Autonomous Interference Monitoring System, Phase 3

Final Report

Issue 1
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EXECUTIVE SUMMARY

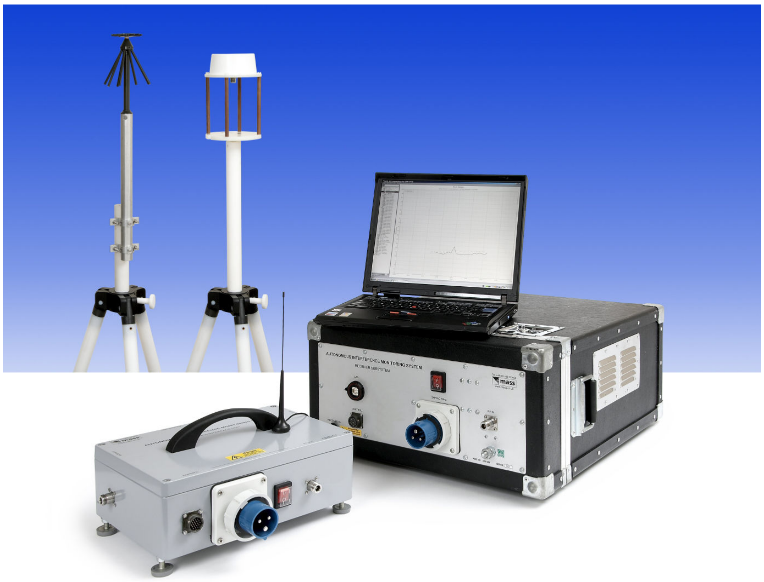

Figure 1 AIMS

MASS has been developing the Autonomous Interference Monitoring System (AIMS) for Ofcom since February 2005. AIMS (Figure 1) has now matured into a multi-function, accurate and highly efficient tool for assessing spectrum quality and usage.

During phase 2 the AIMS functionality was enhanced and the system was used in a series of field trials around the UK to verify its robustness and accuracy. One of the main activities was the measurement of median Interference plus Noise (I+N) levels. This led to the concept of an Ambient Interference Level (AIL) as shown in Figure 2, which is taken from the [Phase 2 Final Report, Volume 1].

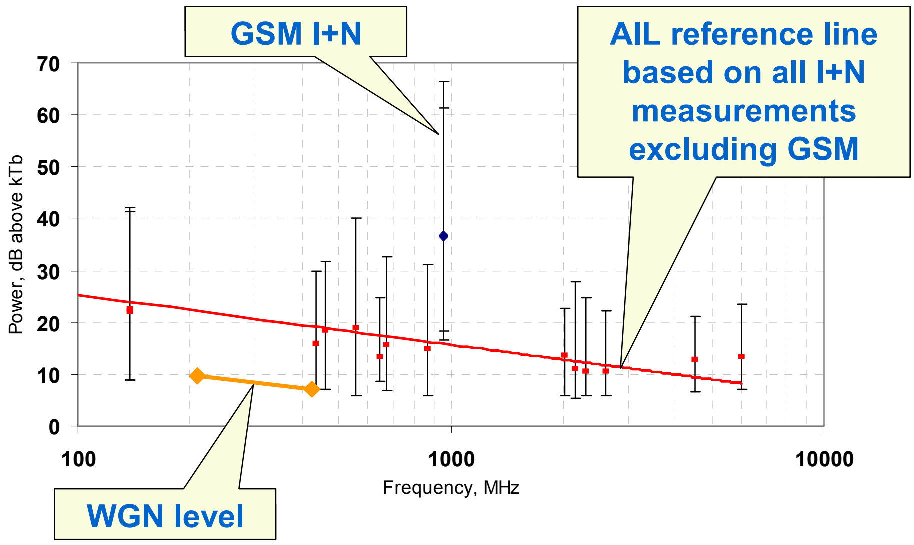

Figure 2 I+N power across all sites plotted versus log frequency

The AIL reference line has been plotted as a straight line against log frequency. The median I+N value in the GSM bands is clearly significantly higher than this line. Phase 2 concluded that this was because the GSM measurements contain significant network self-interference. Further investigation revealed significant diurnal variation in the GSM I+N. This effect is believed to be due to varying loads on the GSM network throughout the day causing variations in the network self-interference. Figure 2 shows an example of this effect, taken from the [Phase 2 Final Report, Volume 2].

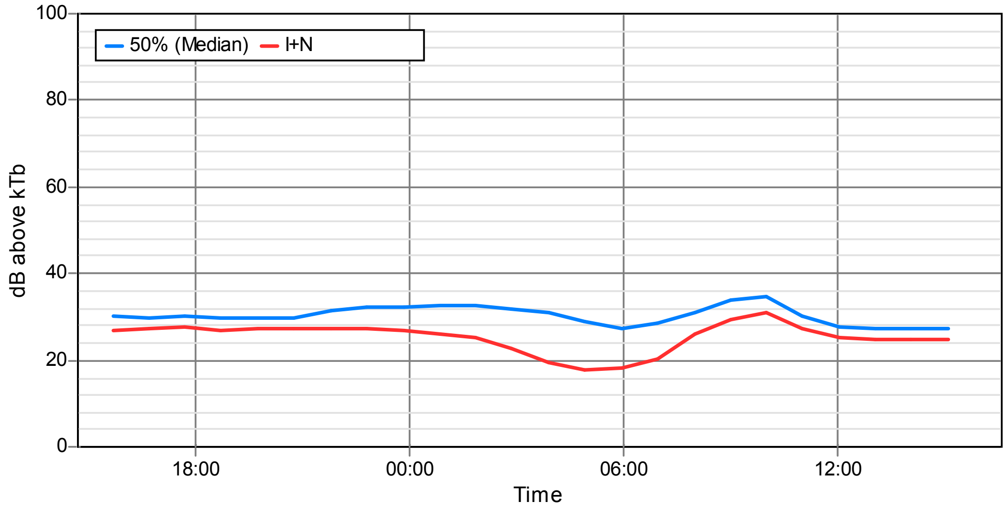

Figure 3 Diurnal variation at Grafham Water, 954.4 MHz

As a measure of spectrum quality, it would be better if this diurnal variation could be removed to give a view of the non-GSM interference and noise below the I+N currently being measured.

During phase 3, the AIMS has been enhanced by adding a mode that uses the channelised subspace algorithm to give a better measure of I+N in the GSM bands. The new mode removes much of the diurnal variation, as shown in Figure 3.

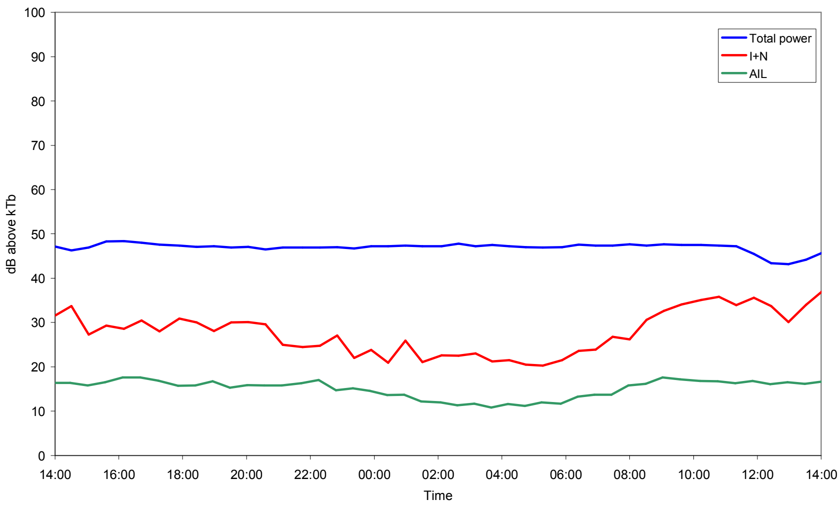

Figure 4 Grafham Water, 948.4 MHz, 18th October, antenna 1

If we plot the results from this new algorithm against the other I+N results, we obtain Figure 5, which shows most of the AIL measurements appearing just below the median I+N level that might be expected at these frequencies. The only exceptions are the measurements made at 954.4 MHz at the Hull Remote Monitoring and Direction Finding (RMDF) site.

