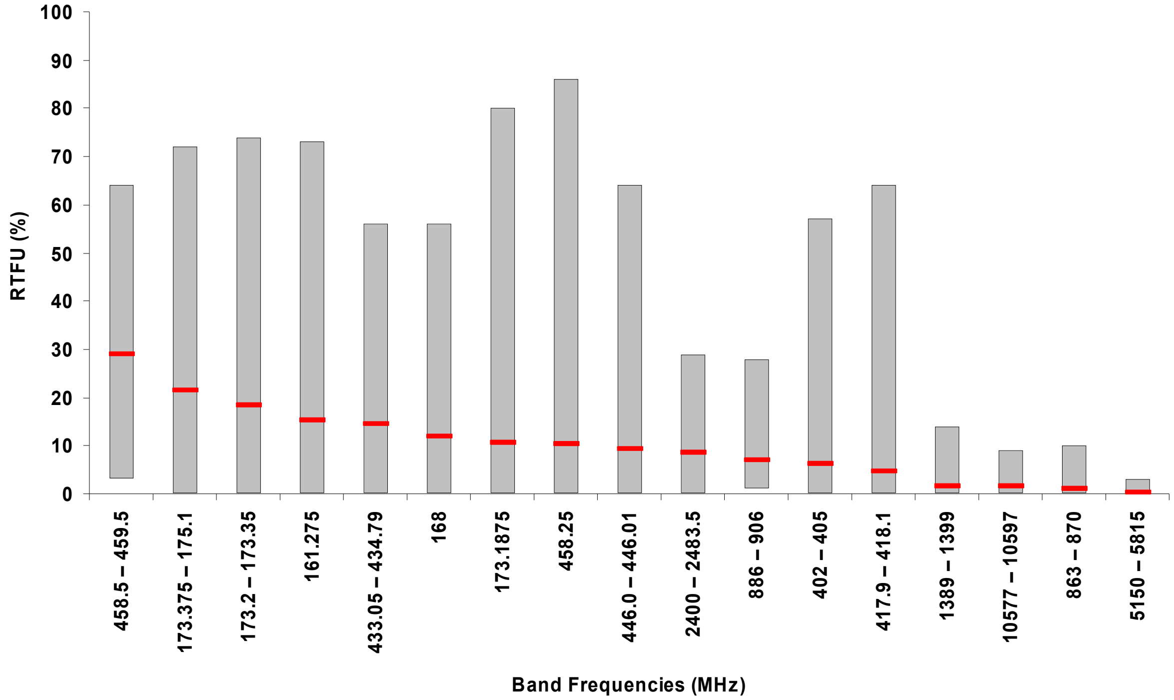


Figure 7. LE band utilisation averaged across all sites, sorted by mean RTFU.

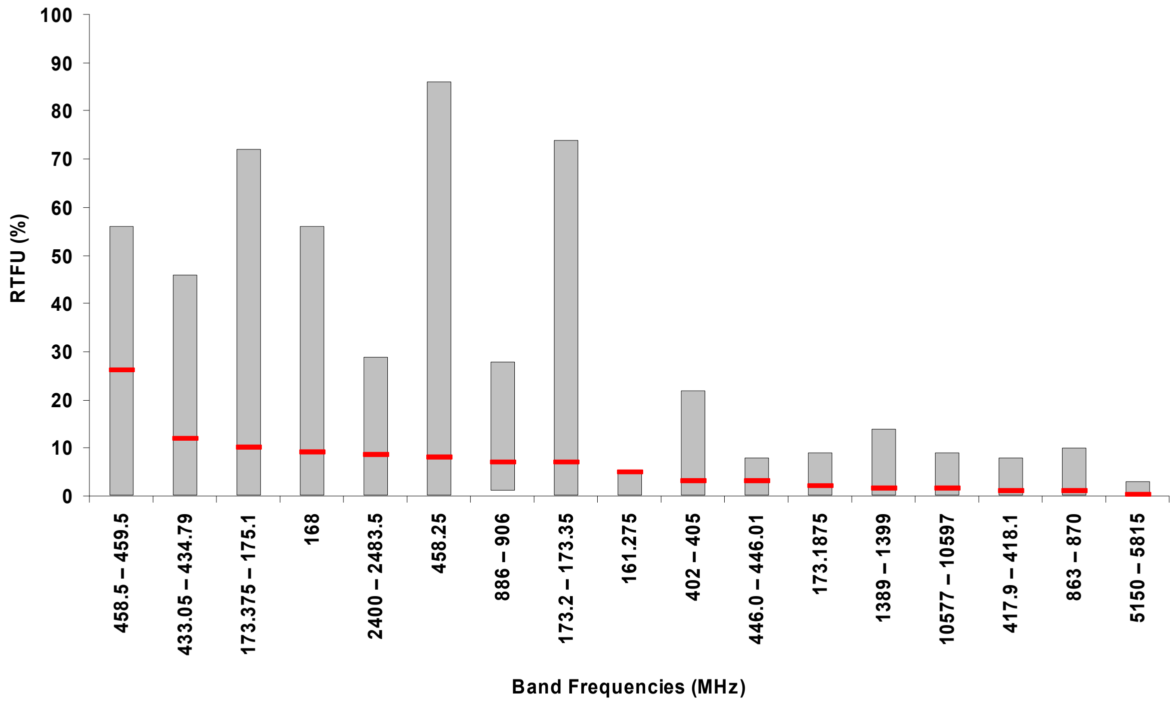


Figure 8. LE band utilisation averaged across all sites, sorted by mean RTFU (effects of interference removed).

4.2 BAND FEATURES

Features of interest within each of the LE bands are discussed in sections 4.2.1 to 4.2.17 below.

4.2.1 161 MHz Band

Services : General Alarms Associated with Marine Applications

Number of Channels : 1

RTFU : Including interference – 15%
Excluding interference – 5%

Discussion : Comparison of this band across the different measurement sites reveals that most of the 15% utilisation is attributable to varying levels of environmental noise / interference rather than carrier signals. Figure 9 shows an example of how the environmental noise floor can vary with time. In this case, the environmental noise floor is measured at its minimum to be approximately 10dB above kTB, whilst at the maximum it reaches 20dB above kTB.

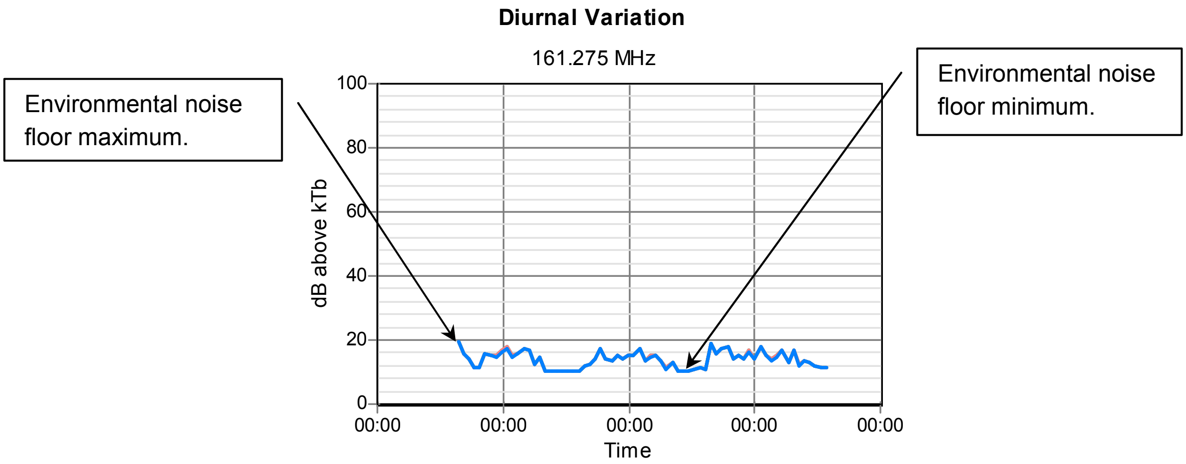


Figure 9. Time-varying environmental noise floor.

This particular example of a time-varying environmental noise floor is particularly interesting. It clearly shows a daylight noise floor some 5 – 10dB below that for hours of darkness. This probably indicates a faulty fluorescent light bulb nearby and is a common operational problem for Ofcom field support teams. This type of noise can cause problems up into the microwave bands and, in the case of the emission described by Figure 9, it is clearly visible up to 1.4 GHz.

Environmental Noise Floor

It is important to distinguish between noise and carrier signal for the purpose of assessing band utilisation. In this study, noise, whether owing to the measurement system or the environment, is defined as a continuous Gaussian distributed power level.

4.2.2 168 MHz Band

Services : ISM

Number of Channels : 1

RTFU : Including interference **–** 12%
Excluding interference **–** 9%

Discussion : Activity measured in the 168 MHz band can be broadly categorised into 4 different patterns, as follows:

1. Continuous Gaussian noise at the same level as adjacent bands, implying that the band is empty;

2. Continuous Gaussian noise at a much higher level than adjacent bands, implying a wideband or Gaussian signal operating on, or close to, the frequency;

3. Continuous Rician emission, implying a narrowband signal operating at, or close to, the frequency;

4. Burst Rician signals of various types, implying that the band is partially utilised.

Most sites exhibit signal type 2, implying a wideband continuous transmission. This activity is most probably not related to the band allocation as the maximum bandwidth allowed under the Ofcom licence exemption is 16 kHz.

4.2.3 173.1875 MHz Band

Services : Alarms: Mobile and Transportable

Number of Channels : 1

RTFU : Including interference **–** 11%
Excluding interference **–** 2%

Discussion : Inspection of the site reports for this band reveal that carrier activity is only detected briefly at site 24 (Moto Services, M18). The other sites that display significant activity are dominated by impulsive man-made noise, probably from faulty fluorescent light bulbs and similar sources of impulsive noise.

4.2.4 173.2 – 173.35 MHz Band

Services : Telemetry and Telecommand: General/Industrial/Commercial, Alarms : Fixed

Number of Channels : 7

RTFU : Including interference – 18%
Excluding interference – 7%

Discussion : Telemetry-type activity is detected at 8 of the 20 sites (for example see Figure 10) and broadband impulsive noise at 7 sites. The telemetry-type activity is generally loud and high duty cycle, operating on and off throughout the day and night.

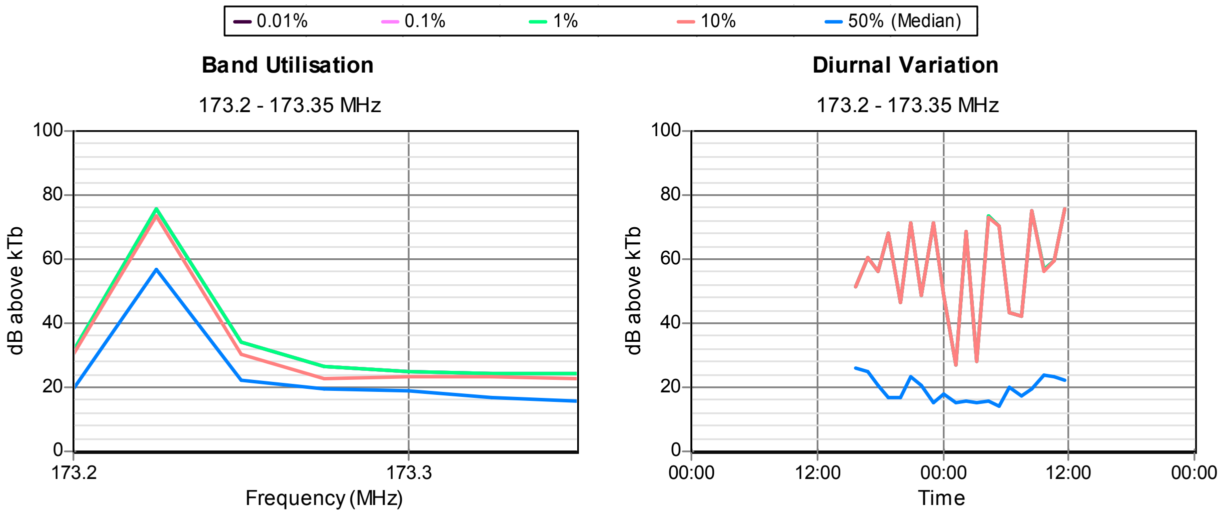


Figure 10 Typical 173.2 – 173.35 MHz band level plots.

4.2.5 173.375 – 175.1 MHz Band

Services : Radio Hearing Aids, Telemetry and Telecommand: General, Medical and Biological Apps, Radio Microphones

Number of Channels : 18

RTFU : Including interference – 22%
Excluding interference – 10%

Discussion : The most common carrier emission in this band appears to be the continuous Rician signal on channel 17. This appears at 5 sites (for example see Figure 11). This FM-type emission could be due to any of the allocated device types, although it is thought not to be telemetry since telemetry equipment in other bands has shown a more structured temporal signature. Wideband noise is detected at 7 sites.

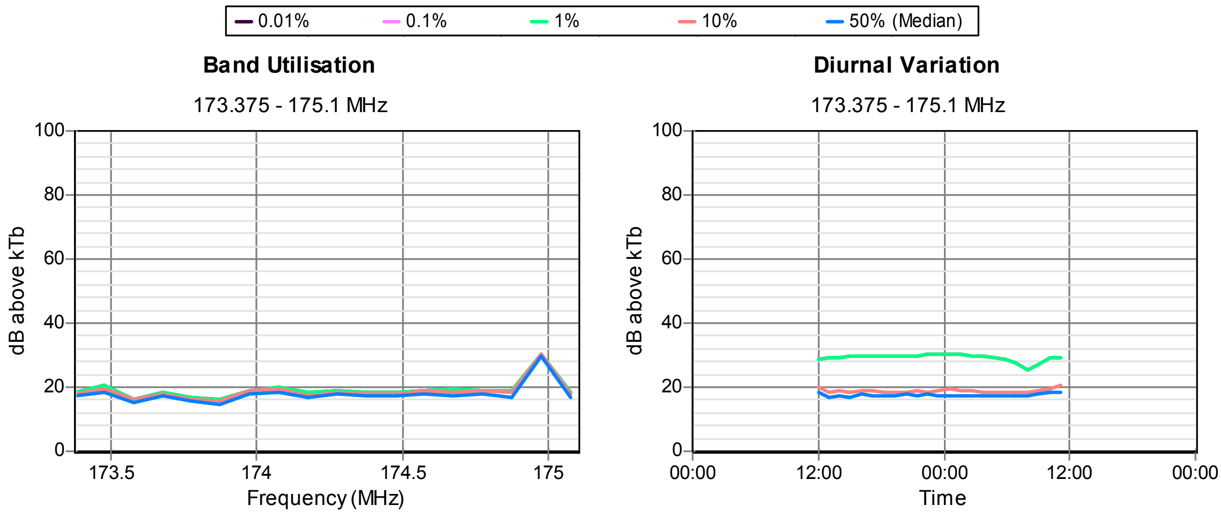


Figure 11. Typical 173.375 – 175.1 MHz band level plots.

