CHARACTERISATION OF THE RADIO NOISE ENVIRONMENT IN NEW ZEALAND

METHODOLOGY AND MEASUREMENTS FOR URBAN, SUBURBAN AND RURAL AREAS

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Paul Russell Banks

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Intellectual Property Rights

Abstract

A methodology for the measurement of the radio frequency environment close to the radio noise floor is presented for urban, suburban and rural areas within New Zealand for the purposes of characterisation and trend monitoring by radio spectrum managers. Flux density measurements in bands within a range of frequencies from 80 MHz to 8 GHz have been made in urban, suburban and rural areas of New Zealand during 2007 and 2008. An analysis of the band occupancy is presented in summary form. These summaries are intended as a starting point for radio spectrum usage and can be used as a reference for any future measurements. A description of the computer directories and charts resulting from these measurements, using 20 MHz bandwidths have also been included. All the results for the work have been collated in a set of computer directories named "NZRFI Directories 2007 2008", which are intended as a reference for use in the determination of local activity in particular frequency ranges. A disc with the full range measurement spectral density charts and channel occupancy charts accompanies this work. Also included on the disc are sets of 20 MHz band charts for some urban, suburban and rural location measurements.

1. Introduction

A requirement has been identified to measure radio frequency usage on a regular basis by the New Zealand Ministry of Economic Development (NZMED), so that the Radio Spectrum Management group under its charge could better manage the radio spectrum in New Zealand. This requirement is driven by the International Telecommunication Union (ITU), who stipulated the need in their Handbook of Spectrum Monitoring as follows:

"Radiocommunications have become an increasingly vital part of the telecommunications infrastructure and economy of a country and economic approaches to national spectrum management are becoming essential. These approaches promote economic, technical, and administrative efficiency, and help ensure that radio services are able to operate on a non-interference basis. In order to have effective radiocommunications, a country must have an effective spectrum management system." (ITU 2005)

The Institute of Radio Astronomy and Space Research of Auckland University of Technology (AUT) is working with the Australia Telescope National Facility (ATNF) in a bid to obtain the rights to host a radio telescope comprising a core telescope array to be built in the Western Desert of Australia surrounded by up to one hundred remote telescope array stations, of which three may be built in New Zealand. The telescope is to be known as the Square Kilometre Array (SKA) because it is intended to construct a telescope array that will have a total collecting area of one square kilometre. An aspect of this bid under consideration, concerns the level of radio frequency interference (RFI) that can be expected at the telescope station sites. A protocol and a method developed to measure the RFI at the telescope sites bear a strong resemblance to the work that would be required to measure RFI in general.

This thesis presents methodology by which general radio spectrum usage trends could be monitored at any location in New Zealand. The methods were developed to measure the spectrum as close to a thermal noise level as possible, which was seen as an starting level to approach and regarded as a level that could not be bettered without access to equipment such as cooled receivers and amplifiers. The thermal noise level is explored further in section 1.3 below. City and suburban locations of Auckland were used for signal capture as well as rural locations at both ends of New Zealand, one of which is a potential SKA station site. Noise maps constructed from recorded signal levels and channel occupancy charts, for various frequency ranges and resolution are shown in appendices A to C. The method makes use of equipment widely used currently, although customisation would be desirable for intended regular monitoring. Some specialist software has been acquired for the work and this is obtainable through ATNF.

1.1 RFI Measurement Project Details

The project objectives agreed between AUT and NZMED were stated and achieved as follows;

1. Provide information on the quality of the radio spectrum resource in New Zealand by measuring the level of unwanted ambient radio noise (pollution). Chapter 3 and the Appendices provide information on the quality of the radio spectrum in the Auckland City and Mount Wellington (Auckland) suburban environments as well as the Karaka (South Auckland), Kauri Flat (Northland) and Awarua (Southland) rural environments.

2. Develop a measurement methodology, taking into account cost, accuracy and reliability considerations. Chapter 2 discusses the methodology developed from protocol used to measure radio frequency interference levels at potential SKA sites (Ellingson et al. 2003). Experience gained in the suburban and city regions identified ancillary equipment required to accommodate transmitters in close proximity to busy radio spectrum environments.

3. Produce information suitable for identifying opportunities for using the radio spectrum resource more efficiently, managing the level of radio noise pollution and the implementation of new technologies such as Ultra Wide Band (UWB). The appendices provide a means of identifying such opportunities in a generic sense. The external drive containing the directory “NZRFI Directories 2007 2008”, that

this work accompanies, provides a means of identifying opportunities at localised frequencies. This is discussed in chapter 3.