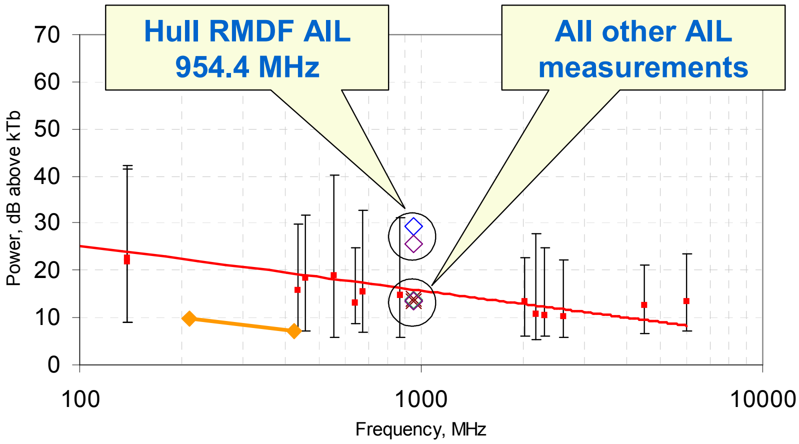

Figure 5 AIL and I+N versus frequency

The new GSM AIL mode therefore removes a large amount of the diurnal variation from the I+N and, apart from the Hull 954.4 MHz results, produces absolute results that are commensurate with the levels to be expected at these frequencies.

The high results at one of the frequencies measured at the Hull RMDF site indicate that the AIL algorithm cannot find a 'look-through' to the noise floor in the dense signal environment found at this site.

It is recommended that further GSM AIL measurements are made as part of future AIMS surveys to determine the robustness of the AIL algorithm at various field sites.

CHANGE HISTORY

Version	Date	IR	Comments
1	22/11/07	-	First formal issue

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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1 INTRODUCTION

Phase 2 of the Autonomous Interference Monitoring System (AIMS) programme produced a system that is capable of measuring the Interference plus Noise (I+N) level in a way that is suitable for general spectrum measurement. The I+N algorithm is modulation-independent and has been evaluated in a wide range of scenarios through a survey around the UK.

This work led to the observation that some of the GSM I+N measurements were affected by intra-network interference. Such interference is managed by the network providers and is an inherent property of the modulations employed. In these GSM cases the combined Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI) powers were included in the I+N measurements.

The research question posed for phase 3 of the AIMS programme was whether it is possible to determine the amount of interference and noise that would be present in the GSM bands if the network were not present. This power level has been termed the Ambient Interference Level (AIL). Measurement of the AIL in the GSM bands requires a modulation-specific algorithm.

The [Phase 2 Final Report, Volume 2] considered likely candidates for such an algorithm and concluded that an extension to the subspace method would be the best starting point. During phase 3 of the AIMS programme, therefore, a subspace algorithm for measuring AIL in the GSM bands has been developed and integrated into the AIMS.

This report summarises the findings of the investigation into GSM AIL measurement using the AIMS.

2 ALGORITHM

Starting with the ideas outlined in the [AIMS 2 Final Report, Volume 2] a variety of algorithmic approaches was investigated in MATLAB using simulated and real sample data. The MATLAB algorithm then formed the basis for the production code in the AIMS Receiver Controller (ARC).

The algorithm developed, tested and implemented in phase 3 is an extension of the existing I+N algorithm used in the current AIMS software. The concept is illustrated in Figure 6.

A channeliser splits a segment of the GSM band into channels with the same separation as the GSM channels. Each channel is then analysed using the I+N algorithm and the minimum is taken across all the channels. This approach does not directly remove the GSM carriers, but rather tries to find the best parts of the spectrum in which to make an AIL estimate.

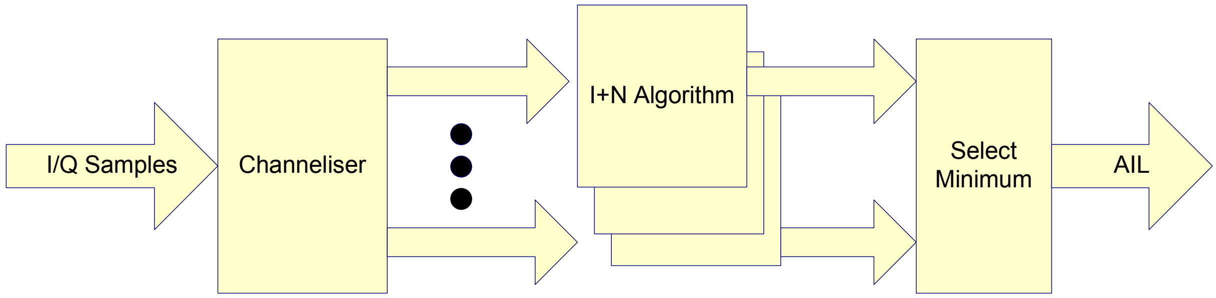

Figure 6 GSM AIL algorithm

The bandwidth over which the algorithm operates is a compromise between the desire to obtain a spot measurement of AIL and the practicality of obtaining a measurement in a densely occupied band. After some experimentation, an input bandwidth of 2.6 MHz was selected, which is channelised into 13 channels. The channels are placed at the expected GSM centre frequencies and are therefore separated by 200 kHz.

3 IMPLEMENTATION IN AIMS

The three main software components of AIMS (AIMS Database, ARC and PlotCIN) have been modified to incorporate the new algorithm. All are backwardly-compatible with previous test definition, calibration and test results files.

3.1 AIMS DATABASE

The GSM AIL measurement has been added as an extra mode in AIMS. From a user perspective, it is only necessary to select the centre GSM channel when the test is defined. Figure 7 shows the selection of GSM AIL mode in the Measurement Editor window.

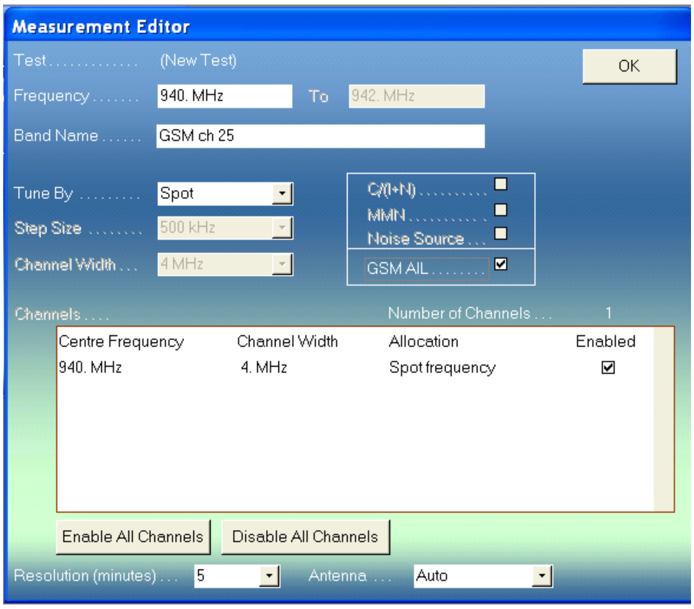

Figure 7 Selecting GSM AIL in Measurement Editor

3.2 ARC

Whilst the majority of the processing takes place in the AIMS Receiver Controller (ARC), this is largely transparent to the user. A test containing a GSM AIL measurement is loaded in exactly the same way as any other test.

3.3 PLOTCIN

The analysis program, PlotCIN, has been upgraded to output the GSM AIL at all levels of the test results hierarchy. By way of example, Figure 8 shows GSM AIL results on the Band Summary Plot and Figure 9 shows the Diurnal Variation Plot for one of the channels monitored.