4.2.6 402 – 405 MHz Band

Services : Wireless applications in healthcare (including ultra low power medical implants).

Number of Channels : 30

RTFU : Including interference – 6%
Excluding interference – 3%

Discussion : Narrowband continuous and burst transmissions are extremely common in this band. Whilst only detected at very low powers, signals of this type are present nevertheless at half the sites measured (see for example Figure 12). The mix of both continuous and burst emissions implies some fixed installations as well as the mobile devices used in body wearable medical applications. Impulsive noise activity is present at 4 sites.

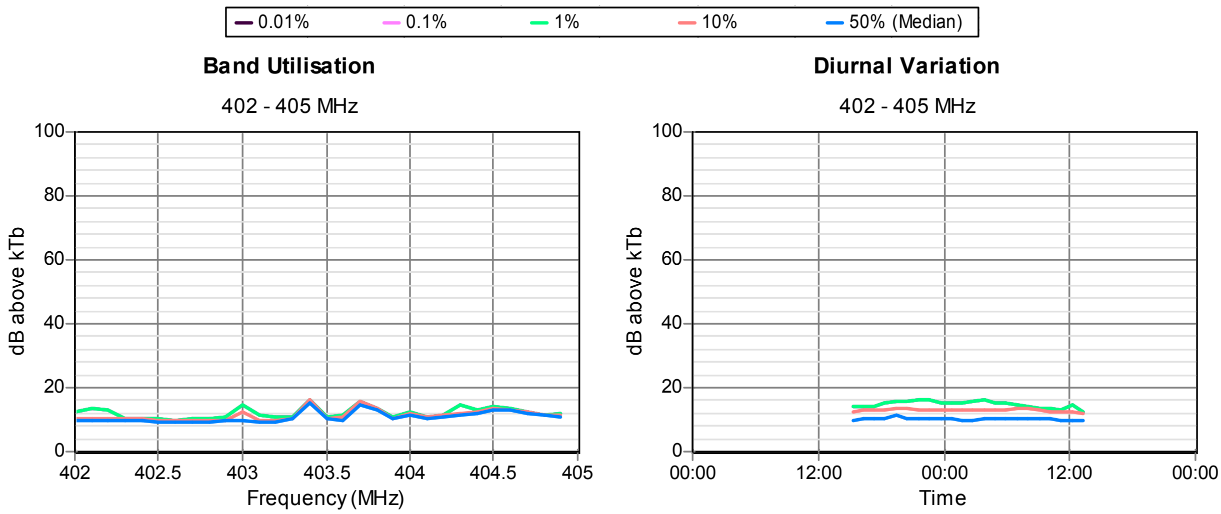


Figure 12. Typical 402 – 405 MHz band level plots.

4.2.7 417.9 – 418.1 MHz Band

Services : Telemetry and Telecommand: General

Number of Channels : 9

RTFU : Including interference – 5%
Excluding interference – 1%

Discussion : Similar narrowband utilisation is detected at 6 sites. Mostly the activity is very faint and infrequent which leads to the low RTFU value of 5%. A particularly loud example is given in Figure 13. Wideband noise is seen at 3 sites.

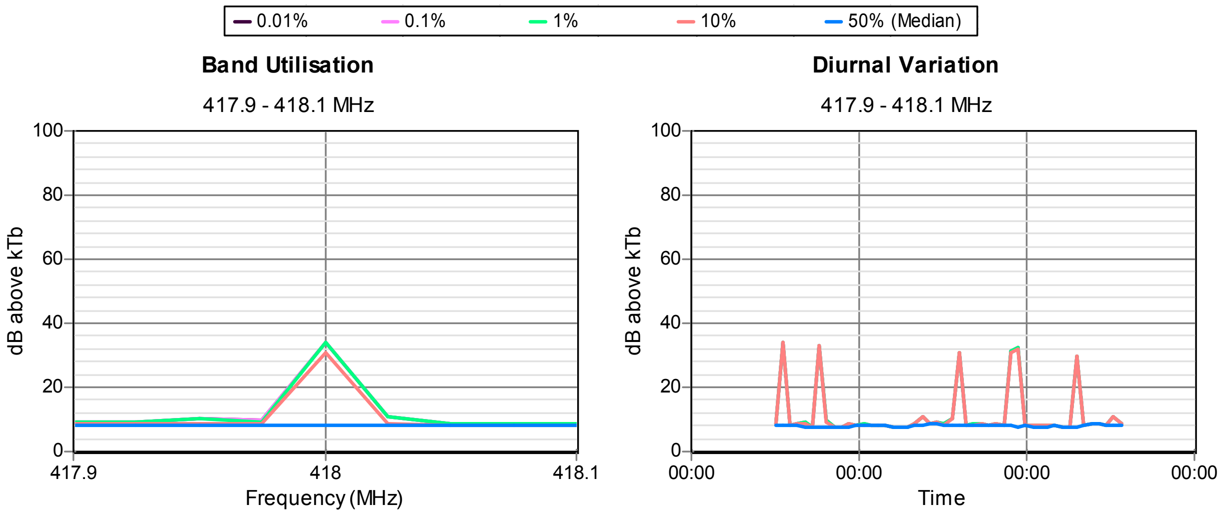


Figure 13. Typical 417.9 – 418.1 MHz band level plots.

4.2.8 433.05 – 434.79 MHz Band

Services : Non-specific, Model control

Number of Channels : 18

RTFU : Including interference – 15%
Excluding interference – 12%

Discussion : This band is often used for devices such as car key alarms and other common short-range devices (SRDs), therefore the fact that activity in this band was detected at most sites is not surprising. The activity tends to be narrowband and bursty, although continuous and broadband transmissions are detected at some sites. A typical example of the activity is given in Figure 14. These plots describe activity at a motorway service station, hence many wireless key fobs would have been in use. Consistent with this conjecture, the activity was lowest during the night.

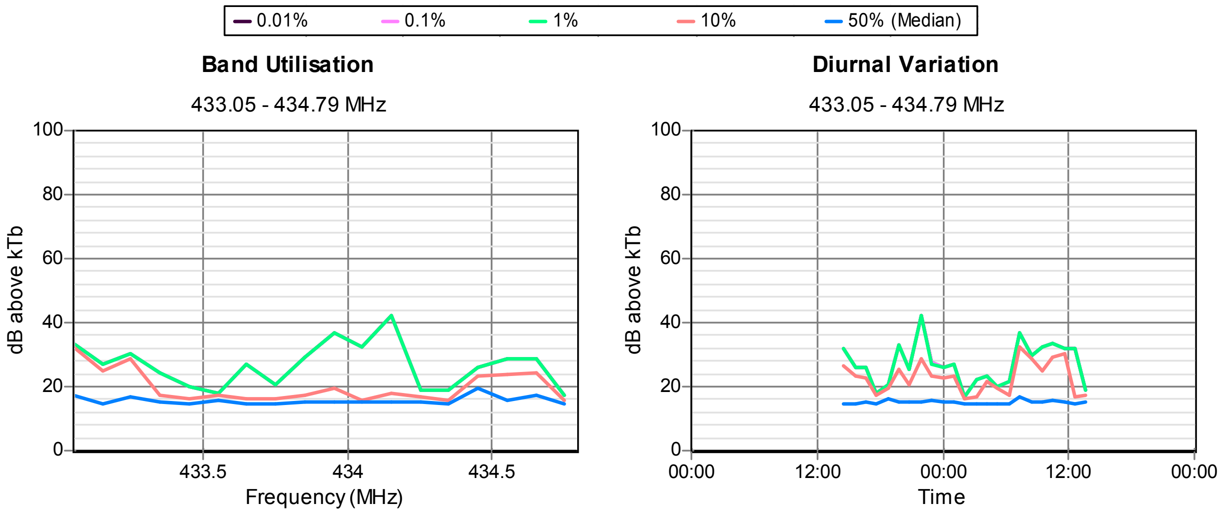


Figure 14. Typical 433.05 – 434.79 MHz band level plots.

4.2.9 446 MHz Band

Services : PMR

Number of Channels : 4

RTFU : Including interference – 9%
Excluding interference – 3%

Discussion : Some very occasional activity was detected at 7 sites. A typical example of the utilisation plots is given in Figure 15, which shows how rare the usage is. This is reflected in the low RTFU value for the site.

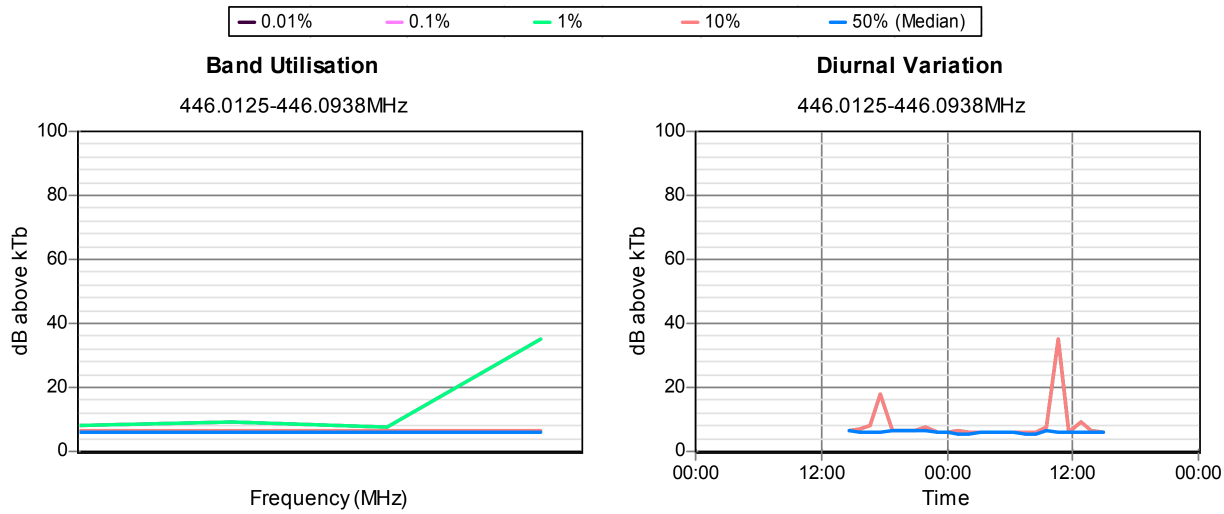


Figure 15. Typical 458.25 MHz band level plots.

4.2.10 458.25 MHz Band

Services : Alarms: Fixed

Number of Channels : 1

RTFU : Including interference – 10%
Excluding interference – 8%

Discussion : Continuous narrowband carrier activity is found at the two motorway service station sites (see for example Figure 16). The carrier power may be seen to vary slightly with time. The reason for this is not known. All other sites show no carrier utilisation, but some impulsive man-made noise is detected, probably owing to a faulty fluorescent light bulb.

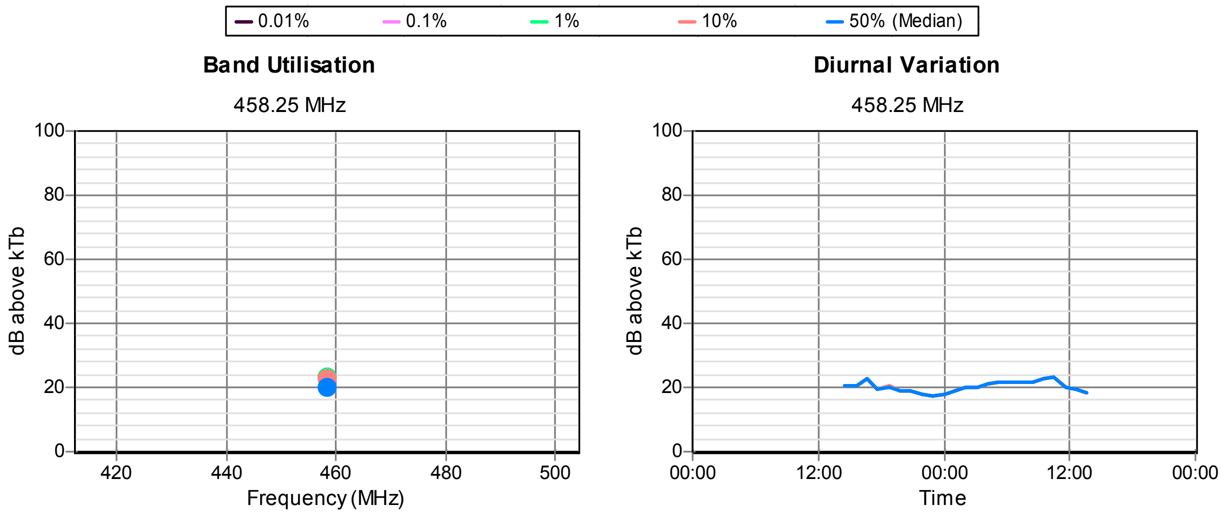


Figure 16. Typical 458.25 MHz band level plots.