4. Support an international bid to host the Square Kilometre Array (SKA) radio telescope project. The base methodology was designed specifically for this purpose, and readings recorded at Awarua (Southland) are being used directly, as this is a potential site for a SKA remote telescope station (Beresford 2006).

5. Support advanced skills in the communications, applied mathematics and geographic information systems industry sectors. The methodology will be further developed for use in radio telescope environments as such monitoring is standard practice at radio observatories. It can be used to support advanced skills in the communications industry as it has only become possible to obtain such records with recent advances in receiver, spectrum analyser and computer technology. Applications in other industries are likely to evolve with time.

The project scope was also agreed to be as follows;

1. Geography to be limited to a region containing one of the three major cities, surrounding suburbs and extending to the rural area. Auckland was selected as the central focus, but logistical issues forced the rural areas measured well beyond the city limits, though Kauri flat (Northland) can be argued as extending to the rural area of Auckland. Some measurements were gathered from near Karaka (South Auckland) and Awarua was also selected as rural as it is a potential SKA site. Measurements were also recorded from locations listed in section 2.4 below, but time limitations prevented their analysis. The data are retained however and it is recommended that these are analysed as the measurements will be useful in building a more substantive record set.

2. Frequency limited between 30 MHz and 30 GHz. Equipment limitations prevented measurements below 80 MHz and above 10 GHz.

3. Measurement time periods to range from short term (instantaneous) periods to a month or longer. The most common time periods from which signal recordings were taken were twelve to twenty four hour periods, as longer times were not practicable. Longer times should only be considered for longer term usage, when the appropriate method is finalised. The project required extensive experimentation in order to recommend an appropriate methodology and time limitations prevented measurements beyond a few days.

4. Polarisation to be horizontal, vertical, slant and circular. Vertical and horizontal polarisations were studied as these were the antenna polarisations available. Slanted polarisation could have been studied but time limitations prevented this.

5. The chosen project methodology was to be scalable dimensions of time, frequency and polarisation. This is achieved with appropriate antennae and ancillaries such as amplifiers and filters.

6. The chosen methodology must be extendable to cover other populated areas of New Zealand. The methodology can be applied in any populated area of New Zealand. For Auckland City, the signals were measured less than 1300 m from the Auckland Sky Tower transmitters which represents a busy transmitter location.

7. The chosen methodology is to take into account cost accuracy and reliability considerations. Standard measurement equipment was used. Australian specialist software was obtained, which should be affordable to interested agencies. Equipment sets were reliable and accurate once developed and can be improved for future requirements.

The following specific requirements were stipulated for the project;

1. Develop and document the methodology for measuring ambient radio noise. Methodology has been developed and is documented in chapter 2.

2. Establish a baseline level of ambient radio noise against which other levels may be compared. Baseline levels are presented in chapter 3 and in the appendices.

3. Monitor the level of ambient radio noise in the geographic, frequency, polarisation and time domains. Levels were monitored in these domains and are presented in appendices A to C and discussed in chapter 3.

4. Analysis, interpretation and presentation of the data to produce geographical representations (noise "maps") showing the ambient noise levels in each of these domains. These are presented in appendices, NZRFI Directories 2007 2008 and discussed in chapter 3.

5. Provide a method for porting the methodology from radio quiet zones to radio noisy zones. Measurements were conducted in quiet and noisy zones. This aspect is discussed in chapter 2.

1.2 Frequency Usage and the Radio Noise Floor

Section 1.1 above indicates a desire to conduct regular observations of the New Zealand radio spectrum usage in order to obtain data to aid its management, and the requisite was for measurements to be as close to the radio noise floor as possible. Experience gained in the course of the project revealed that alignment of these two objectives would require compromise because of the practicalities of the tasks involved, and time limitations. The compromise centred on the resolution bandwidth (RBW) to be used for measurements.

Figure 1.1 below plots the thermal noise level for T = 293 K, which has been assumed as a practical noise floor that could be reached for measurement purposes. The plot is for rising RBW of 1 – 1000 MHz which in terms of the spectrum analyser sensitivity, is lowering resolution. The thermal noise level is given by P = kTB, where k is the Boltzmann constant, T is ambient temperature, assumed as 293 K and B is bandwidth (ITU 2003). The screen readings or displayed average noise level (DANL) of the spectrum analyser used are plotted for the internal pre amplifier switched on and off. If the pre amplifier which has a gain of 20 dB is switched on for all measurements (as it was), then an external low noise amplifier

(LNA) with a further gain in the order of 15 dB will reach the estimated thermal noise level and provide minimum signal detection. An external LNA in the order of 20 dB was necessary for measurement. These were provided by ATNF and AUT. The LNA requirement was guided by the ITU recommendation SM.1753 as discussed in section 1.4 below.