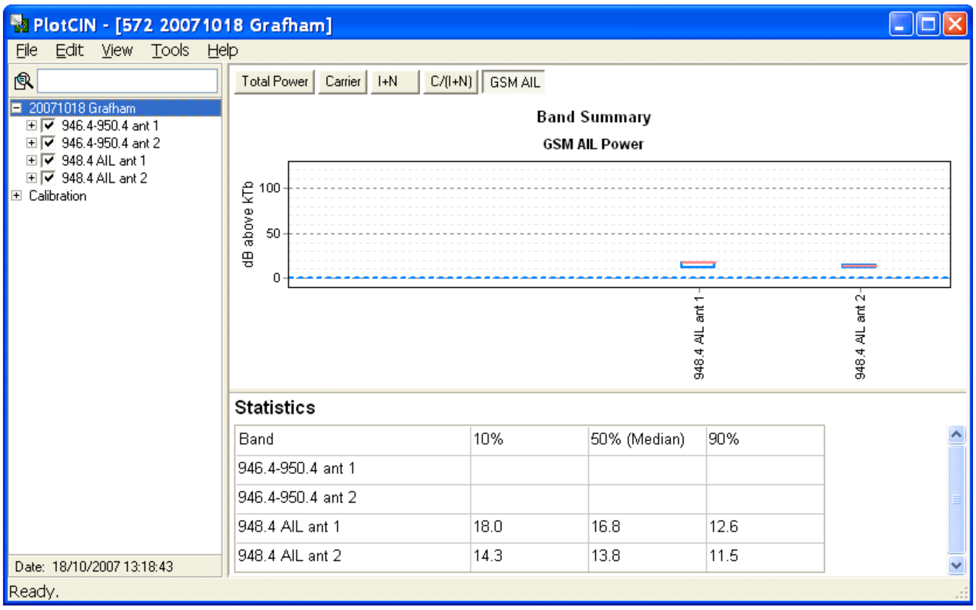

Figure 8 GSM AIL on Band Summary Plot

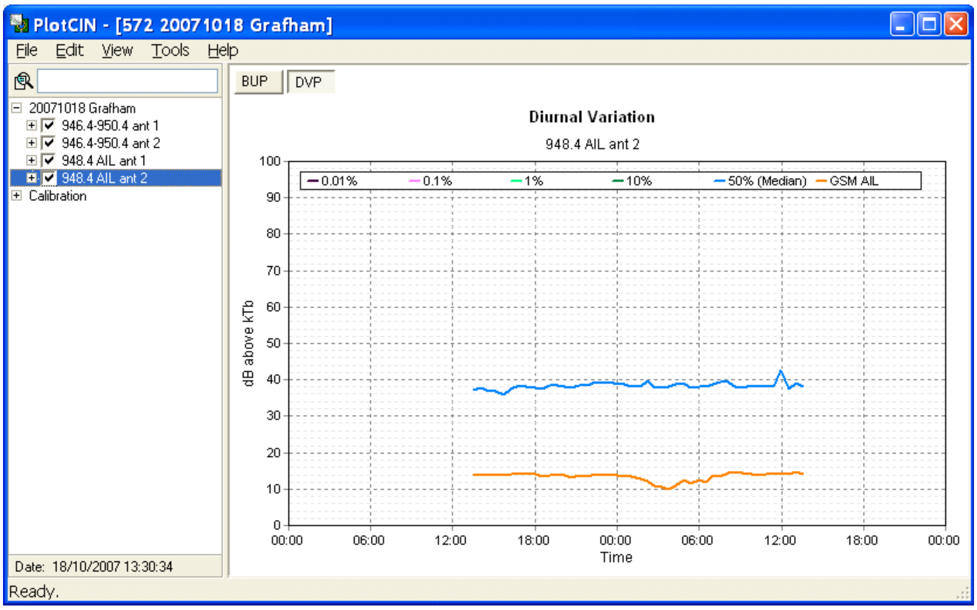

Figure 9 GSM AIL on Diurnal Variation Plot

4 TESTS

The following testing activities have been completed:

- Off-line testing in MATLAB using recorded and simulated signals (section 4.1);
- Off-line testing of AIMS code after implementation of the GSM AIL algorithm;
- Regression tests, which comprised a selected subset of the AIMS phase 2 tests to ensure that existing functionality had not been affected by the addition of the GSM AIL mode;
- Field tests (section 4.2).

4.1 OFF-LINE TESTS

A series of tests were performed to establish the performance of the GSM AIL algorithm before implementing it within AIMS. The results of this testing were documented in the [GSM AIL Algorithm Test Results] and are summarised below.

Figure 10 shows a typical recorded signal used for the testing. A number of GSM channels can be clearly seen within the measurement bandwidth. Figure 11 shows the output of the GSM AIL algorithm for varying levels of noise added to the signal.

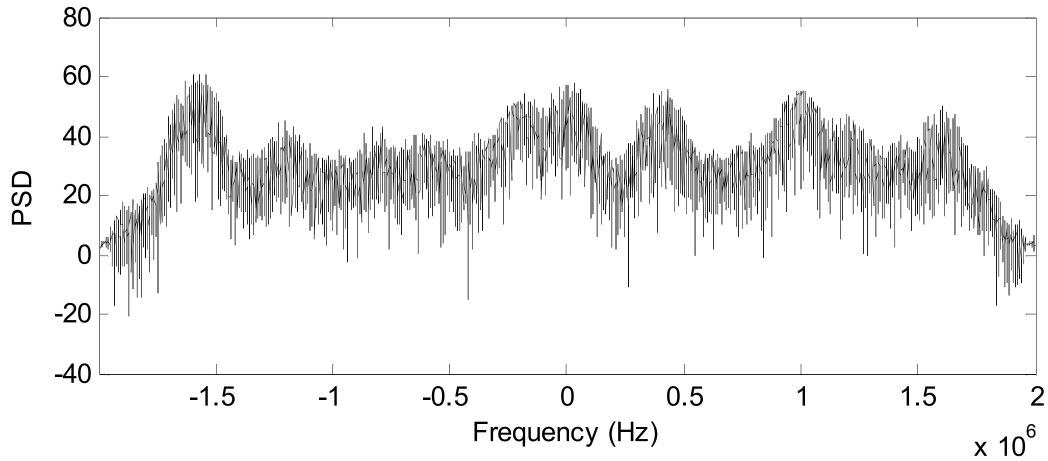

Figure 10 Recorded signal

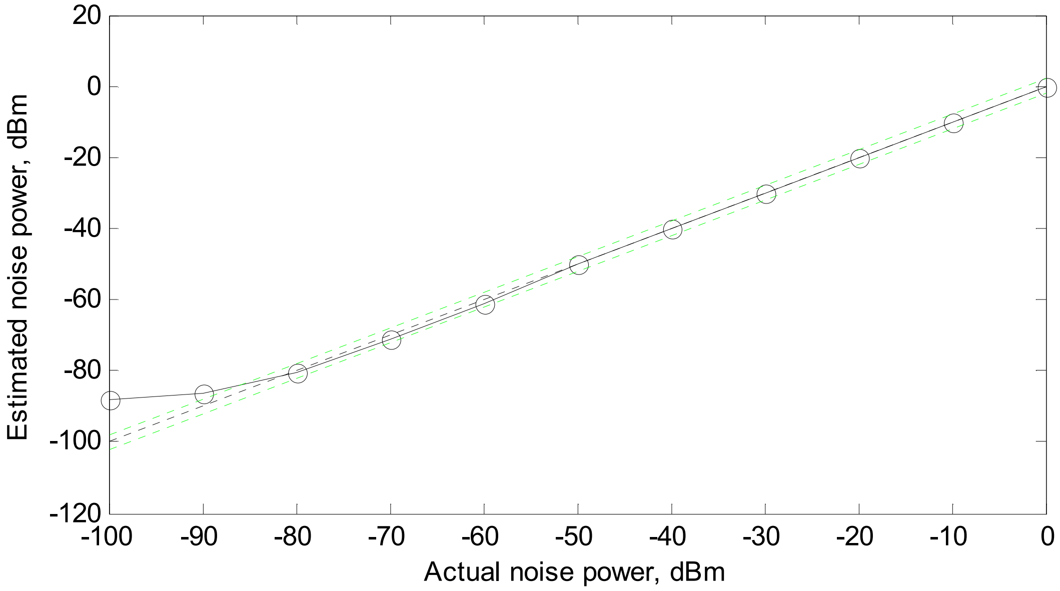

Figure 11 Estimated AIL for varying noise levels

The off-line testing showed that the GSM AIL algorithm performs correctly, providing that the band is not too full. Strong, highly structured signals can be treated as part of the carrier rather than part of the noise, but it was not felt that this would be a significant problem in practice and it was agreed with Ofcom to proceed with implementation of the algorithm in the AIMS.

4.2 FIELD TESTS

Field tests were performed at the Grafham Water camp site and at the Hull Remote Monitoring and Direction Finding (RMDF) site. These were locations at which the GSM noise variations had been observed clearly in the AIMS phase 2 results. As a confidence check a further field test was performed at MASS' Grove House site.

4.2.1 Grafham Water Camp Site

The AIMS was run overnight at the Grafham Water camp site on the night of 18th October. Two AOR DA5000 antennas were used. These were close together, but antenna 1 had an additional pre-selection filter fitted (as an additional check for out-of-band interference effects). The test used the frequency of a base station channel that exhibited clear diurnal I+N variation in phase 2.

Figure 12 and Figure 13 show the results of this test, from which the following observations are made:

1. The median AIL is 17 dB above kTb on antenna 1 and 14 dB above kTb on antenna 2;

2. The diurnal variation in the I+N and AIL levels is summarised in the following table:

	I+N (σ_{I+N}, dB rms)	AIL (σ_{AIL}, dB rms)
Antenna 1	5	2
Antenna 2	6	1

3. We see that the I+N exhibits considerable diurnal variation in the way previously seen, confirming that this effect is still visible at this site;

4. The GSM AIL algorithm successfully removed most of the diurnal variation and reached an overall minimum at about 04:00;

5. There are minor differences between the measurements from the two antennas, but these can be attributed to local multipath differences. The differences are not significant enough to warrant further investigation. Pre-selection did not, therefore, appear to have a significant effect at this site.