4.2.11 458.5 – 459.5 MHz Band

Services : Alarms: Mobile and Transportable/Vehicle Paging, Medical and Biological Applications, Model Control, Telemetry and Telecommand: Industrial/Commercial

Number of Channels : 10

RTFU : Including interference – 29%
Excluding interference – 26%

Discussion : Loud transmissions were received at most sites, with both narrowband continuous and burst activity detected (see for example Figure 17). This activity is attributed to industrial telemetry devices, as it is known that a large number of these devices are available on the market at low cost for applications such as Electronic Point-of-Sale (EPOS), security, data-loggers, environmental monitoring, Automatic Meter Reading (AMR) and automotive electronics.

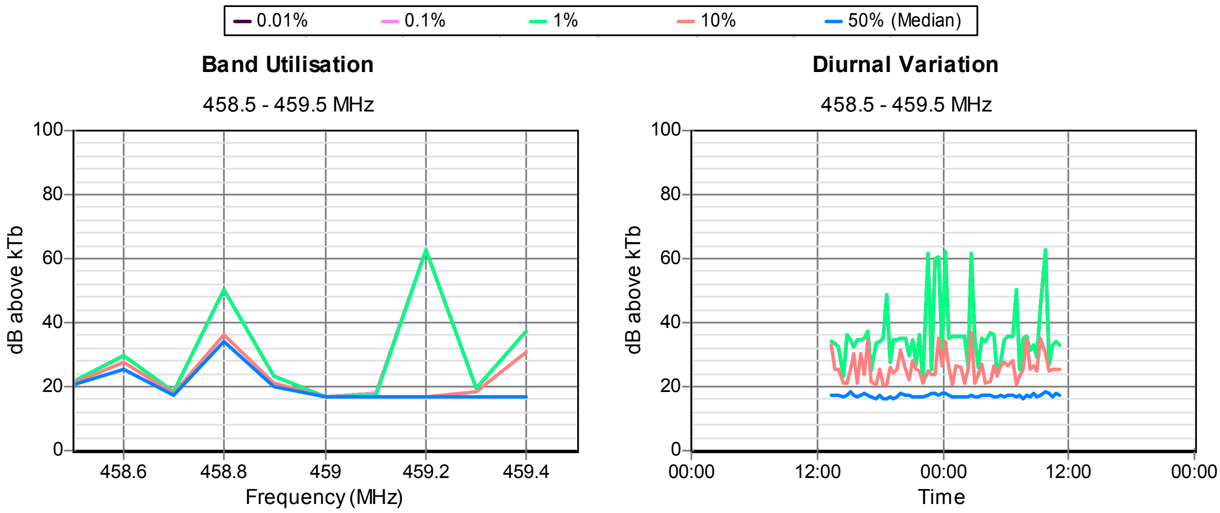


Figure 17. Typical 458.5 – 459.5 MHz band level plots.

4.2.12 863 – 870 MHz Band

Services : Alarms (including social alarms), Non-specific, RFID, Wireless Audio (including narrowband analogue voice)

Number of Channels : 70

RTFU : Including interference – 1%
Excluding interference – 1%

Discussion : Most sites exhibit some utilisation in this band, which tends to be narrowband, either continuous or bursty. A relatively close-range example is given in Figure 18 for a motorway service station, which shows significant activity during the daytime, falling off during the night. Car key alarms are one likely source of this activity, although continuous services, which have been measured at other sites, are more likely to be fixed installations of some sort. No impulsive noise was detected in this band, implying that propagation effects are causing interference to be more localised.

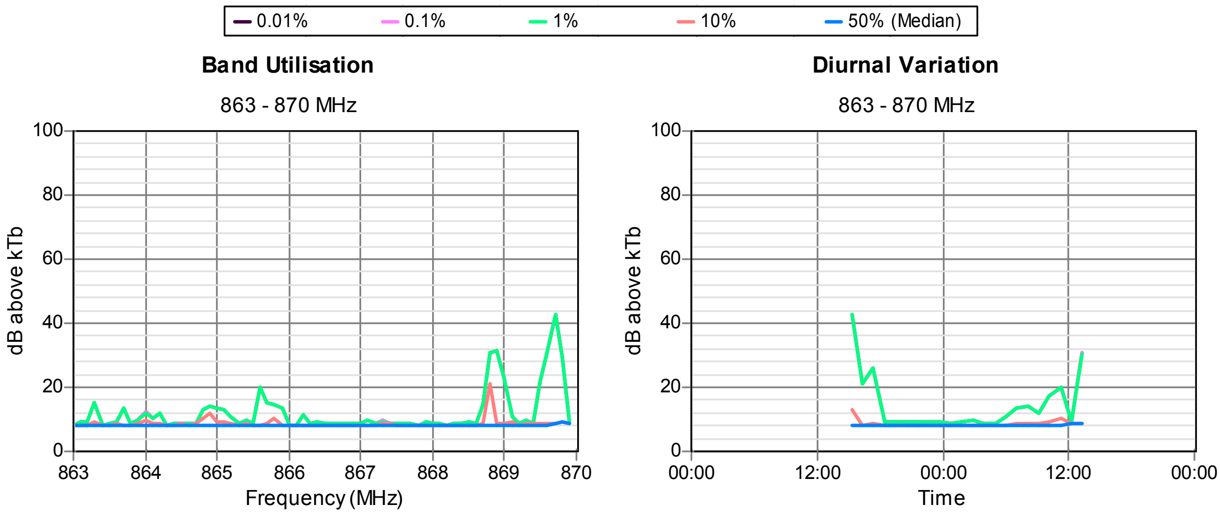


Figure 18. Typical 863 – 870 MHz band level plots.

4.2.13 886 – 906 MHz Band

Services : ISM (RF Heating Apparatus)

Number of Channels : 200

RTFU : Including interference – 7%
Excluding interference – 7%

Discussion : Every site displays significant activity due to RF heating apparatus, i.e. industrial microwave ovens (for example see Figure 19). The common features of these emissions include the high power, which is common to all sites despite the propagation behaviour at these frequencies, the line spectrum common to pulsed signals and the diurnal variation, which is high throughout the day and tends to reduce significantly during the night.

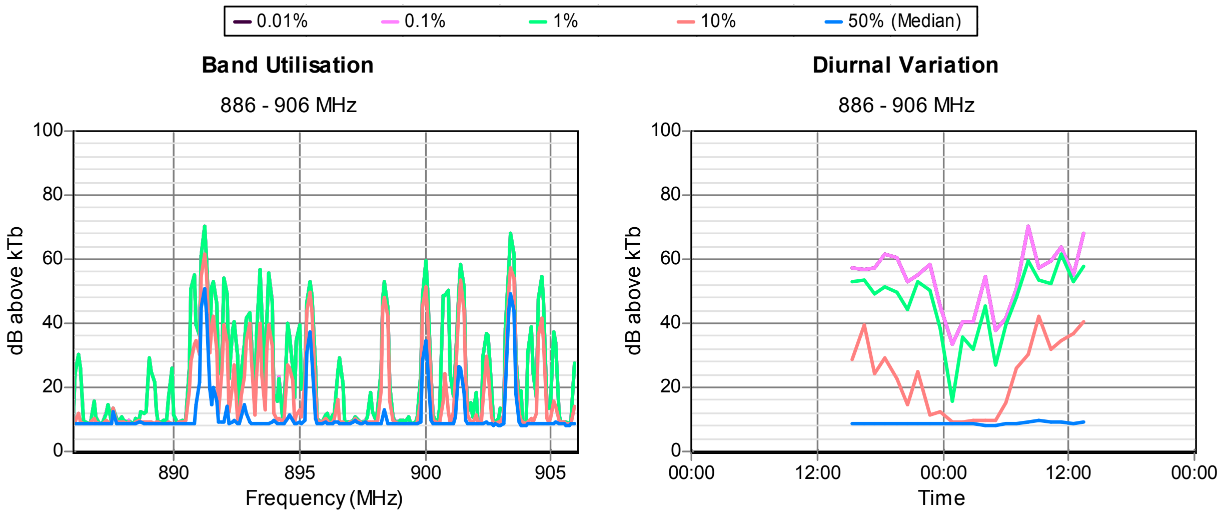


Figure 19. Typical 886 – 906 MHz band level plots.

The pulsed nature of these emissions, described more clearly by the Amplitude Probability Distribution (APD) (Figure 20), leads to an RTFU of only 7% because of the clear time between pulses.

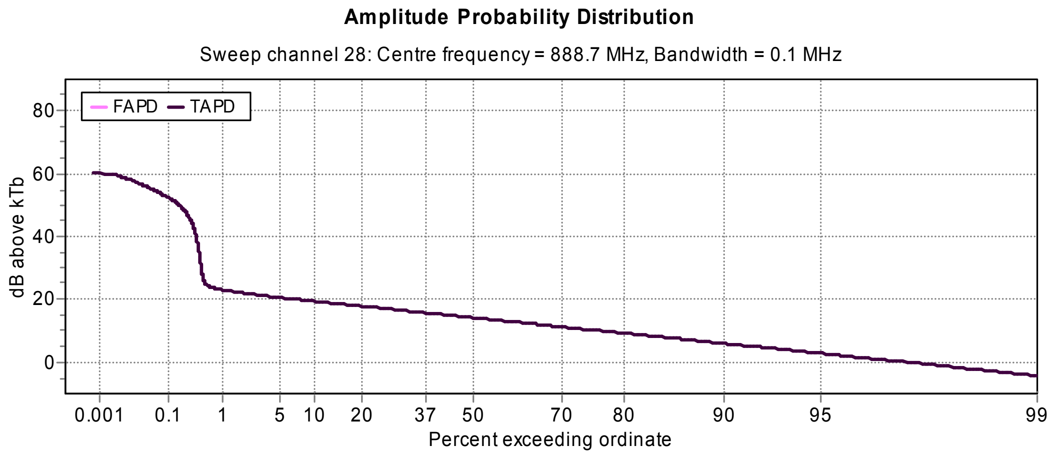


Figure 20. Typical 886 – 906 MHz band APD.

Readers unfamiliar with the APD plot are referred to Appendix A.

4.2.14 1389 – 1399 MHz Band

Services : Wireless video distribution for private use

Number of Channels : 101

RTFU : Including interference – 1%
Excluding interference – 1%

Discussion : 5 sites show very faint but nonetheless detectable signals of a type consistent with the band allocation. These narrowband and continuous emissions are typified by Figure 21, although one site did reveal a broadband continuous emission (Figure 22). The narrow bandwidth of most emissions accounts for the very low RTFU in this band.

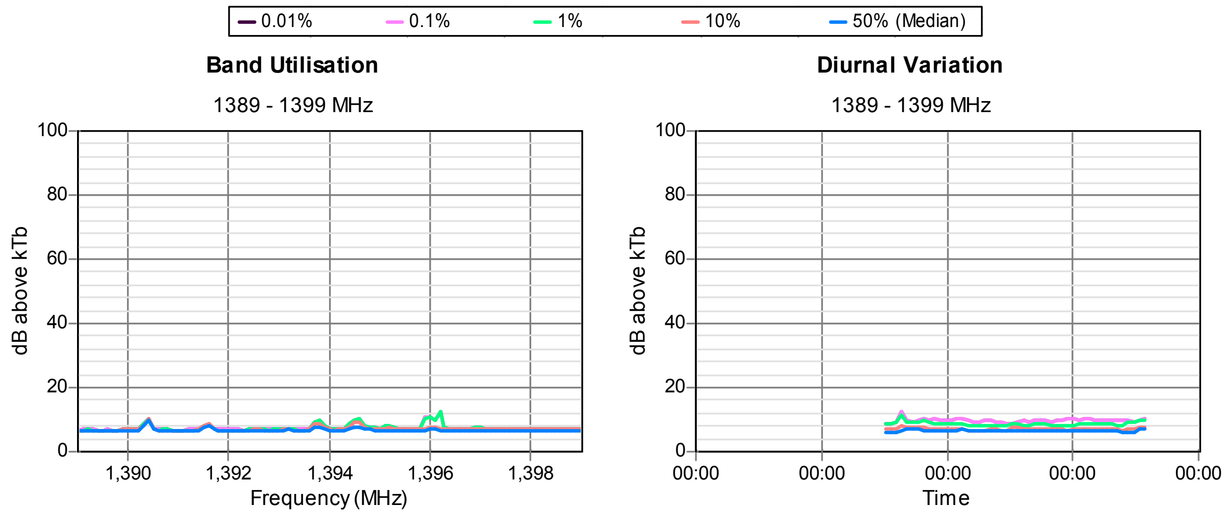


Figure 21. Typical 1389 – 1399 MHz band level plots.

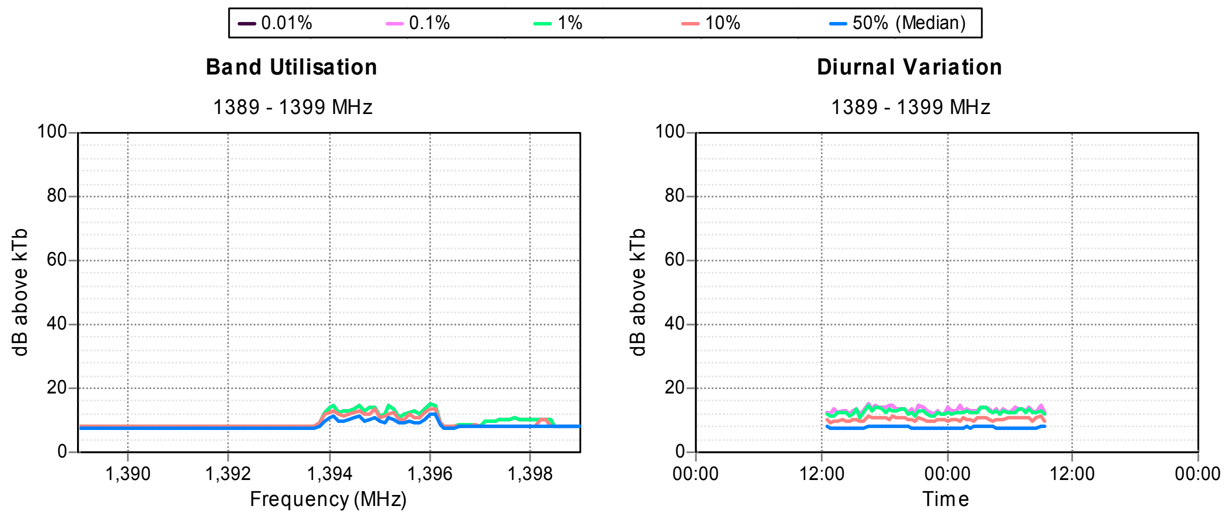


Figure 22. 1389 – 1399 MHz band broadband emission.