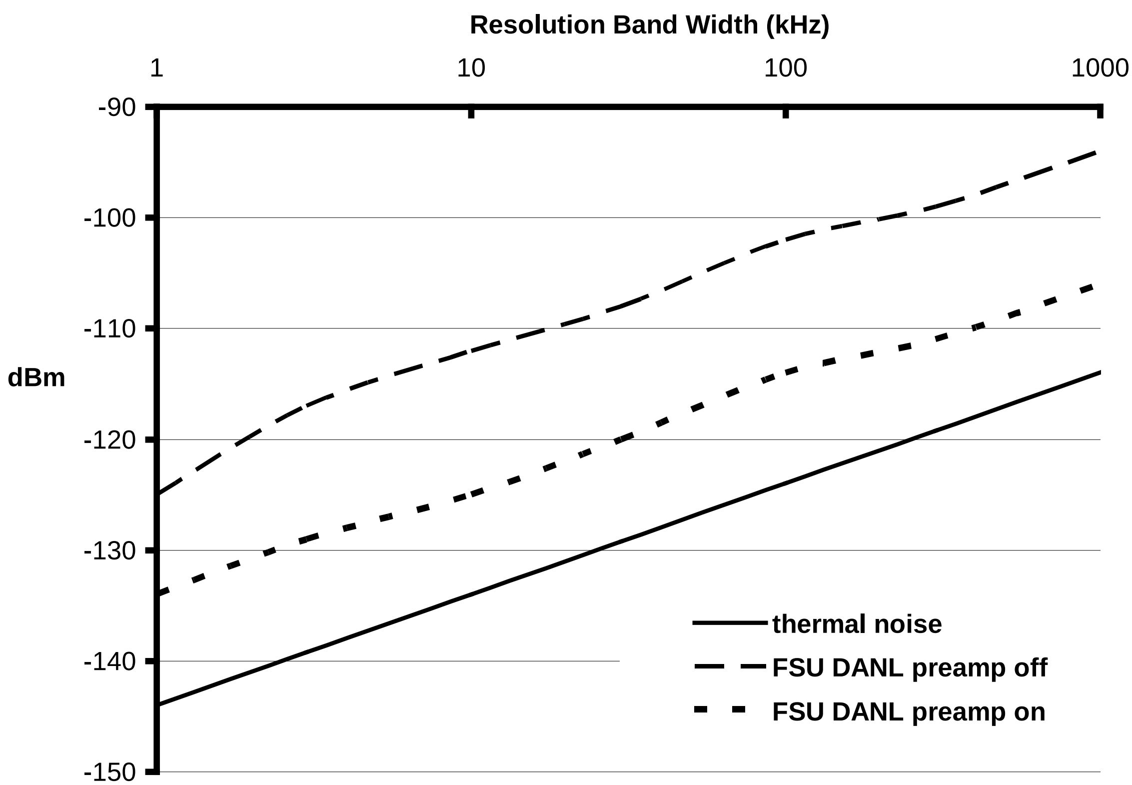


Figure 1.1: Thermal noise (= kTB) for T = 293 K and spectrum analyser DANL

1.3 International Telecommunication Union (ITU)

The ITU publications regarding spectrum monitoring are substantive in terms of fundamentals, mathematical principles, measurement systems and instrumentation applicable. The recommendation ITU-R P.372-8 Radio noise defines sources of radio noise as radio noise external to the radio receiving system deriving from the following causes (ITU 2003):

- radiation from lightning discharges
- unintended radiation from man made sources
- emissions from atmospheric gases and hydrometeors
- the ground or other obstructions within the antenna beam
- radiation from celestial sources

Recommendation ITU-R SM.1753, Method for measurements of radio noise refers to P372 and goes further in defining radio noise as the sum of emissions from multiple sources that do not originate from radiocommunication transmitters (ITU 2006). This document specifies the use of an LNA to keep the measured noise at least 10 dB above the equipment noise floor and specifies further requirements for equipment and processes used for the measurement of radio noise as defined. Both of these specify signals from transmitting or receiving systems as beyond the document scope. This project merged noise floor and spectrum usage measurements so that both could be gauged from the data produced. The noise floor can be examined in frequency bands free of spurious emissions as per the SM.1753 recommendation.