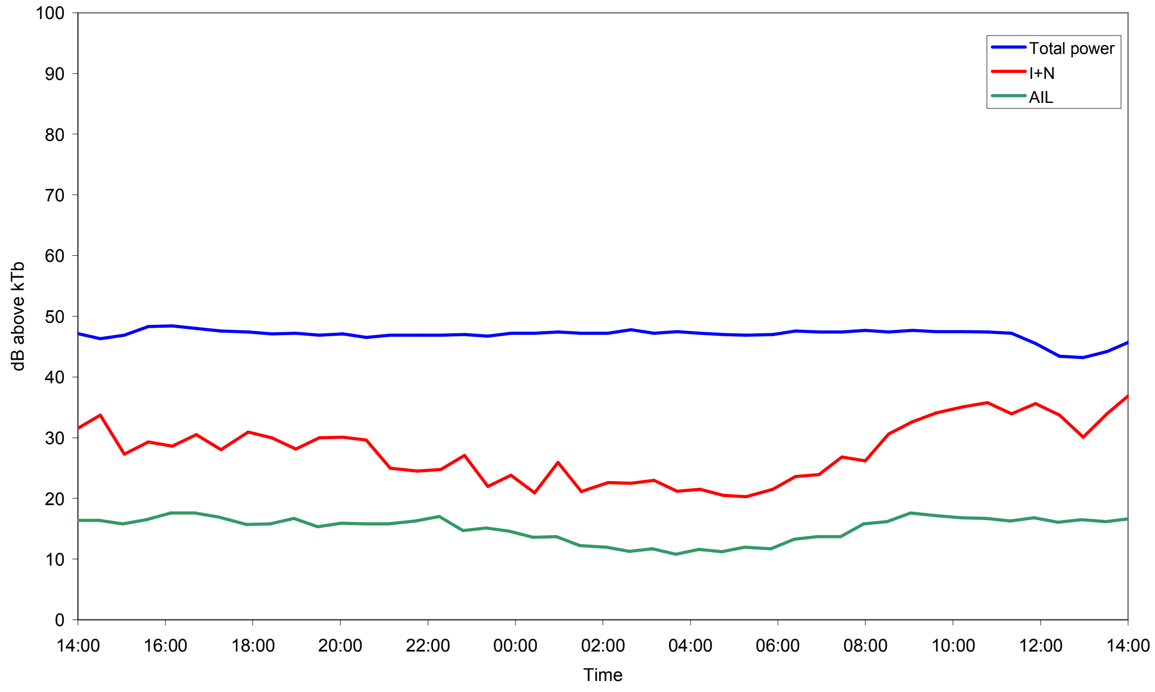

Figure 12 Grafham Water, 948.4 MHz, 18th October, antenna 1

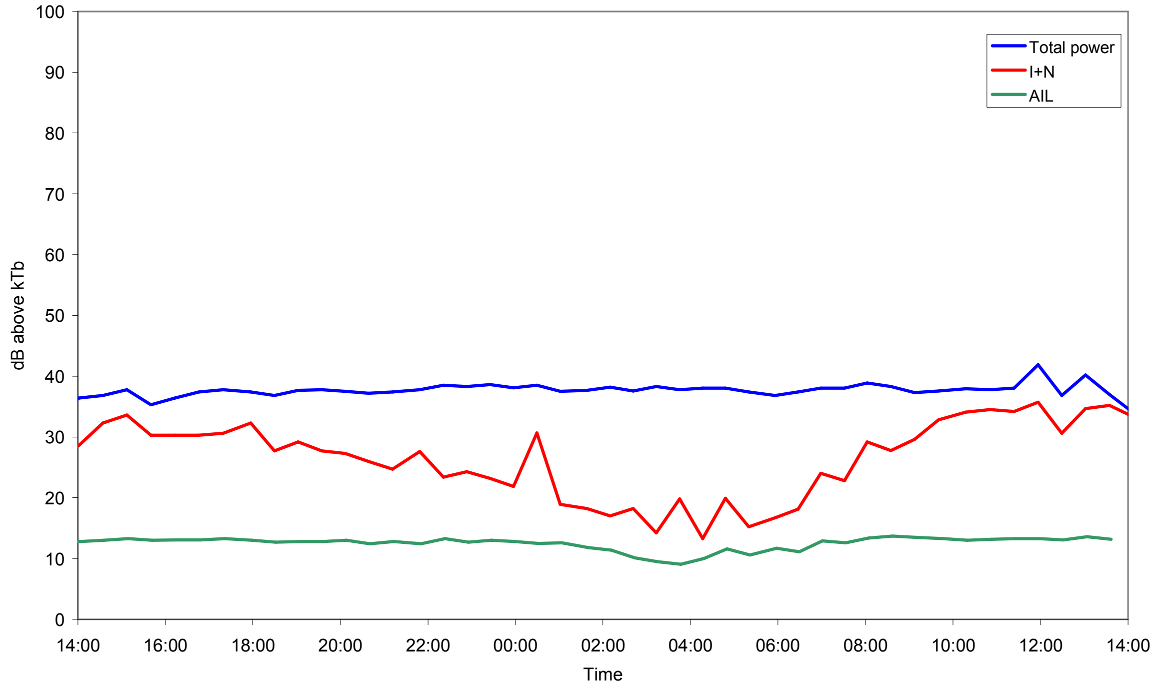

Figure 13 Grafham Water, 948.4 MHz, 18th October, antenna 2

4.2.2 1st Hull RMDF Test

The AIMS was run overnight at the Hull RMDF site on the night of 26th October. A similar configuration was used to the Grafham Water test with two AOR DA5000 antennas and an additional pre-selection filter on antenna 1. The test used the frequency of a base station channel that exhibited clear diurnal I+N variation in phase 2.

Figure 14 and Figure 15 show the results of this test, from which the following observations are made:

1. The median AIL is 29 dB above kTb on antenna 1 and 27 dB above kTb on antenna 2. These levels are significantly higher than those measured at Grafham Water;

2. The diurnal variation in the I+N and AIL levels is summarised in the following table:

	I+N (σ_{I+N}, dB rms)	AIL (σ_{AIL}, dB rms)
Antenna 1	4	1
Antenna 2	4	1

3. We see that the I+N exhibits considerable diurnal variation in the way previously seen, confirming that this effect is still visible at this site;

4. The GSM AIL algorithm successfully removed most of the diurnal variation and reached an overall minimum at about 04:00;

5. The difference between antenna 1 and antenna 2 was about 2 dB for this test, compared to 3 dB in the Grafham Water test. On this occasion the median AIL power was lower on antenna 2 rather than antenna 1. This strongly supports the conclusion that it is the siting of the antennas that is the dominant effect rather than any other possible cause, such as out-of-band interference, calibration variations, etc.;

6. It is possible that the AIL estimate is accurate and indicates a high level of interference at this site. However, Ofcom's Baldock staff have checked the band using the RMDF and have not found any significant interferers. Without an explicit identification of an interferer, the conclusion must be that the algorithm has not been able to cope with the dense signal environment at this location. It is suspected that, although the diurnal variation has been removed, the AIL estimate is too high because not all the GSM ACI and CCI power has been removed. The only way of absolutely proving this would be to turn off all the GSM transmitters within range of the receiver, which is clearly impractical.