The Wraysbury site, near to Heathrow airport, reveals the presence of a radar-type emission operating at 1.396 GHz (Figure 23). This may be operating in a licensed band that overlaps the LE allocation, possibly a Fixed / Mobile military band.

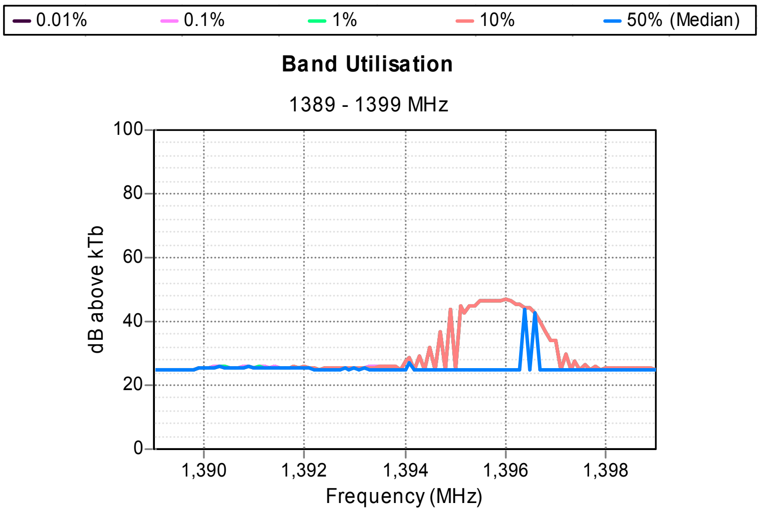


Figure 23. 1389 – 1399 MHz BUP showing radar type emission.

The APD (Figure 24) shows that the peak power exceeds 80dB above kTB.

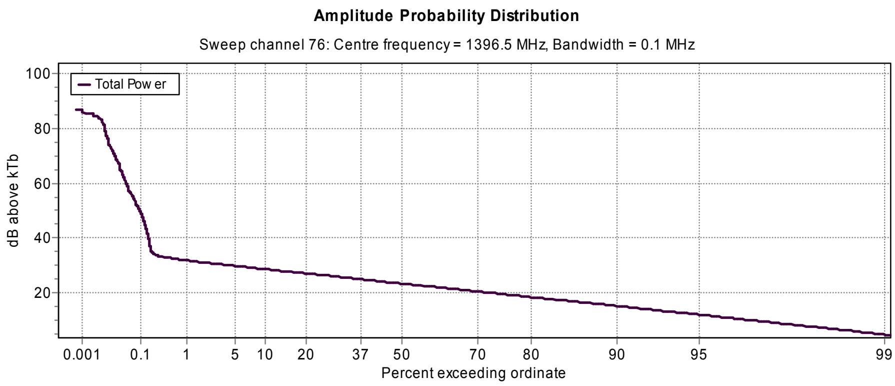


Figure 24. 1389 – 1399 MHz APD showing radar type emission.

4.2.15 2400 – 2483 MHz Band

Services : ISM (Non Specific), Wideband data/RLANs, Cordless Audio Equipment, Wireless Video Cameras (Non Broadcasting), Movement detection, Equipment for the Detection of Movement or Alert, Short Range Indoor Data Links, Telemetry and Telecommand: Industrial/Commercial, RFID, Automatic vehicle ID for railways

Number of Channels : 84

RTFU : Including interference – 9%

Excluding interference – 9%

Discussion : RLAN activity is detected at 7 sites and microwave oven activity at 4 sites. Some other narrowband transmissions are also occasionally detected, especially continuous signals associated with movement detection devices. An example of a site exhibiting both RLAN and microwave activity together is given in Figure 25. Despite reaching the median level in time, RLAN activity is still very bursty and significant clear time between packets combines with a general dearth of activity to give a RTFU of 9%. This is somewhat surprising given the abundance of 2.4 GHz devices on the market and may imply that the propagation behaviour at these frequencies is helping to localise the hotspots of RLAN activity. Nearly a quarter of all sites visited exhibited no measurable activity whatsoever.

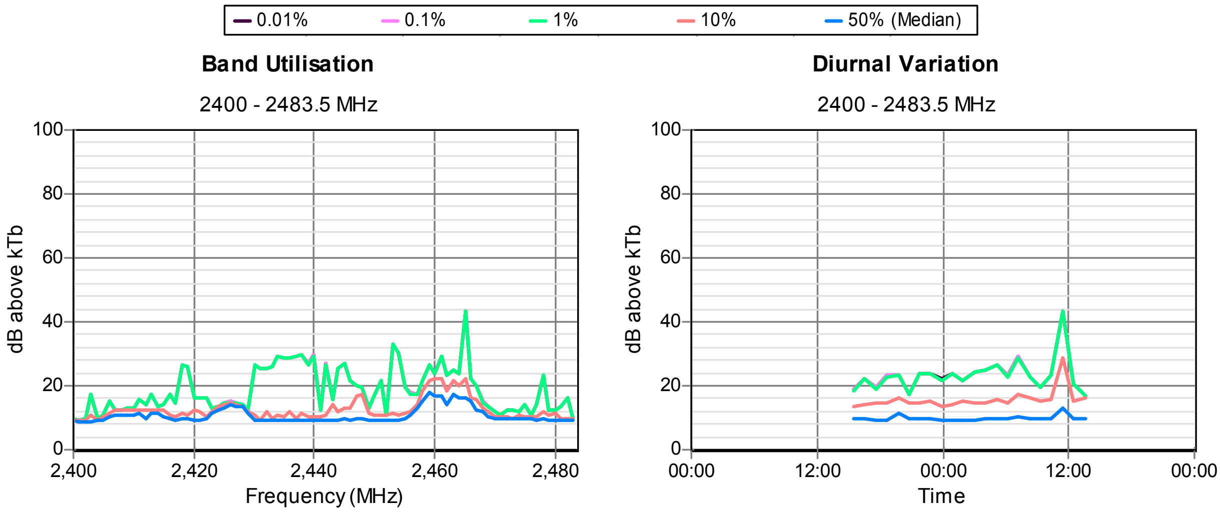


Figure 25. Typical 2400 – 2483 MHz band level plots.

4.2.16 5150 – 5815 MHz Band

Services : ISM (Non Specific), Wideband data/RLANs, Equipment for the Detection of Movement or Alert, Short Range Indoor Data Links, Wireless Video Cameras (Non Broadcasting), Road transport and traffic telematics

Number of Channels : 222

RTFU : Including interference – 0%

Excluding interference – 0%

Discussion : Virtually no activity was detected in this band at any site. Some very faint transmissions were occasionally visible but nothing of any significance was evident.

Most of this band has only recently been made available. RLANs, for which use of most of the band is intended, have hardly reached the market at the time of this report.

4.2.17 10577 – 10597 MHz Band

Services : Equipment for the Detection of Movement or Alert

Number of Channels : 21

RTFU : Including interference – 1%

Excluding interference – 1%

Discussion : Only three sites exhibited any activity in this band, as may be expected owing to the propagation behaviour at these frequencies. Figure 26 shows the activity detected at site 14, which is faint yet clear. Inspection of the site reports reveals that activity is sometimes present on adjacent channels concurrently rather than simultaneously, as if the carrier frequency is drifting across the band.

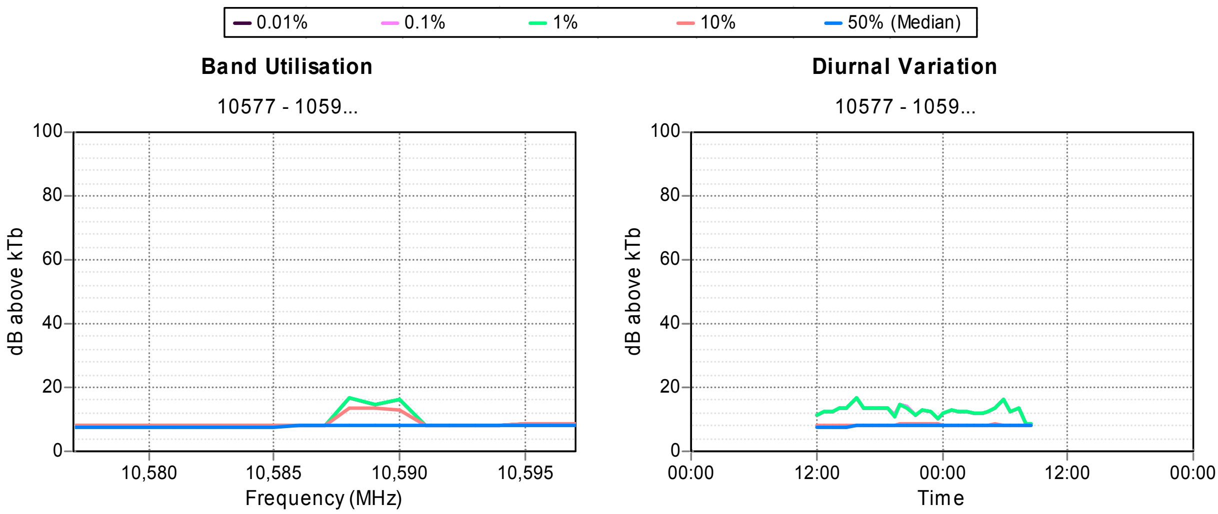


Figure 26. Typical 10577 – 10597 MHz band level plots.

4.3 COMPARISON WITH PREVIOUS MEASUREMENTS

Sites 9 (Ninestiles School), 14 (IET Savoy Place) and 16 (Addenbrookes Hospital) were all used for both the [2.4 GHz Study] in 2003 and the 2006 AIMS LE Study. Each of these sites was located indoors. Comparison between the measurements conducted then and now provides a useful insight into how usage of this band has changed over the last three years. The results may be summarised in terms of RTFU for the two sets of measurements at each site, as shown in Figure 27.

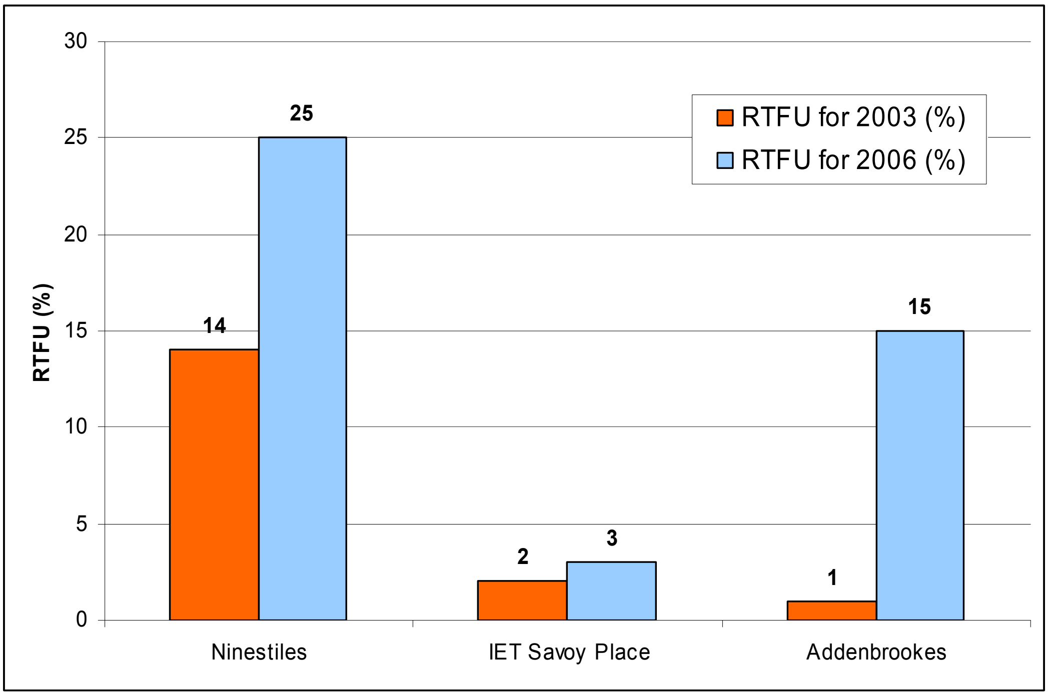


Figure 27. Comparison of RTFU values between 2003 and 2006.

Detailed examination of the individual site data for the two campaigns (sections 4.3.1 to 4.3.3) demonstrates that this increased activity is caused primarily by WLAN systems.

When comparing the measurements, the following differences between the two sets of measurements should be taken into consideration:

- The 2006 measurements covered 17 separate LE bands, including the 2.4 GHz band. The AIMS was set to sweep continuously from 2,400 MHz to 2,484 MHz using a resolution bandwidth of 1 MHz. Because of the need to cover all 17 LE bands, less than 10% of the measurements were concerned with the 2.4 GHz band and consequently data was only available to the 1% probability level;

- In comparison, the 2003 measurements were solely concerned with the 2.4 GHz band. The measurement system was set to sweep continuously from 2,365 MHz to 2,519 MHz using a resolution bandwidth of 1 MHz. Measurements were taken continuously and aggregated over ten minute periods. As this system was designed to monitor just the 2.4 GHz band it was possible for it to accumulate more utilisation data, resulting in smoother plots and estimation at the 0.01% probability level;

- It was not possible for the measurements to be repeated in identical locations within each site because of site operator arrangements. Therefore the closest convenient location to the original was chosen for the repeat measurement. This should be borne in mind when comparing RTFU values.

4.3.1 Site 9 – Ninestiles School

Comparison of the RTFU metric for the two measurements at this site shows a marked increase in the amount of activity between 2003 and 2006, from 14% to 25%. This is attributed to the increased use of WLAN equipment in the school. Further details are provided below.

4.3.1.1 Site Usage Information

Ninestiles School established their WLAN in July 2000. Site usage information was obtained prior to both the 2003 and 2006 measurements, as follows:

2003: The network had 50 access points supporting over 1,000 laptops. An access point can support around 25 laptops. Students used the WLAN for both internet access and to access and store files on a server. The internet connection was limited to 2Mb, which helped to prevent the WLAN network from becoming saturated.

2006: Ninestiles School now has 72 access points with a further 11 being installed. There are 120 wireless desktop PCs, 450 wireless laptops, distributed 10-off in 45 class rooms, and 540 student-owned wireless laptops. The total number of wireless PCs is therefore similar to the 2003 total. The existing wireless network uses 802.11.b. The latest 11 access points use 802.11.g but this facility is not yet enabled. It would be reasonable to expect a higher level of network traffic for the 2006 study, consistent with the increased number of access points.

4.3.1.2 Comparison of Measurement Locations

In 2003, the monitoring equipment was located in the IT support room on the first (top) floor. The nearest access point was in a neighbouring classroom. In 2006, the monitoring equipment was located in the Headmaster's Office on the Ground Floor. The nearest access point was located in a classroom 10-20m away. The two locations are shown in Figure 28.

2003 **2006**

Figure 28. Comparison of 2003 and 2006 measurement locations.

4.3.1.3 Comparison of Band Utilisation Plots

Two utilisation plots are shown in Figure 29. The 2003 plot shows a typical 10-minute period of peak activity. The 2006 plot is aggregated over the complete test (22 hours).

2003 **2006**

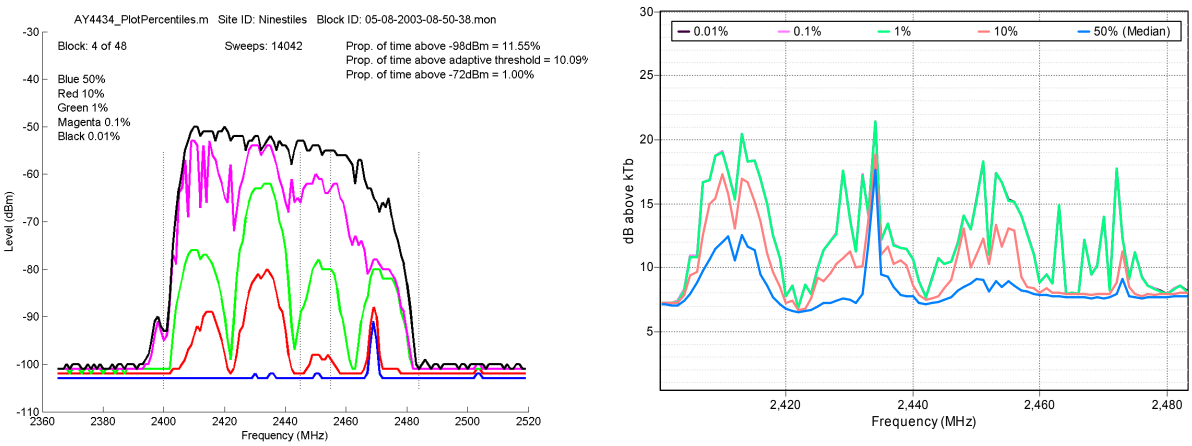


Figure 29. Comparison of Ninestiles school band utilisation.

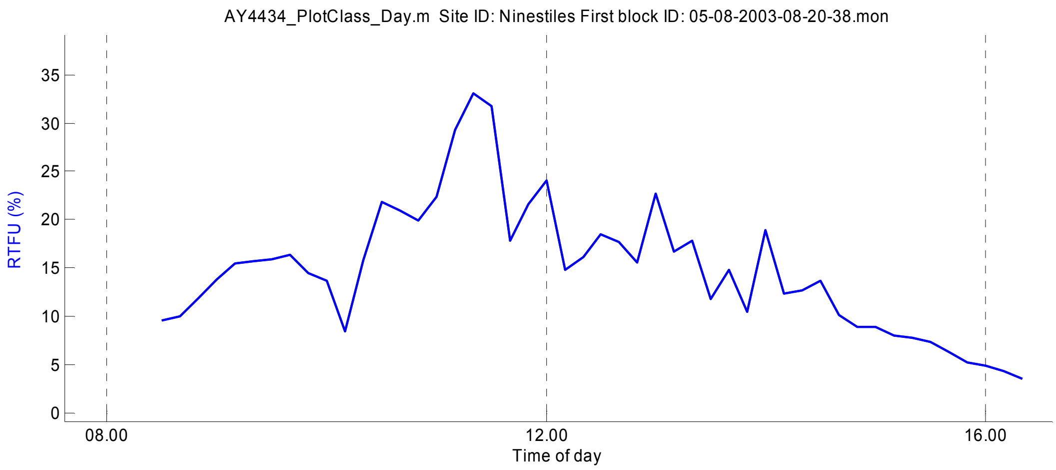
Four channels of WLAN activity can be seen in both plots. The system noise floor for the 2003 measurements is at about 10dB above kTB, compared to 5dB above kTB for the more sensitive 2006 AIMS system. Increased band utilisation and the greater sensitivity of the 2006 system allows the received power to be well defined at the median level, whereas much of the median level power is lost in the system noise in the 2003 plot. At the 10% level, the peaks of the 4 WLAN channels range from 15-33 dB above kTB in 2003 and 11-17 dB in 2006. They are therefore broadly comparable. The higher power measured in 2003, at the 10% level, is mainly due to closer proximity to the access point. With only 30 sweeps of the band during the test, the 2006 plot does not have sufficient measurements to calculate the lower percentiles (0.1% and 0.01%) accurately and so comparison with the 2003 measurements at these levels would be nugatory.

The two plots both show a continuous signal. In 2003, it was centred at 2,470 MHz, whereas in 2006 it was centred at 2,436 MHz. These could be due to video senders or movement detectors.

4.3.1.4 Comparison of Diurnal Variation Plots

The diurnal variation plots for the two studies, Figure 30, are presented differently: the 2003 plot shows the RTFU as a function of time; whereas the 2006 plot shows the received power above kTB for different *spectral* occupancies (see Appendix A). Both plots achieve similar aims and allow the variation of activity with time to be identified.

2003



2006

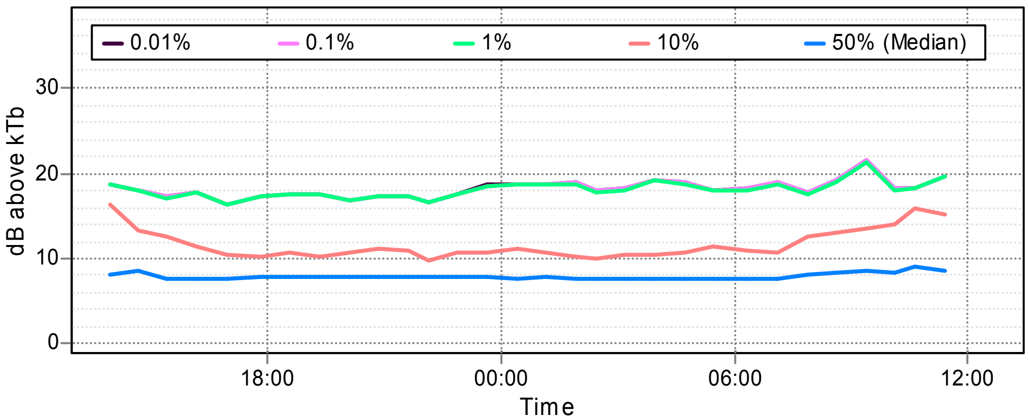


Figure 30. Comparison of Ninestiles diurnal variation.

The 2003 plot shows peak activity around 11:30. The 2006 plot, which ran from 13:28 to 11:29 the next day (and so omits the busiest time from the 2003 test), shows peak activity at the extremes of the test and so is consistent with the 2003 plot. The 2006 plot additionally shows a continuous emission present for the entire duration of the test at the 1% spectral occupancy level. This is attributable to the movement detector or video sender identified in Figure 29.

4.3.2 Site 14 – IET Savoy Place

Comparison of the RTFU metric for the two measurements at this site shows a small increase in the amount of activity between 2003 and 2006, from 2% to 3%, but this change is not regarded as significant. The details of the comparison are expanded below.

4.3.2.1 Site Usage Information

Savoy Place is the headquarters of the IET (formerly IEE), located in central London just off the Embankment. The building houses administrative offices, meeting rooms, catering facilities and a library. No particular change in the radio environment usage between 2003 and 2006 was expected.

4.3.2.2 Comparison of Measurement Locations

In 2003, the monitoring equipment was located in an empty corner office on the second floor with a North Westerly outlook. In 2006, the monitoring equipment was located in the President's room on the third floor with a Westerly outlook. The two locations are shown in Figure 31.

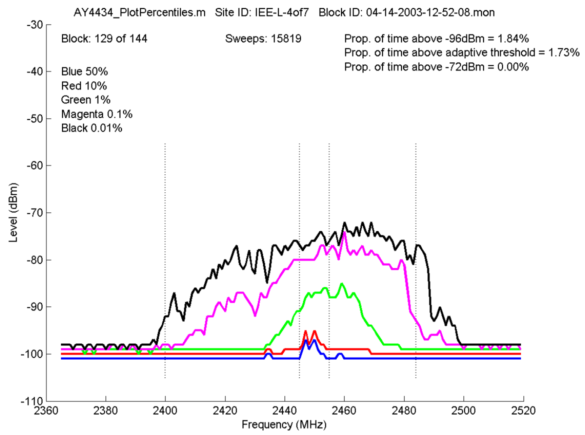
2003 **2006**

Figure 31. IET Savoy place monitoring locations.

4.3.2.3 Comparison of Band Utilisation Plots

Two utilisation plots are shown in Figure 32. The 2003 plot shows a typical 10-minute period of peak activity. The 2006 plot is aggregated over the complete test (22 hours).

2003



2006

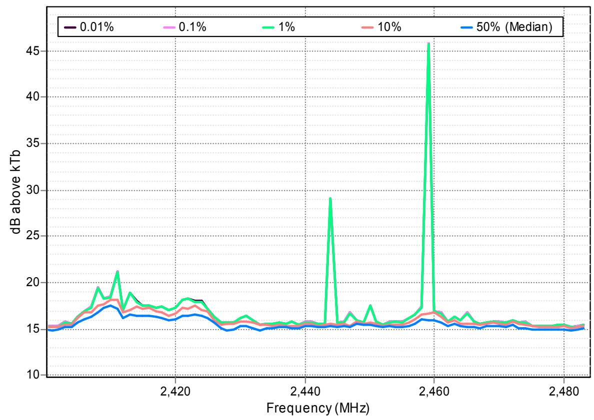


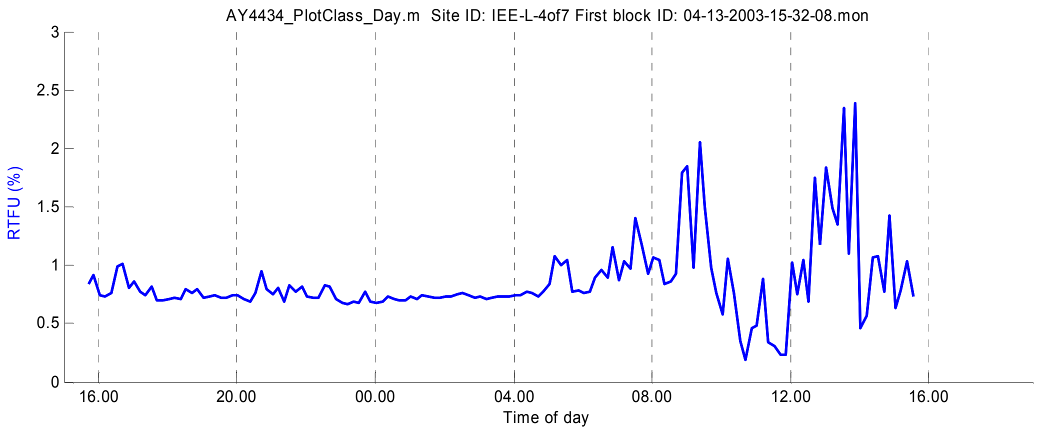
Figure 32. Comparison of IET Savoy Place band utilisation.

Both plots show some activity above the noise floor at the median and 10% levels. A WLAN may just be visible at the lower end of the band in the 2006 measurement, which was not present in 2003. Conversely, microwave oven activity is visible in the 2003 measurement which is not visible in the 2006 result. The lack of WLAN signal strength is surprising and possibly attributable to the thick stone walls employed in the building structure.

4.3.2.4 Comparison of Diurnal Variation Plots

The two diurnal variation plots are shown in Figure 33. The 2003 plot shows a typical day's activity from the measurement period of 7 days. The 2006 plot shows the entire 22 hour test.

2003



2006

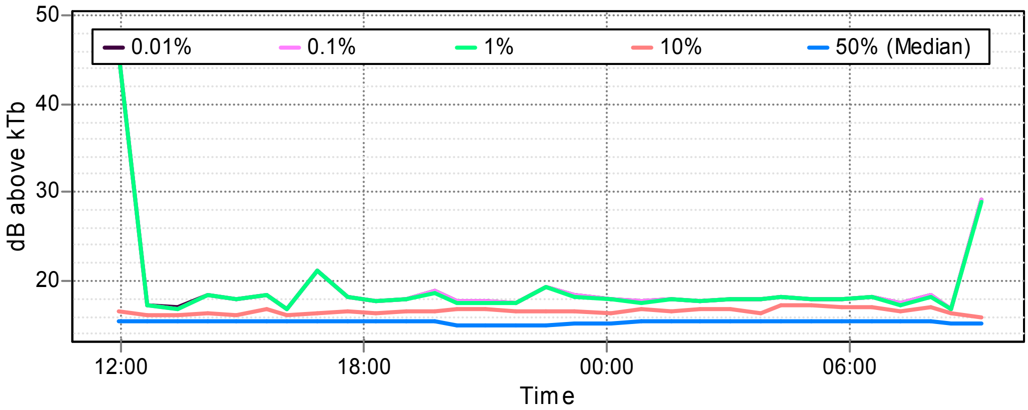


Figure 33. Comparison of IET Savoy Place diurnal variation.