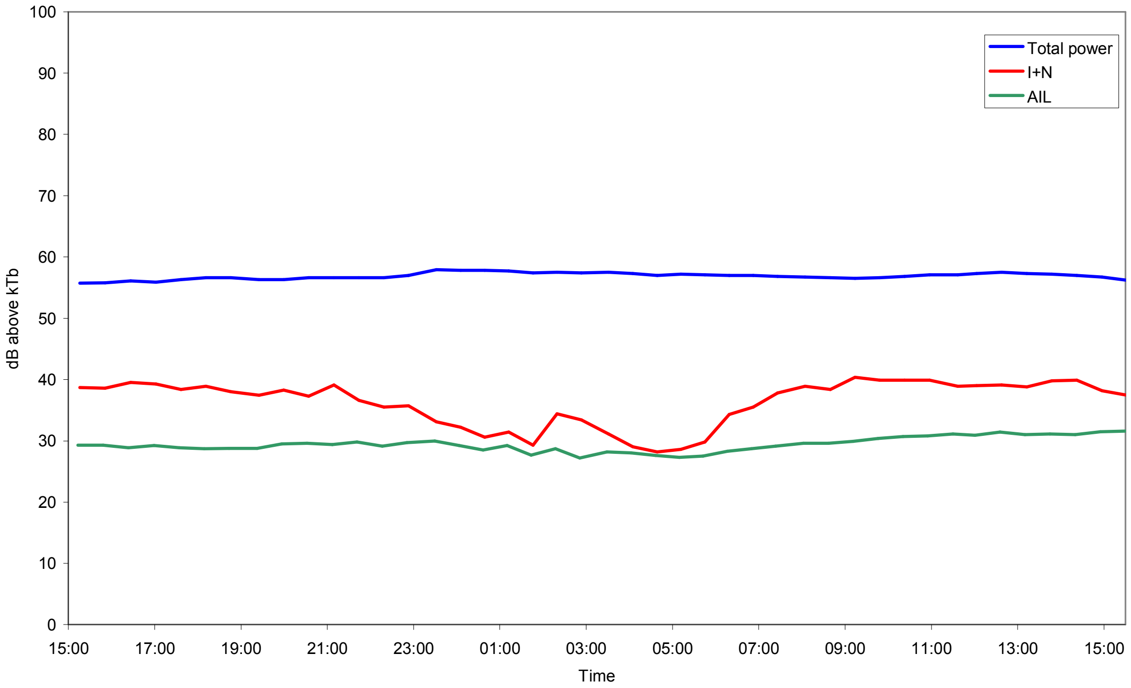

Figure 14 Hull RMDF, 954.4 MHz, 26th October, antenna 1

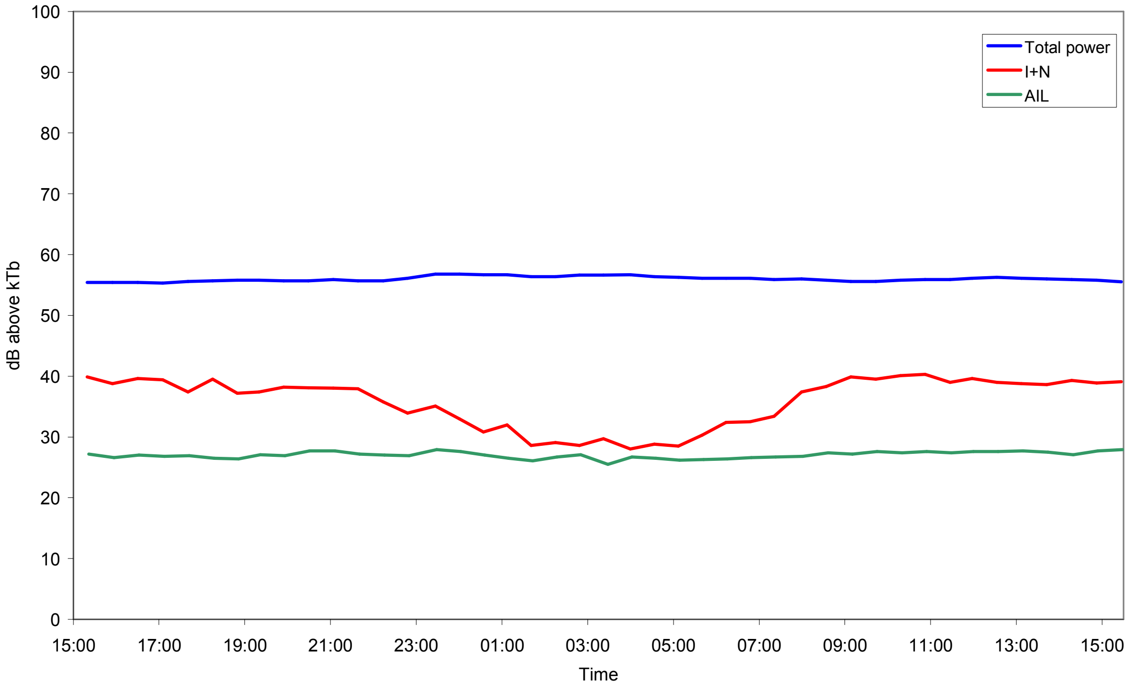

Figure 15 Hull RMDF, 954.4 MHz, 26th October, antenna 2

Looking at the Amplitude Probability Distribution (APD) for the first measurement at 954.4 MHz (Figure 16) we see that there is no significant ‘hump’ to indicate a dominant GSM signal. By way of comparison, Figure 17 shows a different channel at the Grafham Water site which exhibits a more typical, fully occupied base station signal with a clear ‘hump’ at about 95%.

From these graphs we conclude that the environment at 954.4 MHz is very noise-like. The impulsive noise graphs do not suggest any significant impulsive noise levels and Figure 16 suggests that the amplitude distribution is approaching a constant gradient similar to that of White Gaussian Noise (WGN), except that it turns down towards the left hand side.

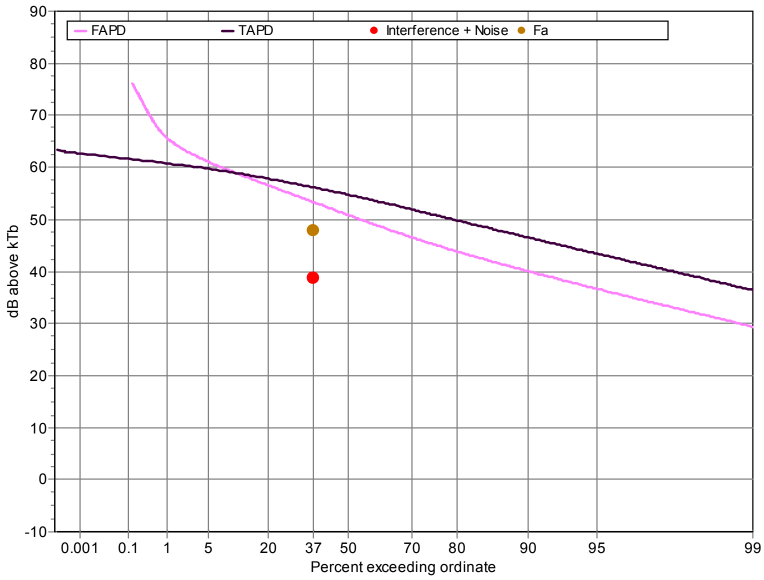

Figure 16 Hull RMDF, 954.4 MHz, 26th October, antenna 1, APD

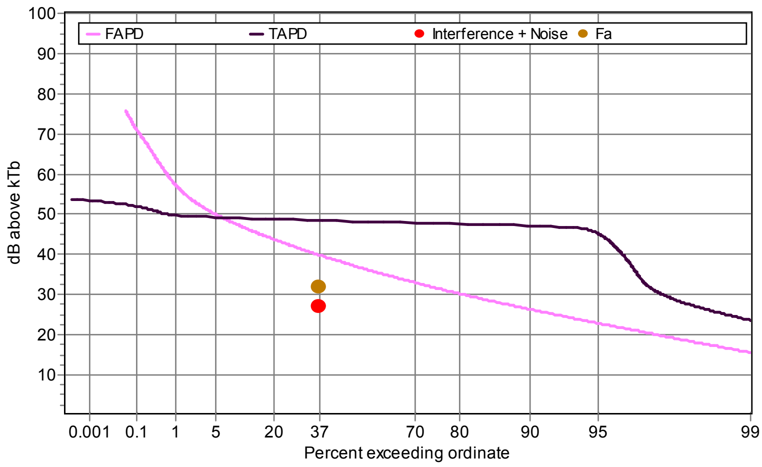

Figure 17 Grafham Water, 946.8 MHz, 18th October, antenna 1

From analysing the APDs we can deduce that, either:

- The neighbouring channels are fully occupied and are contributing very high levels of ACI and CCI, or

- There is a strong source of WGN-like interference at 954.4 MHz. Ofcom's Baldock staff were consulted about this, but they could find no obvious interferer using the RMDF.

This leads to the conclusion that there are some sites with very high levels of self-interference, making it very hard to discern an AIL at these locations. A possible short-term solution would be to widen the receiver bandwidth, but this would have the disadvantage of reducing the frequency resolution.

A second visit to the Hull RMDF was carried out (Section 4.2.4) so that this problem could be investigated in more detail.

4.2.3 Grove House

The AIMS was run overnight at MASS' Grove House site on the night of 29th October. A similar configuration was used to the previous tests with two AOR DA5000 antennas and an additional pre-selection filter on antenna 1.

In this case, both the 948.4MHz channel and the 954.4MHz channel were monitored, corresponding to the frequencies used at Grafham Water and the Hull RMDF respectively.

Figure 18 and Figure 19 show the results at 948.4 MHz and Figure 20 and Figure 21 show the results at 954.4 MHz, from which the following observations are made:

1. At both frequencies the median AIL is 14 dB above kTb on antenna 1 and 13 dB above kTb on antenna 2. These are slightly lower than the values obtained at Grafham Water.

2. The diurnal variations in the I+N and AIL levels are summarised in the following table:

		I+N (σ_{I+N}, dB rms)	AIL (σ_{AIL}, dB rms)
948.4 MHz	Antenna 1	0.5	0.5
	Antenna 2	2	1
954.4 MHz	Antenna 1	0.3	0.5
	Antenna 2	0.2	0.4

3. There is some variation in the total power in Figure 19 that is not seen in Figure 18. Whilst it is possible that this is due to out of band effects on antenna 2, it is believed that the variation is in fact due to multipath affecting one antenna more than the other.

4. In all cases the I+N and AIL graphs show negligible diurnal variation, indicating that the GSM network load was fairly constant throughout the monitoring period.

5. The difference between antenna 1 and antenna 2 was about 1 dB for this test, compared to 3 dB in the Grafham Water test and 2 dB in the Hull RMDF test. On this occasion the median AIL power was lower on antenna 2 rather than antenna 1. This further supports the conclusion that it is the siting of the antennas that is the dominant effect.

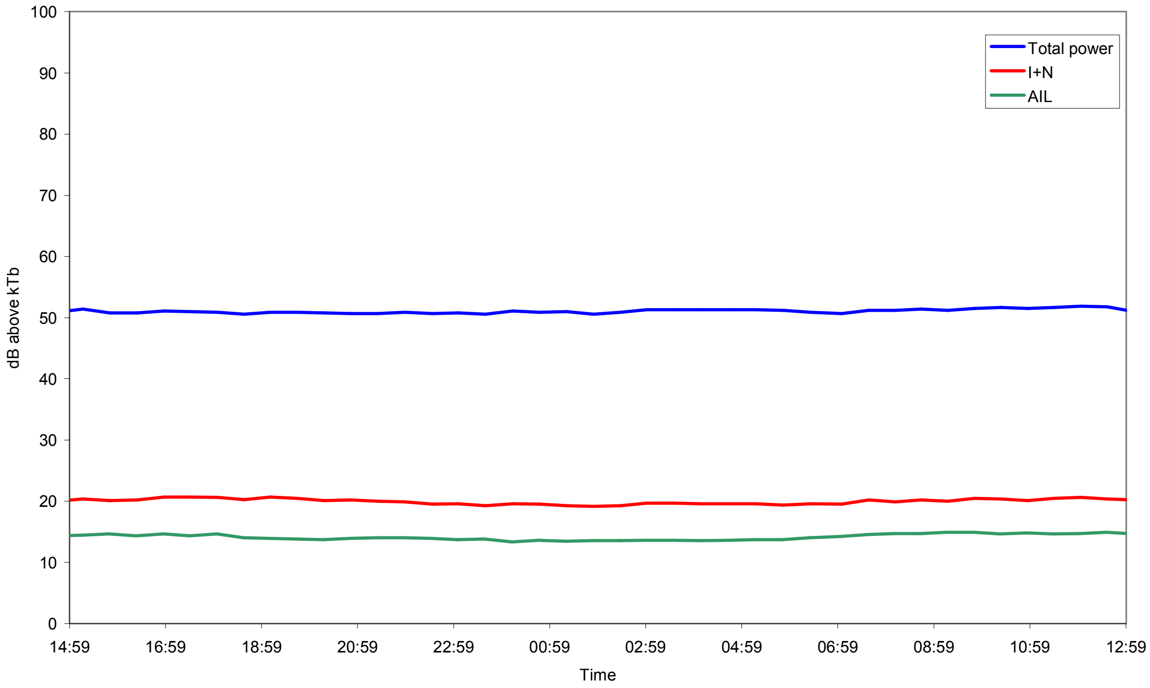

Figure 18 Grove House, 948.4MHz, 29th October, antenna 1

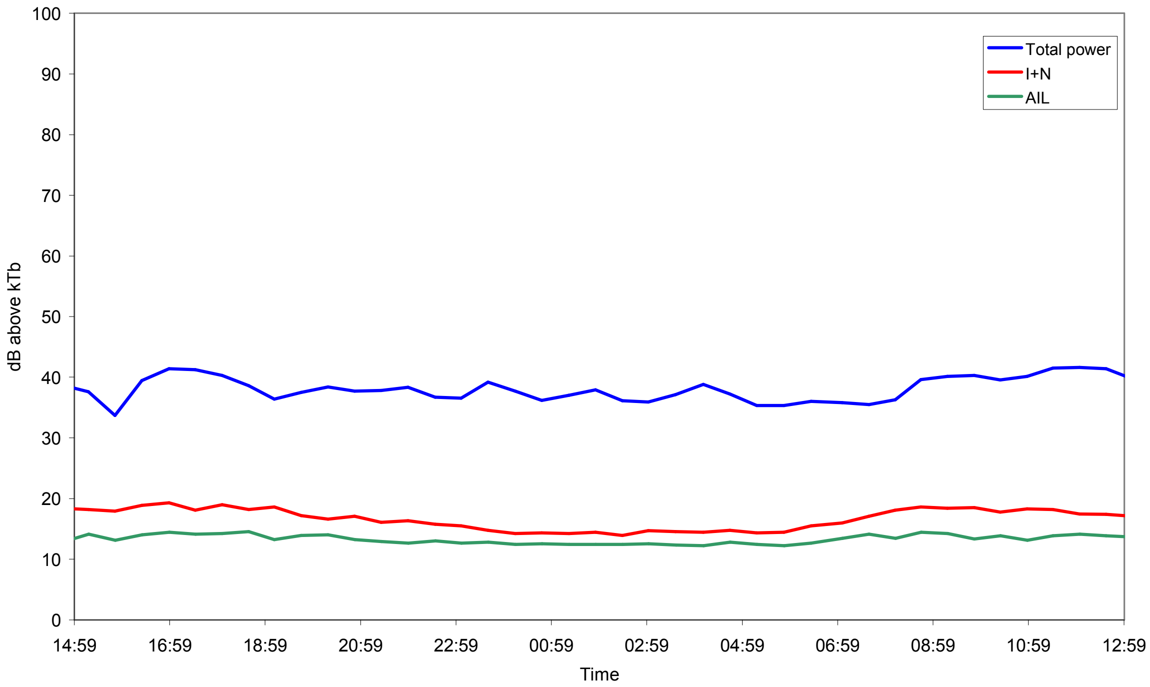

Figure 19 Grove House, 948.4MHz, 29th October, antenna 2

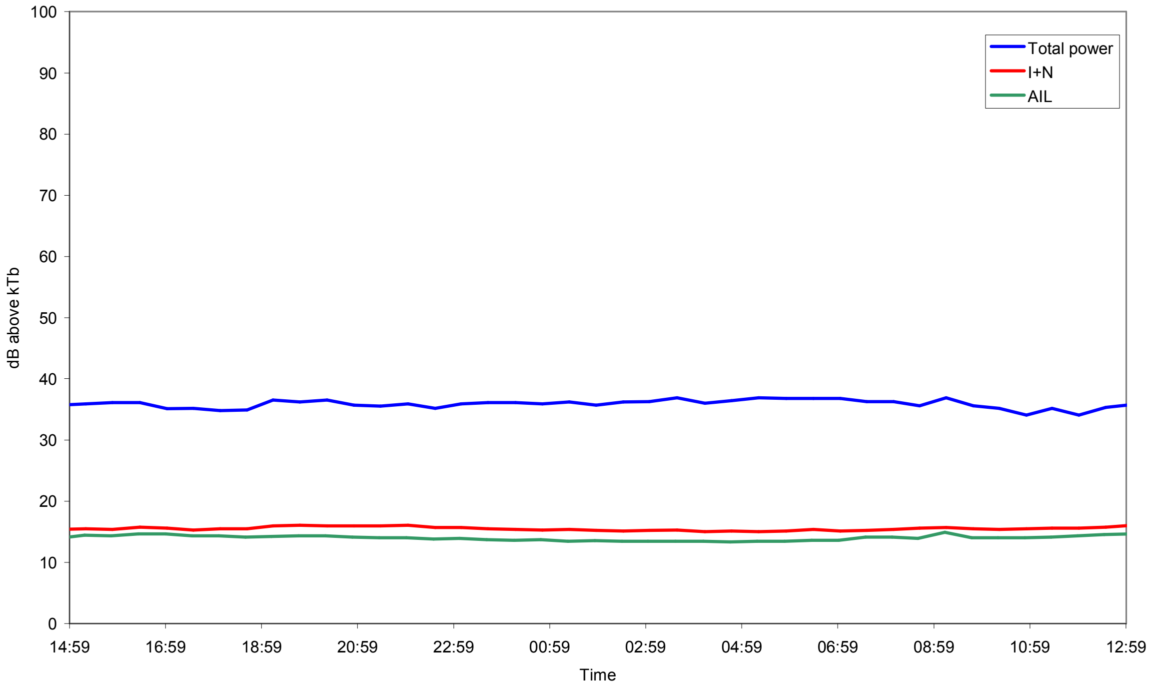

Figure 20 Grove House, 954.4MHz, 29th October, antenna 1

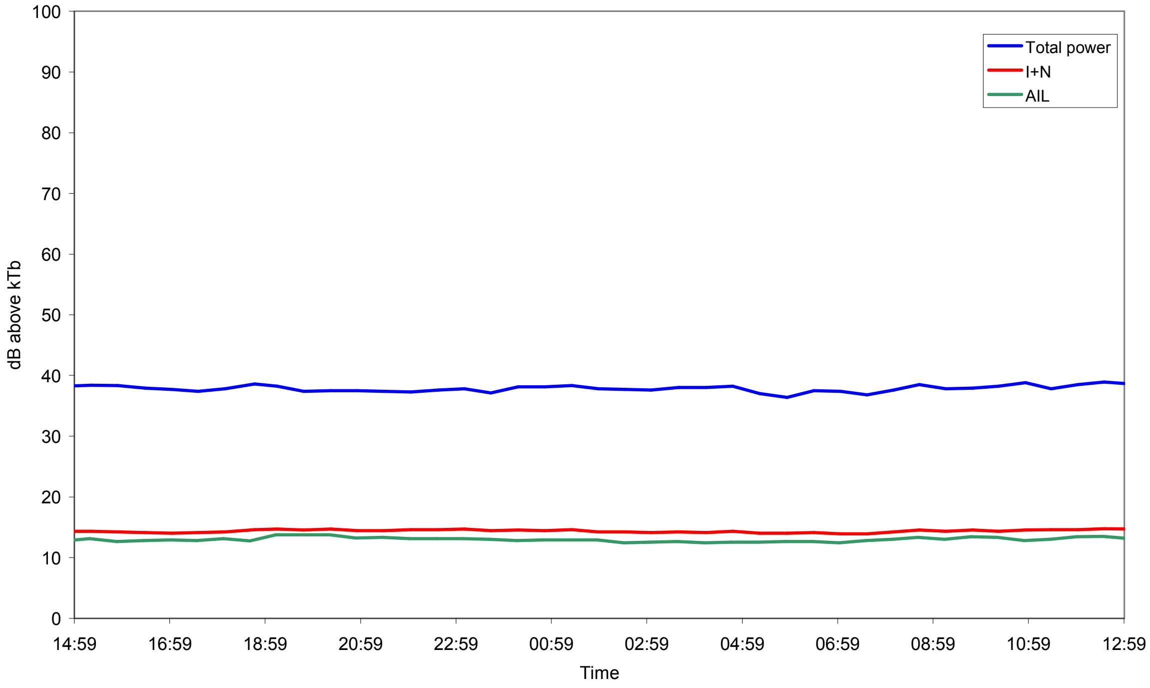

Figure 21 Grove House, 954.4MHz, 29th October, antenna 2

4.2.4 2nd Hull RMDF Test

In order to investigate further the noise-like environment encountered at the Hull RMDF site (Section 4.2.2), the AIMS was run for a second time, this time on the night of 7th November. The same configuration of two AOR antennas was used for this test. In this case, however, both the 948.4 MHz and 954.4 MHz centre frequencies were used.

Figure 22 to Figure 25 show the results of this test, from which the following observations are made:

1. At 948.4 MHz the median AIL is 13.6 dB above kTb on antenna 1 and 12.9 dB above kTb on antenna 2. At 954.4 MHz the medians are 25.7 dB and 24.5 dB respectively.

2. The diurnal variation in the I+N and AIL levels is summarised in the following table:

	948.4 MHz		954.4 MHz	
	I+N (σ_{I+N}, dB rms)	AIL (σ_{AIL}, dB rms)	I+N (σ_{I+N}, dB rms)	AIL (σ_{AIL}, dB rms)
Antenna 1	4	2	4	1
Antenna 2	4	2	4	2

3. The relatively high value of AIL seen at this site previously at 954.4 MHz was seen again on this occasion. It was not seen, however, at 948.4 MHz.

4. The APDs at 954.4 MHz again exhibit noise-like profiles, similar to Figure 16. There is no clearly discernible GSM signal at APD level, again suggesting that there are multiple carriers affecting the one of interest.

5. These test results suggest that the GSM AIL algorithm cannot see through the network self-interference when centred on 954.4 MHz at the Hull RMDF site. It produces an estimate that is too high and leads to the conclusion that the current algorithm cannot remove enough of the self-interference to see the AIL.