The 2003 plot shows peak activity around morning and lunchtime, likely to be microwave oven emissions. The 2006 plot shows a significant peak over lunchtime, in accordance with the 2003 result.

4.3.3 Site 16 – Addenbrookes Hospital

Comparison of the RTFU metric for the two measurements at this site shows a significant increase in the amount of activity between 2003 and 2006, from 1% to 15%, attributed to increased WLAN activity. The details of the comparison are expanded below.

4.3.3.1 Site Usage Information

The following site usage information was obtained:

2003: Addenbrookes was then running a WLAN pilot scheme, with only a few PCs connected. Their plan was to roll out a comprehensive wireless IT network over the following couple of years. Other devices emitting in the 2.4 GHz band include microwave ovens in the kitchens and medical equipment in the theatres and treatment rooms. This site was monitored to establish a baseline for a hospital environment with the knowledge that minimal WLAN activity should be encountered.

2006: A limited 802.11b WLAN is now in operation. This uses Cisco access points and has been set up using default wireless channels. The nearest access point is on Level 9, one floor below the monitoring location (on Level 10), and approximately 20m away. Other 2.4 GHz devices include microwave ovens on every floor, for staff use. The operating theatres, which use some 2.4 GHz equipment, are on Level 6 and so are unlikely to influence the measurements.

4.3.3.2 Comparison of Measurement Locations

In 2003, the monitoring equipment was located in a cabinet room on Level 7 adjacent to a lift shaft. The location is central to the core of the building, which carries all of the main hospital services. In 2006, the monitoring equipment was located in a plant room on Level 10, containing air-conditioning and ventilation systems. See Figure 34 for photos of these locations.

2003 **2006**

Figure 34. Addenbrookes Hospital monitoring locations.

4.3.3.3 Comparison of Utilisation Plots

Two utilisation plots are shown in Figure 35. The 2003 plot shows a typical 10-minute period of peak activity around lunchtime. The 2006 plot is aggregated over the complete test (21.5 hours).

2003 **2006**

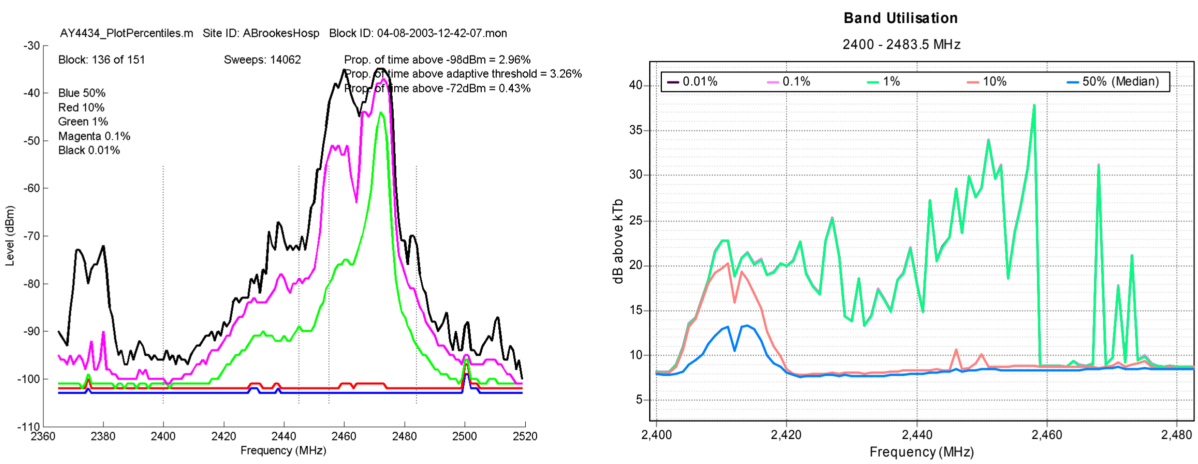


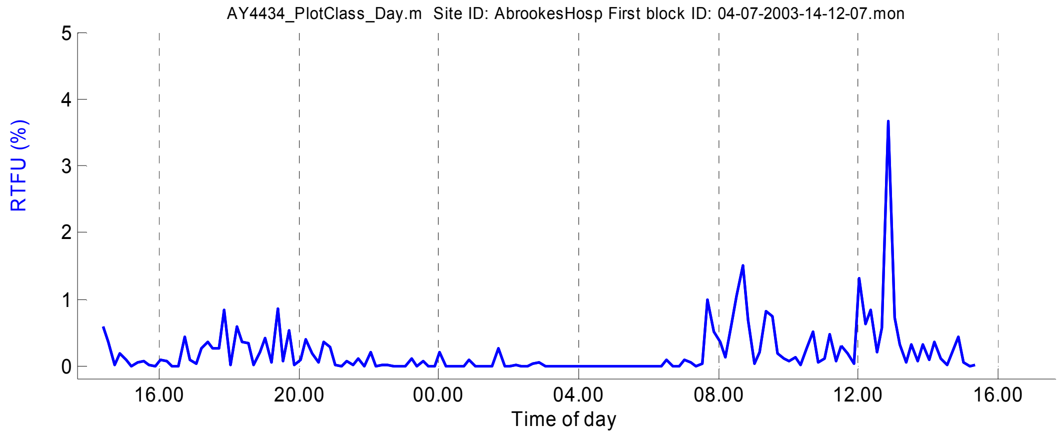
Figure 35. Comparison of Addenbrookes Hospital band utilisation.

The 2003 plot shows microwave oven emissions (the measurement site was close to the kitchens) but little activity above the 10% level. The 2006 plot shows a single WLAN channel operating for at least 50% of the time. The low duty cycle activity in the middle of the band is likely to be microwave oven emissions, as seen in the 2003 test.

4.3.3.4 Comparison of Diurnal Variation Plots

The two diurnal variation plots are shown in Figure 36 below:

2003



2006

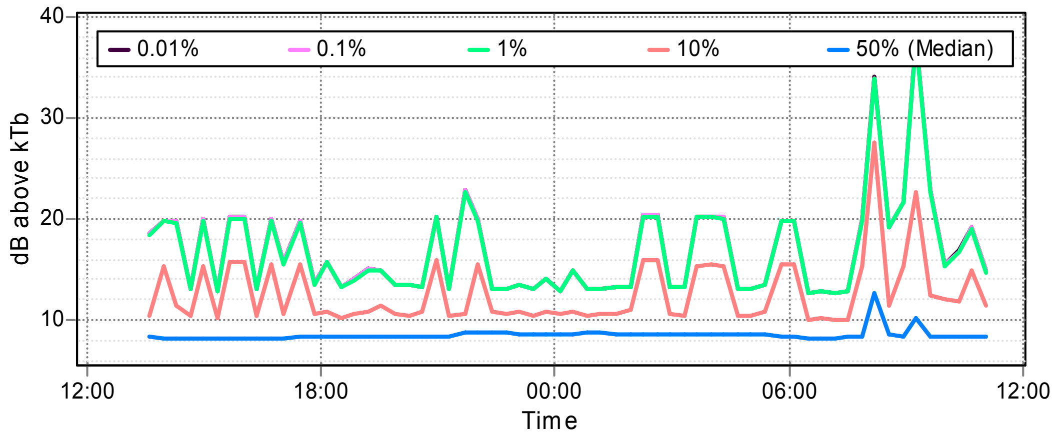


Figure 36. Comparison of Addenbrookes Hospital diurnal variation.

The 2003 plot shows the main period of activity is around 1pm, consistent with microwave oven activity from the nearby kitchens. The 2006 plot shows peak activity between 08:00 and 10:00, probably due to microwave oven activity. The lesser peaks from 13:00-18:00, 21:00-22:00 and 02:00-06:00 are due to WLAN activity. The extra activity due to WLAN emissions is in line with the hospital’s network upgrades.

5 STUDY CONCLUSIONS & RECOMMENDATIONS

Based on the wide range of sites measured and the utilisation metric developed for this work, it appears that licence-exempt bands are in general not heavily used.

The band displaying the highest general use is the 458.5 – 459.5 MHz band which is designated for industrial / commercial telemetry & telecommand, vehicle paging, fixed / mobile / transportable alarms, model control, and medical and biological applications. This band has a mean utilisation of 29% and at one site was as high as 86%. It can also be noted that even though the RTFU value for the ISM / RF heating apparatus band (886 – 906 MHz) is not particularly high at 7%, visual (and hence largely subjective) assessment of activity in this band at all sites indicates very wide usage of this technology. Perhaps surprisingly, and with the exception of the fully covered Ninestiles School, little use was found of Radio LANs in the 2.4 GHz band. Even at the IET, which is in the centre of London, only a small amount of RLAN activity was detected, but this perhaps reflects the isolation provided by very thick walls, both internal and external.

This latter observation about apparently limited RLAN usage leads on to some important observations about the nature of the measurement approach. Firstly it has to be remembered that the remit of the work was to investigate LE bands across a very large part of the spectrum (100 MHz to 10.6 GHz) in which many different radio technologies are deployed. In practical terms this necessitates the use of automated and unattended equipment with very wideband front ends and based on the non-coherent detection of power. The wideband characteristic sometimes leads to the need to desensitise the receiver across the whole of the frequency range supported by a particular antenna through front end attenuators when a strong signal is present in just one of the bands being measured. The other characteristic (i.e. non-coherent detection) means that the processing gain provided by coherent detection is missing and would explain why, in the case of RLANs, very little activity was detected when it is known that generally an RLAN receiver is able to pick out and identify very low signal levels coming from access points situated some distance away.

Without wishing to focus too much on the 2.4 GHz band, although it can be noted from the [LE Economics Study] that one of the 2.4 GHz applications had the highest economic value, it is interesting to note that the utilisation values determined for the three sites common to the 2.4 GHz measurement campaign of 2003 have gone up. This shows that the automated RTFU measure provides a useful indication of band usage in the immediate area around the respective measurement point and that it can track changes in utilisation over time.

Two other interesting aspects emerged from the measurements. Firstly, the impact that faulty light fittings, especially those relating to fluorescent tubes, can have on environmental noise over a significant part of the whole spectrum – e.g. in all the bands up to 500 MHz and tailing off up to 1 GHz. Secondly, the unexpected presence of a very high power low duty cycle transmitter in the 1389 – 1399 MHz band which could be attributable to Heathrow airport activities (purely because the measurement location was relatively nearby) or the military who are responsible for managing the allocation within which this licence-exempt band resides.

Overall, the results presented in this report give a good indication of the degree to which the licence-exempt bands are utilised. This in itself is useful information to potential users of the bands who might need to assess whether a planned application would operate satisfactorily or not. It has to be borne in mind that the measurements are specific to specific locations and a relatively small area round about each location. So, while the utilisation metric covers the frequency and time dimension, with a small element of the area dimension, it cannot indicate whether a frequency band is fully occupied. This requires a much wider geographic spread of results and/or further precision in what is being measured, both of which have significant resource implications.

It is recommended that:

1. Further measurements be undertaken in the future at the same sites and preferably at exactly the same locations. This would allow for a more consistent interpretation of measurement results in terms of increased utilisation with time. Measurements should be at least 24 hours in duration, preferably 48 hours, to provide a good indication of the diurnal variation.

2. Efforts be made with regard to the identification of signal types (functionality already under development as part of the ongoing AIMS programme) as this would further improve interpretation of the measurement results. The APD is a useful tool in distinguishing between types of communication signal and noise but further precision is required.

3. Consideration be given to the coherent detection for some specific frequency bands as this would allow even greater precision in the detection of devices. It would allow for the development of metrics that characterise the more widescale deployment of devices potentially enabling a closer link to be made between utilisation and occupancy.

6 ABBREVIATIONS

AIMS	Autonomous Interference Monitoring System
AIU	Antenna Interface Unit
AMR	Automated Meter Reading
APD	Amplitude Probability Distribution
BDV	Band Diurnal Variation
BSP	Band Summary Plot
BUP	Band Utilisation Plot
CDF	Cumulative Distribution Function
CDV	Channel Diurnal Variation
DV	Diurnal Variation
EPOS	Electronic Point Of Sale
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
ID	Identification
IEE	Institute of Electrical Engineers
IET	Institute of Engineering & Technology
ISM	Industrial, Scientific, Medical
kTb	Thermal noise power in a bandwidth, b, at temperature, T, of 290 K
LE	Licence-Exempt
LNA	Low Noise Amplifier
MASS	Mass Consultants Ltd
PC	Personal Computer
PMR	Private Mobile Radio
RF	Radio Frequency
RFID	Radio Frequency Identification
RLAN	Radio Local Area Network
RMDF	Remote Monitoring Direction Finding (Ofcom fixed monitoring site)
RSE	Relative Spectrum Efficiency
RTFU	Relative Time & Frequency Utilisation
RU	Receiver Unit
SMS	Simple Messaging Service
SPDT	Single Pole Double Throw
SRD	Short Range Device
SUE	Spectrum Utilisation Efficiency
WLAN	Wireless Local Area Network

APPENDIX A – AIMS ANALYSIS FEATURES

This Appendix provides details of AIMS' various analysis graphs and metrics that can be used by the analysis to interpret the measurement environment.

AIMS' analysis graphs and features are relevant to a particular *level* of measurement in the AIMS heirarchy, as shown in Figure 37.

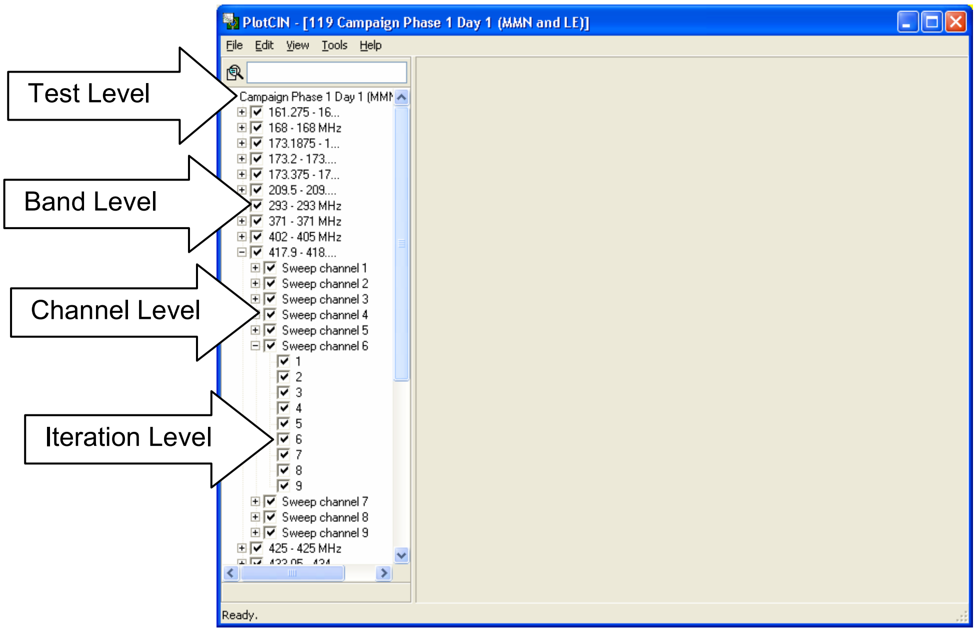


Figure 37. AIMS Heirarchy

A list of the graphs available at each level is provided in Table 1.

Measurement Level	Plots Available at Measurement Level
Test	Band Summary Plot (BSP)
Band	Band Utilisation Plot (BUP), Band Diurnal Variation (BDV)
Channel	Channel Diurnal Variation (CDV)
Iteration	Amplitude Probability Distribution (APD), Spectrum Snapshot

Table 1. Plots available at each measurement level

Note that here and throughout the rest of this report the term channel is used to denote a measurement channel, which is not the same as the designation of a radio channel for a particular type of radio system. So, for example, in the 2.4 GHz band, 84 x 1 MHz wide (measurement) channels were employed, whereas common reference is made to 13 overlapping 22 MHz RLAN channels (in the European regulatory arena).

The fundamental unit of data is the cumulative distribution function (CDF) for a particular channel and period. This CDF is contained at the AIMS' iteration level. CDFs are scaled and combined in order to analyse the spectrum in different ways.

The graphical outputs for each site are discussed in more detail in [Volume 2]. Particular features of the measurement results relevant to this summary report are discussed in the sections below.

Band Utilisation Plot (BUP)

The BUP, found at the band level, shows the variation of the measured power across the entire band as a function of frequency. An example of a BUP is shown in Figure 38.

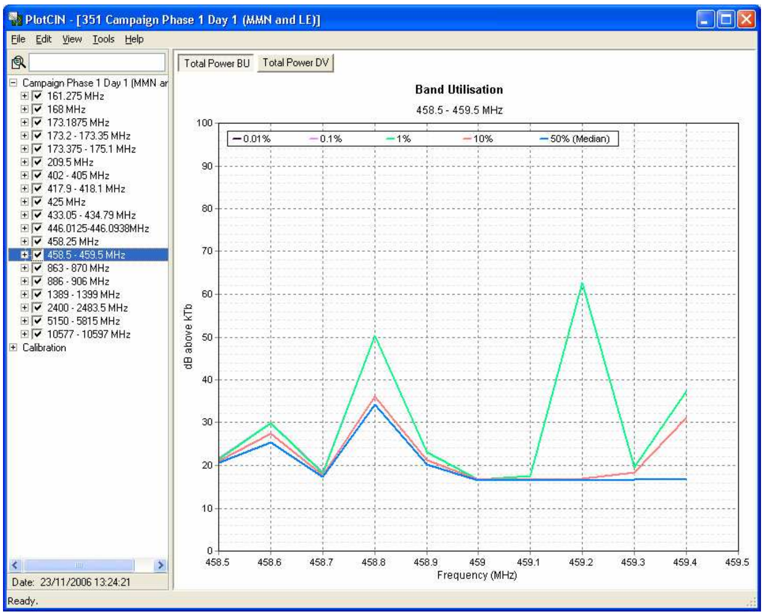


Figure 38. Band Utilisation Plot

Five traces show the spectral utilisation at different probability levels in time, showing the bandwidth and duty cycle of the detected transmissions as well as the power received. This enables a degree of manual emitter identification to be achieved, as some transmissions have characteristic features. These plots were used for analysis purposes in the [2.4 GHz Study].

The BUP in Figure 38 shows the power in each channel at different probability levels. The coloured lines show the signal power level that is exceeded for the specified proportion of *time* (Blue = 50%; Red = 10%; Green = 1%; Magenta = 0.1%; Black = 0.01%). Note that in Figure 38, there is insufficient data to display the 0.1% and 0.01% probability levels. The degree of temporal activity can be gauged by considering which curves are *raised*. For example, if the 10% line remains at the noise level but the 1% line is lifted, then the proportion of the time over which this signal is active must lie between 1% and 10%.

Band Diurnal Variation (BDV)

The BDV plot, found at the band level, shows the variation of the measured power across the entire band as a function of time. An example BDV plot is shown in Figure 39.

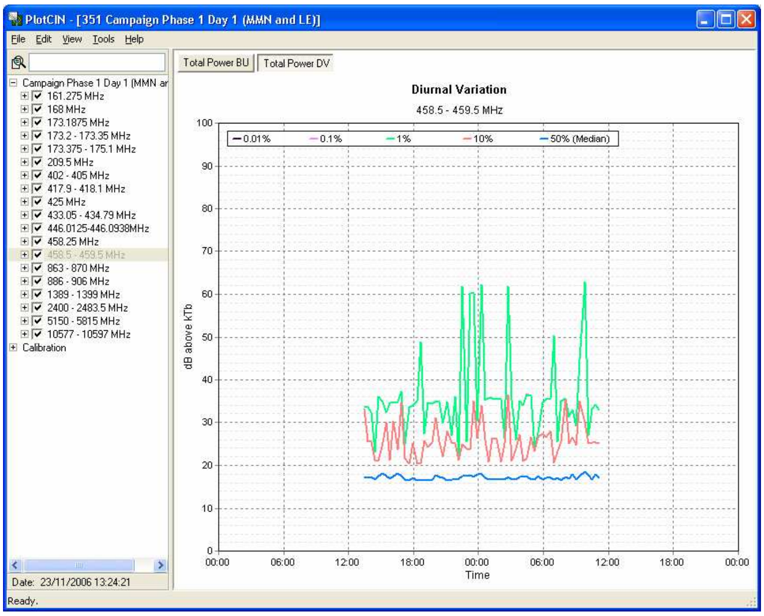


Figure 39. Band Diurnal Variation Plot

Five traces show the temporal utilisation at different probability levels in frequency. This is useful for showing trends in usage and matching that to patterns of device / human behaviour. It is also helpful in identifying emitter types by showing something of the time structure of the signal.

In this plot, the different curves show the signal power level that is exceeded for the specified proportion of *frequency* (Blue = 50%; Red = 10%; Green = 1%; Magenta = 0.1%; Black = 0.01%). Note that in Figure 39, there is insufficient data to display the 0.1% and 0.01% probability levels. The degree of spectral activity can be gauged by considering which curves are *raised*. For example, if the 10% line remains at the noise level but the 1% line is lifted, then the proportion of the band frequency range over which this signal is active must lie between 1% and 10%.

Amplitude Probability Distribution (APD)

The APD, displayed at the iteration level, is a Rayleigh scaled version of the Cumulative Distribution Function (CDF) for a portion of data relating to a particular channel and a particular time slice (iteration). An example is shown in Figure 40.

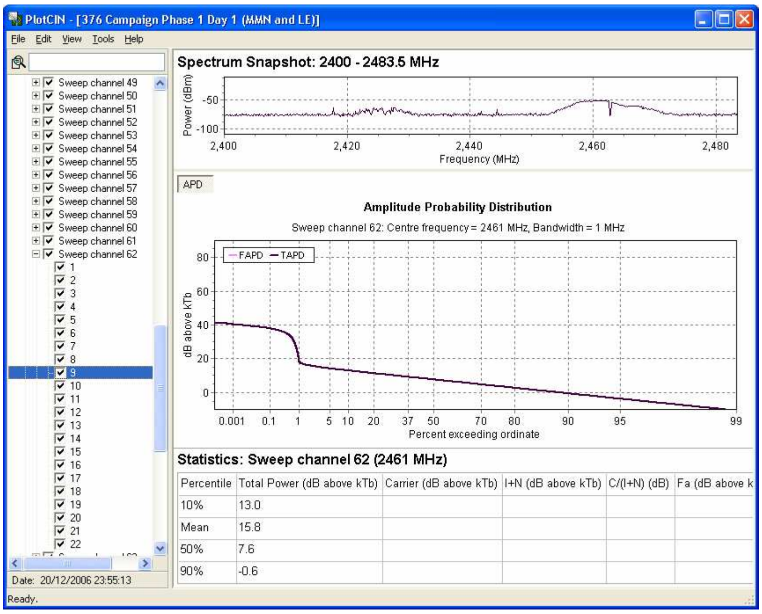


Figure 40. Amplitude Probability Distribution Plot

The salient features of the APD are displayed in the statistics table below the graph.

A key feature of the APD is that Gaussian noise is represented as a slope of -10dB between the 37% and 90% points. This is vital for distinguishing between continuous carrier signals and noise. For example, Figure 41 and Figure 42 show two APDs, the former a continuous narrowband (Rician) signal and the latter a Gaussian signal. Note the ordinate scales showing the 2dB fall between 37% and 90% for the Rician signal and approximately 10dB for the Gaussian signal.

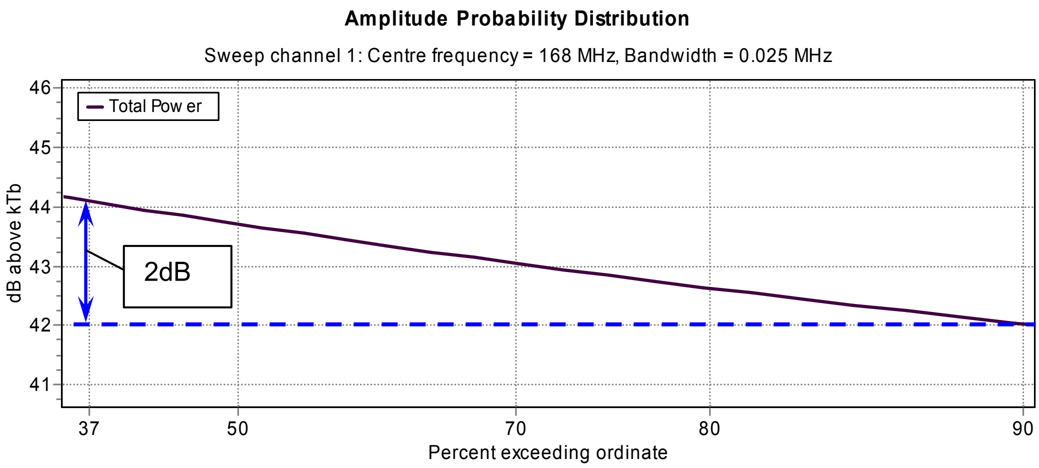


Figure 41. Rician signal on the APD

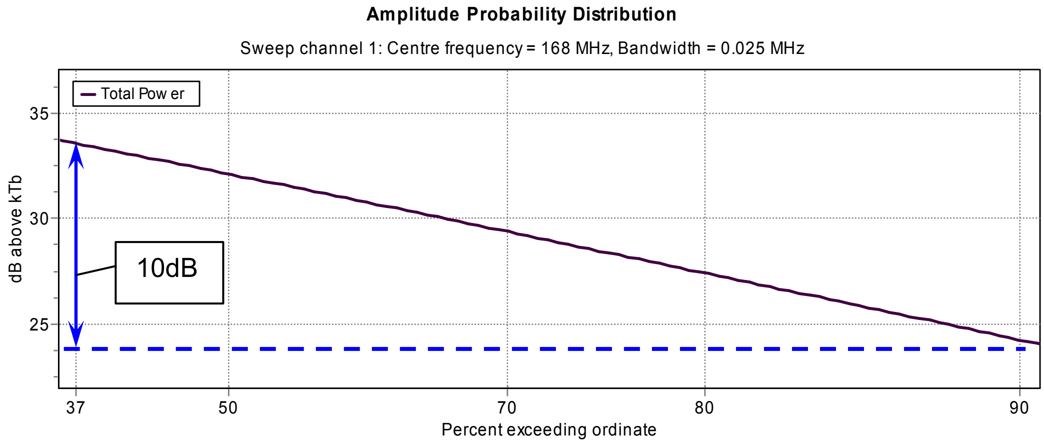


Figure 42. Gaussian signal on the APD

Figure 43 shows impulsive noise on the APD, where there is a low probability of receiving a high signal strength in amongst Gaussian noise. Figure 44 shows a burst or packet of constant amplitude carrier such as WLAN, in this case with a duty cycle of approximately 20%. Gaussian noise is also present between the bursts.