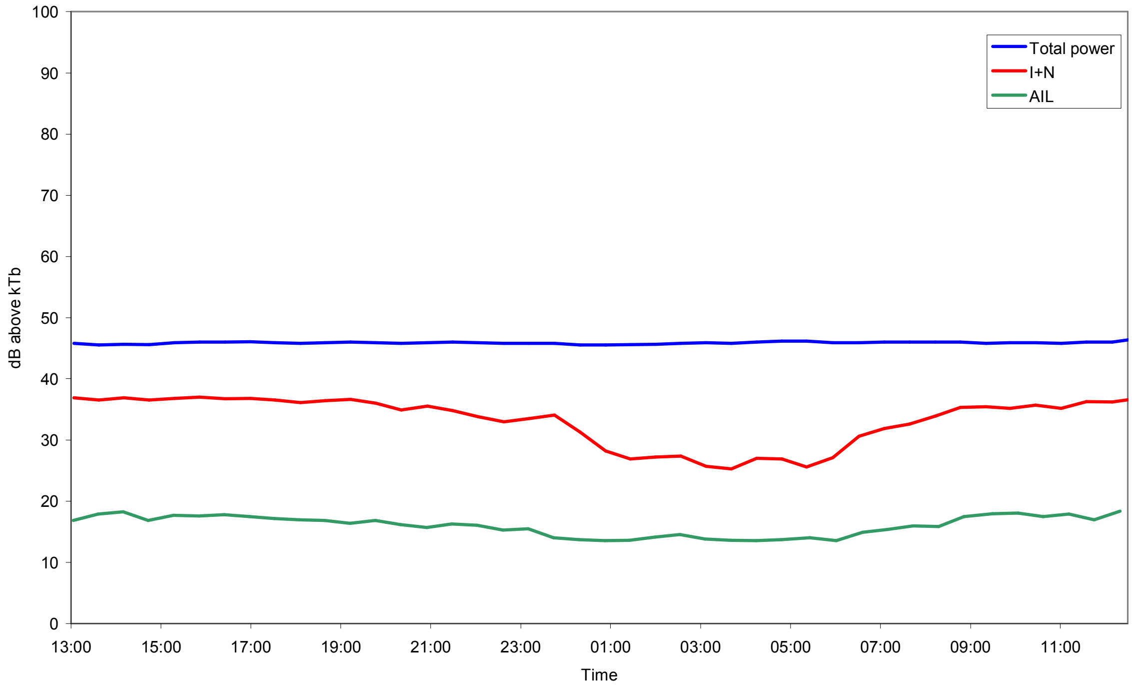

Figure 22 Hull RMDF, 948.4 MHz, 7th November, antenna 1

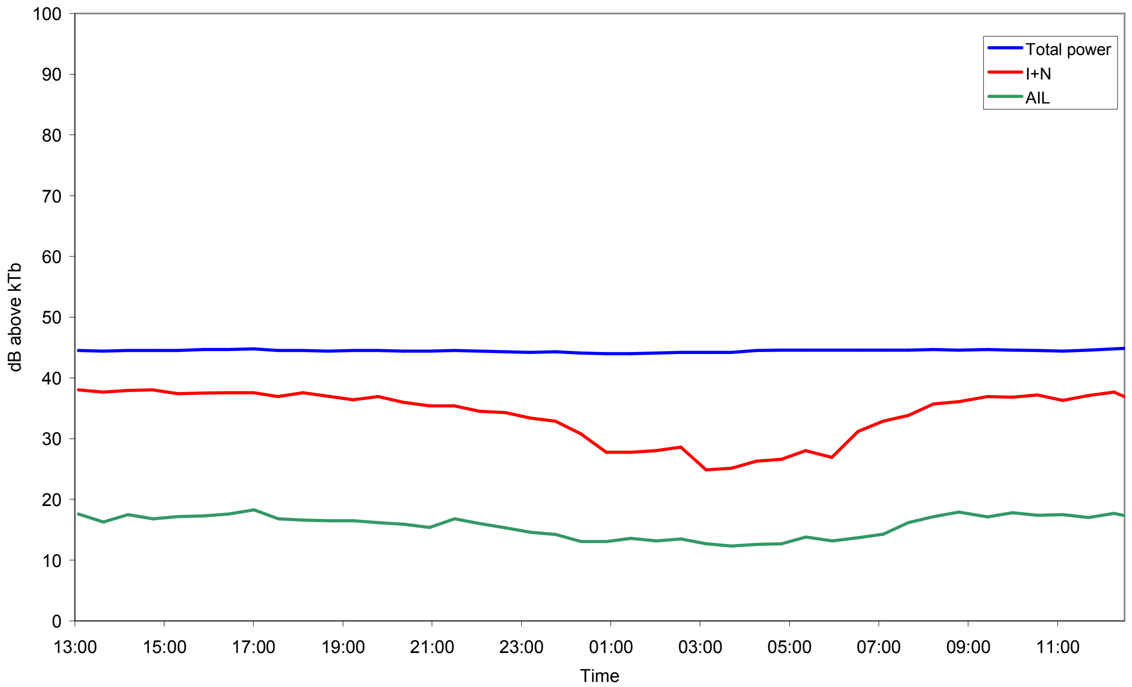

Figure 23 Hull RMDF, 948.4 MHz, 7th November, antenna 2

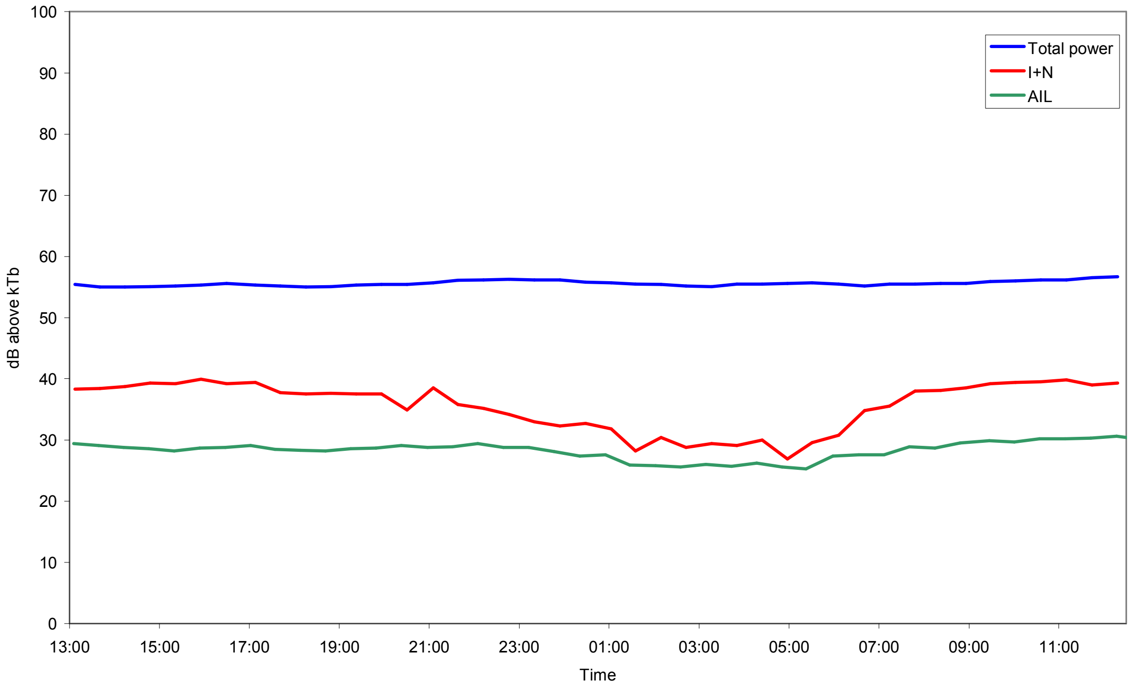

Figure 24 Hull RMDF, 954.4 MHz, 7th November, antenna 1

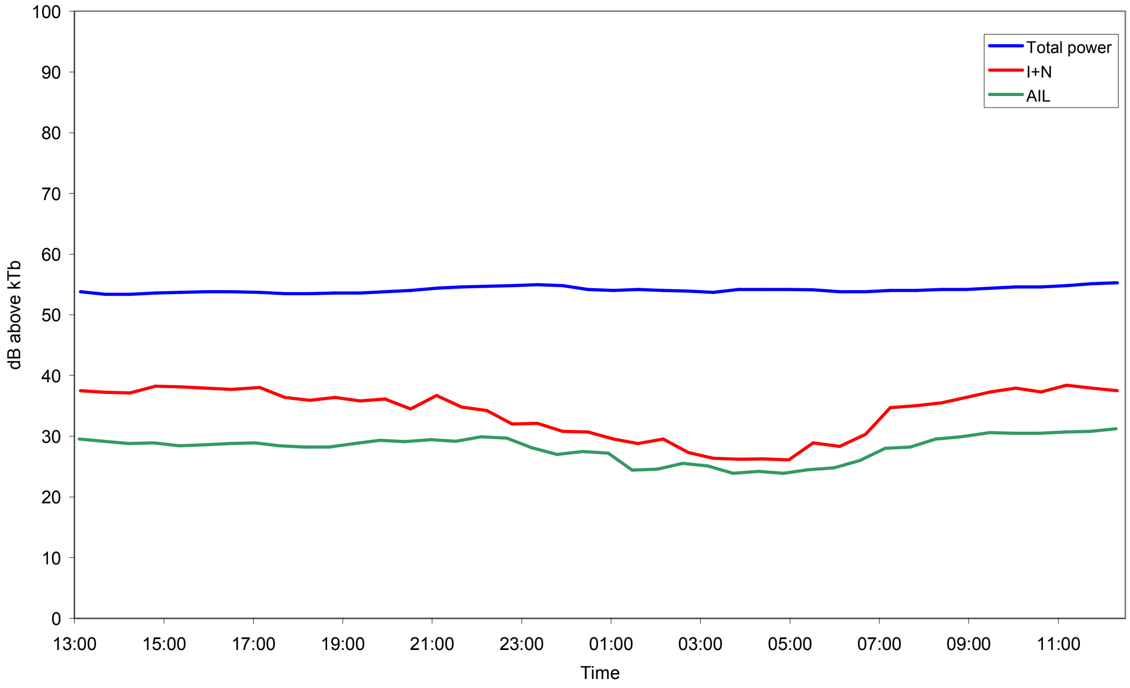

Figure 25 Hull RMDF, 954.4 MHz, 7th November, antenna 2

4.3 ANALYSIS OF FIELD TRIALS RESULTS

Figure 26 shows how the field measurements from this phase fit into the overall picture. The orange line gives the MMN levels, measured using the *Fa* parameter (see ITU-R P.372). Higher than this is the I+N line, which has been derived by averaging all the locations used in the phase 2 survey for all frequencies, except GSM.

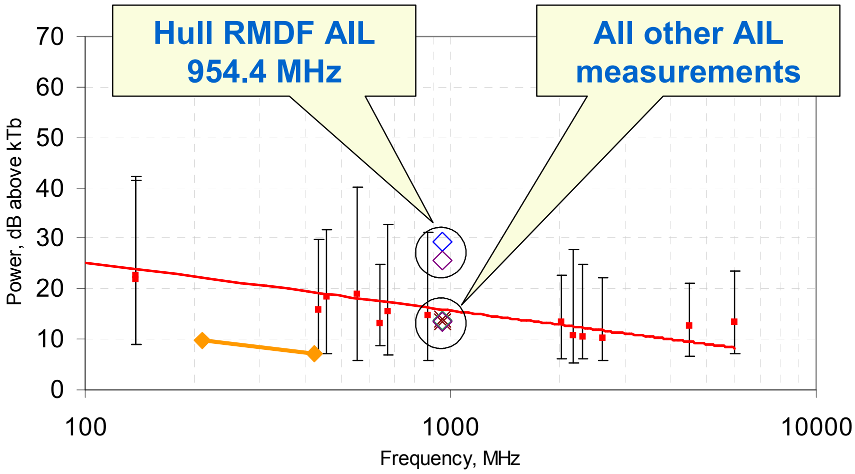

Figure 26 AIL and I+N versus frequency

It is clear that the AILs measured at Grafham Water, Grove House and 948.4 MHz at Hull RMDF fit well with the level to be expected by interpolation of the I+N measurements. We have a high level of confidence that the AIL mode is working correctly in these cases.

The Hull RMDF results at 954.4 MHz appear to be too high and are believed to be erroneous. Moving to 948.4 MHz at the same site yielded an acceptable AIL measurement, which further supports the belief that it is the density of the environment at this frequency that is a problem for the algorithm.

Looking back at the data gathered during the phase 2 campaign suggests that this problem may impact up to 40% of measurements in the densest areas of GSM network usage. This could be addressed by widening the bandwidth over which the algorithm is applied.

5 CONCLUSIONS & FURTHER WORK

The AIMS has been modified to incorporate a GSM AIL measurement mode, which has been tested in a range of laboratory and field tests, using both simulated and real data. The algorithm used in this mode effectively suppresses the diurnal variation in I+N level. The remaining variation is typically 2 dB rms or less.

It was found that the additional pre-selection filter did not have a significant effect on the results, indicating that out-of-band interference was not an issue for these tests.

This project has demonstrated that it is possible to make an AIL measurement in the GSM bands. The GSM AIL measurements fit well with the level to be expected by interpolation of the (non-GSM) I+N measurements from phase 2.

It is recommended that GSM AIL measurements be made as part of future AIMS surveys. The results across a number of sites and at various frequencies can then be compared. As well as gaining confidence in the metric, an extended survey would yield results that would help to indicate the sensitivity of the AIL to location.

6 REFERENCES

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7 ABBREVIATIONS

ACI	Adjacent Channel Interference
AIL	Ambient Interference Level
AIMS	Autonomous Interference Monitoring System
APD	Amplitude Probability Distribution
ARC	AIMS Receiver Controller
CCI	Co-Channel Interference
GSM	Global System for Mobile communication
I+N	Interference plus Noise
RMDF	Remote Monitoring and Direction Finding
RU	Receiver Unit
WGN	White Gaussian Noise