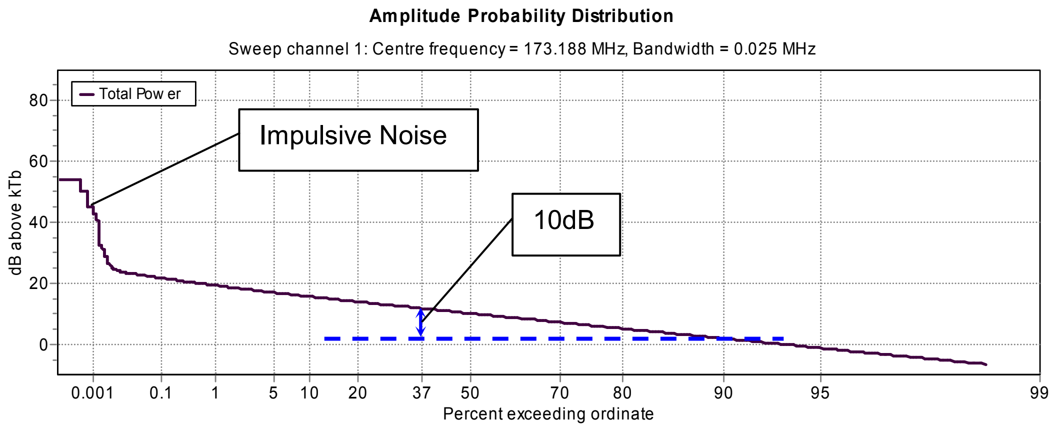


Figure 43. Impulsive noise on the APD

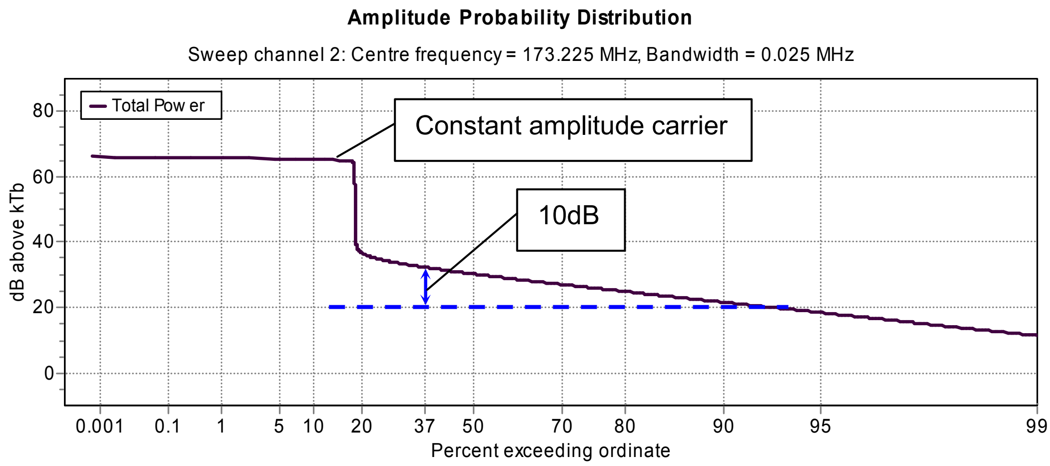


Figure 44. Burst carrier on the APD

Emitter Analysis Example

To illustrate how the analyst might use the various graphs to interpret the measurement environment, consider Figure 45. This shows the BUP and BDV for the 433 MHz band, allocated to Non-specific and Model Control use. Activity is visible on 5 channels across the band, shown by the peaks in the BUP at 433.15 MHz (channel 2), 433.65 MHz (channel 7), 433.95 MHz (channel 10), 434.45 MHz and 434.65 MHz. The higher two channels are not considered further here as they do not help to illustrate the case.

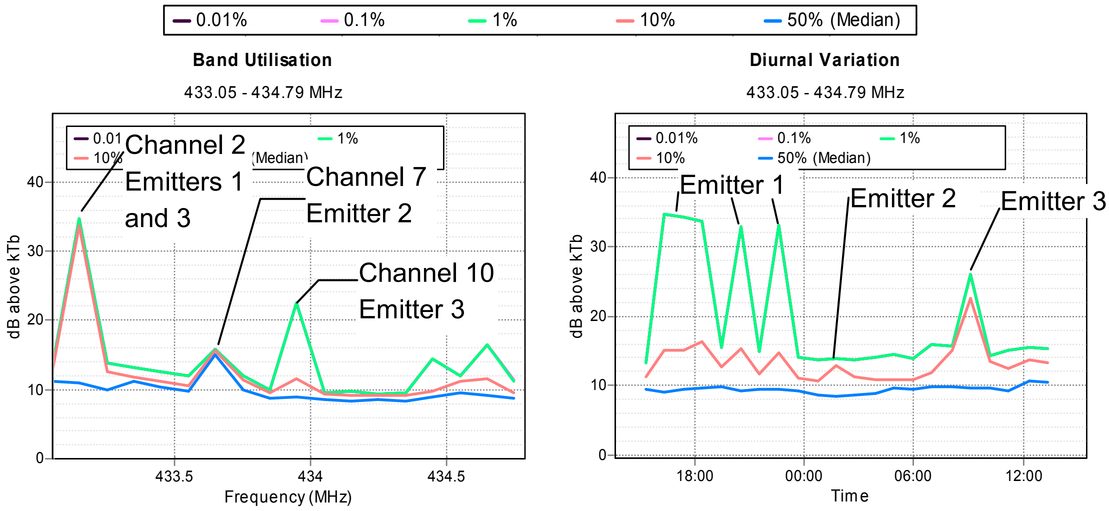


Figure 45. 433.05 – 434.79 MHz band level plots

The activity on channels 2, 7 and 10 is marked in the figure as being caused by Emitters 1, 2 and 3. Using the two plots together, it is possible to identify the frequency and time distributions of the three emitters:

Emitter 1. Looking at the BUP, channel 2 shows significant activity at a received power of approximately 34dB above kTB. This power level is also seen on the BDV, occurring in a number of discrete bursts between the start of the test and midnight. The fact that Emitter 1 only reaches the 10% probability level in time on the BUP implies that it is not continuous and this is reinforced by the bursty response in the BDV. Furthermore, the BDV shows that this activity up to midnight only reaches the 1% probability level in frequency, implying it is present on just a single channel for this band of 18 channels. The event which occurs at 09:00, near to the end of the test, also has to be present on channel 2. The reason for this is discussed under Emitter 3;

Emitter 2. This lower level emission on channel 7 reaches 16dB above kTB on the BUP. It reaches the 50% probability level in time, implying a continuous emission. This conclusion is reinforced by the BDV, which shows, at the 1% probability level (i.e. on a single channel), that the underlying power (ignoring the emitter 1 bursts) remains fairly constant at 16dB above kTB. Other channels add to this 1% BDV power, but the continuous signal is always present on channel 7;

Emitter 3. Emitter 3 is present on channel 10 at the 1% probability level in time. This implies that it occurs no more than 1% of the time and the power level of 22dB above kTB is mirrored on the BDV at 09:00. However, the BDV reaches the

10% probability level in frequency at this time, implying that the event is present on more than 1 channel. The only other channel with activity at this power level is channel 2 and therefore emitter 3 must be present simultaneously on channels 2 and 10. Another explanation is that two emitters coincidentally emitted signals which were received by AIMS with similar powers at the same time.

These conclusions are all deduced from just the BUP and BDV graphs. It is often helpful to include the data from the channel and iteration levels in the analysis. In particular, the APD is useful in ascertaining the type of emission and differentiating carrier from noise.

APPENDIX B – AIMS MEASUREMENT HARDWARE

The AIMS system comprises three main hardware components:

- Receiver unit (RU): Comprising a spectrum analyser mounted in a lightweight protective case, this unit performs the RF acquisition, data digitisation and processing. The processed data is stored in the analyser for retrieval on completion of the test. The RU is controlled via a laptop PC.

- Antenna Interface Unit (AIU): This unit accepts inputs from up to three antennas and, under command from the RU, switches the appropriate antenna into circuit. It also comprises other features including a noise source for auto-calibration, a Low Noise Amplifier (LNA), and a GSM modem.

- Antenna fit: Different antennas may be employed depending on the monitoring requirements.

Figure 46 shows how the AIMS components are interconnected.

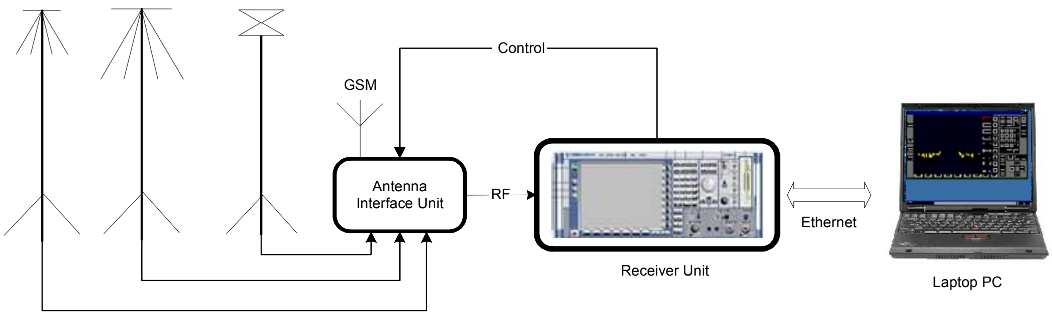


Figure 46. AIMS components

Receiver Unit

The receiver unit (Figure 47) consists of the following components:

- Rohde & Schwarz FSQ26 Spectrum Analyser;

- Lightning protection;

- Power line filter;

- Internal cooling fans.

Figure 47. AIMS Receiver Unit

Antenna Interface Unit

The AIU (Figure 48 and Figure 49) acts as an interface between the antennas and the receiver unit.

Figure 48. Antenna Interface Unit

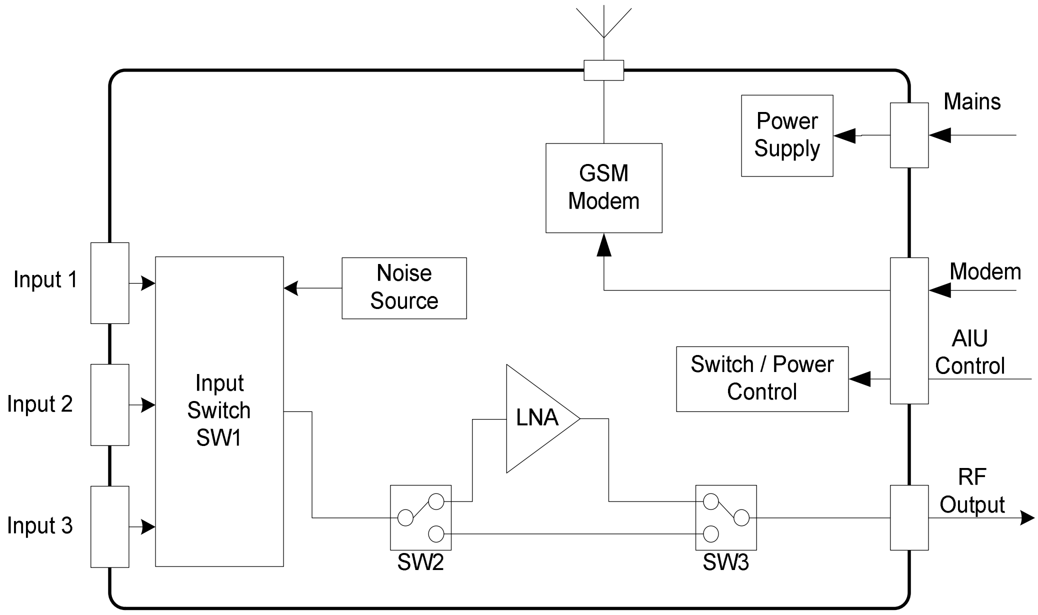


Figure 49. AIU Block Diagram

The AIU houses the following main components:

- 4-way input switch (SW1): This allows for selection of the desired antenna input or alternatively a noise source for calibration purposes;
- LNA: This component may be switched into circuit to provide 28dB of gain and a 2.8dB noise figure across the entire frequency range of 100 MHz to 10.6 GHz;
- LNA Bypass: The bypass is achieved by use of a pair of single pole double throw (SPDT) RF electromechanical switches (SW2 and SW3);
- Noise Source: This unit provides a steady, calibrated, temperature-independent noise power, which is used for functional testing and calibration purposes;
- GSM modem: SMS messages may be sent at predefined intervals and on error conditions to provide status information about the system whilst it is engaged in monitoring;
- Power supply: This provides the various voltages required by the other internal components.

Antennas

The LE antenna fit is designed to provide broadband omni-directional coverage between 100 MHz and 10.6 GHz. This is done in three stages as described in Table 2.

Antenna 1	Antenna 2	Antenna 3
		
Jaybeam discone covering the range 100 MHz to 600 MHz	AOR DA5000 discone, covering the range 600 MHz to 3 GHz	York EMC bicone covering the range 3 GHz to 10.6 GHz

Table 2. LE antenna fit

APPENDIX C – BANDS OF INTEREST

Band Number	Min Freq (MHz)	Max Freq (MHz)	Bandwidth (MHz)	Services	Resolution (kHz)	Num Channels
1	161.27499	161.27501	0.00	General Alarms Associated with Marine Apps	25	1
2	167.992	168.008	0.02	ISM	25	1
3	173.187499	173.187501	0.00	Alarms: Mobile and Transportable	25	1
4	173.2	173.35	0.15	Telemetry and Telecommand: General/Industrial/Commercial, Alarms : Fixed	25	7
5	173.375	175.1	1.72	Radio Hearing Aids, Telemetry and Telecommand: General, Medical and Biological Apps, Radio Microphones	100	18
6	402	405	3.00	Wireless applications in healthcare (including ultra low power medical implants).	100	30
7	417.9	418.1	0.20	Telemetry and Telecommand: General	25	9
8	433.05	434.79	1.74	Non-specific, Model control	100	18
9	458.2499	458.2501	0.00	Alarms: Fixed	25	1
10	458.5	459.5	1.00	Alarms: Mobile and Transportable/Vehicle Paging, Medical and Biological Applications, Model Control, Telemetry and Telecommand: Industrial/Commercial	50	20
11	466	466.1	0.10	Private Mobile Radio (PMR)	25	4
12	863	870	7.00	Alarms (including social alarms), Non-specific, RFID, Wireless Audio (including narrowband analogue voice)	100	70
13	886	906	20.00	ISM (RF Heating Apparatus)	100	200
14	1389	1399	10.00	Wireless video distribution for private use	100	100
15	2400	2483.5	83.50	ISM (Non Specific), Wideband data/RLANs, Cordless Audio Equipment, Wireless Video Cameras (Non Broadcasting), Movement detection, Equipment for the Detection of Movement or Alert, Short Range Indoor Data Links, Telemetry and Telecommand: Industrial/Commercial, RFID, Automatic vehicle ID for railways	1000	84
16	5150	5815	665.00	ISM (Non Specific), Wideband data/RLANs, Equipment for the Detection of Movement or Alert, Short Range Indoor Data Links, Wireless Video Cameras (Non Broadcasting), Road transport and traffic telematics	10000	67
17	10577	10597	20.00	Equipment for the Detection of Movement or Alert	1000	20