Recommendation ITU-R RA.769-2 outlines the Detrimental-level interference criterion as follows (bandwidth notation changed to from Δf_0 to B for consistency);

"The sensitivity of an observation in radio astronomy can be defined in terms of the smallest power level change ΔP in the power level P at the radiometer input that can be detected and measured. The sensitivity equation is:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{Bt}} \qquad (1)$$

where:

P and ΔP:	power spectral density of the noise
B:	bandwidth
t:	integration time, P and ΔP in equation (1) can be expressed in temperature units through the Boltzmann's constant, k:

$$\Delta P = k\Delta T \;; \quad \text{also} \quad P = kT \qquad (2)$$

Thus we may express the sensitivity equation as:

$$\Delta T = \frac{T}{\sqrt{Bt}} \tag{3}$$

$$T = T_A + T_R$$

This result applies for one polarization of the radio telescope. T is the sum of T_A (the antenna noise temperature contribution from the cosmic background, the Earth's atmosphere and radiation from the Earth) and T_R, the receiver noise temperature. Equations (1) or (3) can be used to estimate the sensitivities and interference levels for radio astronomical observations." (ITU 2003)

Equation (3) indicates that bandwidth B or integration time t should be increased to maintain a low noise level, but when a signal of interest is of a bandwidth close to or less than the noise bandwidth, it will be diluted by the noise and hence the resolution bandwidth must be kept narrow. In this case the integration time must be increased to maintain low noise. The problem then occurs that scan times increase substantially. This methodology obtained used resolutions derived from the recommendation above and the issues outlined can be seen in the results. Further study of these aspects is recommended in chapter 4 below.

1.4 Square Kilometre Array (SKA)

Methodology developed for this work stemmed primarily from a protocol published as RFI Measurement Protocol for Candidate SKA Sites (Ellingson et al. 2003). The document outlined frequency bands of interest, instrumentation, resolution required and time periods required for the characterisation of the possible SKA station sites. It concentrated on two measurements cycles, the first intended to eliminate totally unsuitable sites and the second to focus on frequency bands of particular interest to radio astronomers. While many parameters from the protocol were used in the development of the methodology for New Zealand, specific frequency bands have not been targeted as those chosen were all that were possible with the available equipment. Resolution, numbers of pointings and other parameters used have been tested in the interests of the overall methodology, designed to capture the most useful results, across the broadest frequency ranges possible. ATNF carried out measurements at the proposed Australian SKA site of the Western Desert based on the SKA protocol, and the New Zealand work has used equipment, software and methods that were used for the work in Australia, provided by ATNF.

1.5 Radio Frequency Interference (RFI) Surveys

It appears that while ITU recommendations are seeking regular monitoring for spectrum management purposes, the results of any such monitoring taking place is not published in general and there is no data available for comparative purposes except that available to the university for SKA purposes such as in figure 1.2 below.

U.S. Department of Commerce, NTIA Reports of Broadband Spectrum Surveys at Los Angeles, San Diego, San Francisco and Denver describe a mobile system used that is similar to the method used in this work (Sanders, Ramsey et al. 1997). These reports present charts of maximum, mean and minimum flux density, similar to those in Appendix A, although they focused on radio environments with substantial operations such as coastal and military components, as opposed to urban, suburban and rural components used for this work. It is pointed out that attenuation and filtering is necessary for the reduction of inter-modulation products and that this will reduce the chance of receiving some signals of interest. It is necessary to filter and attenuate to minimum levels possible when measuring. The work similar to this in terms of locations gives median value estimate charts for business, residential and rural areas between 200 kHz and 200 MHz (Spaulding and Disney 1974).

Logistics drove the location selection for this work. In each location presented in this report, mains power was available and security levels were high allowing equipment to be left running unattended. There were air conditioning blowers within 10 m of the AUT location used and high tension power lines within 500 m of the Mt. Wellington location. While it may have been more ideal to move away from these noise sources, it will be desirable to determine any effects from these sources on frequencies in future. If measurements for this work were effected, it is not observable. The method used here is portable and comparisons can be made in future.

Figure 1.2 below shows records of measurements made in Australia in Sydney, Narrabri and Mileura (the intended core site for the SKA in Australia), using the methods applied in this work, and figure 1.3 was recorded during training at ATNF, Marsfield, Sydney.

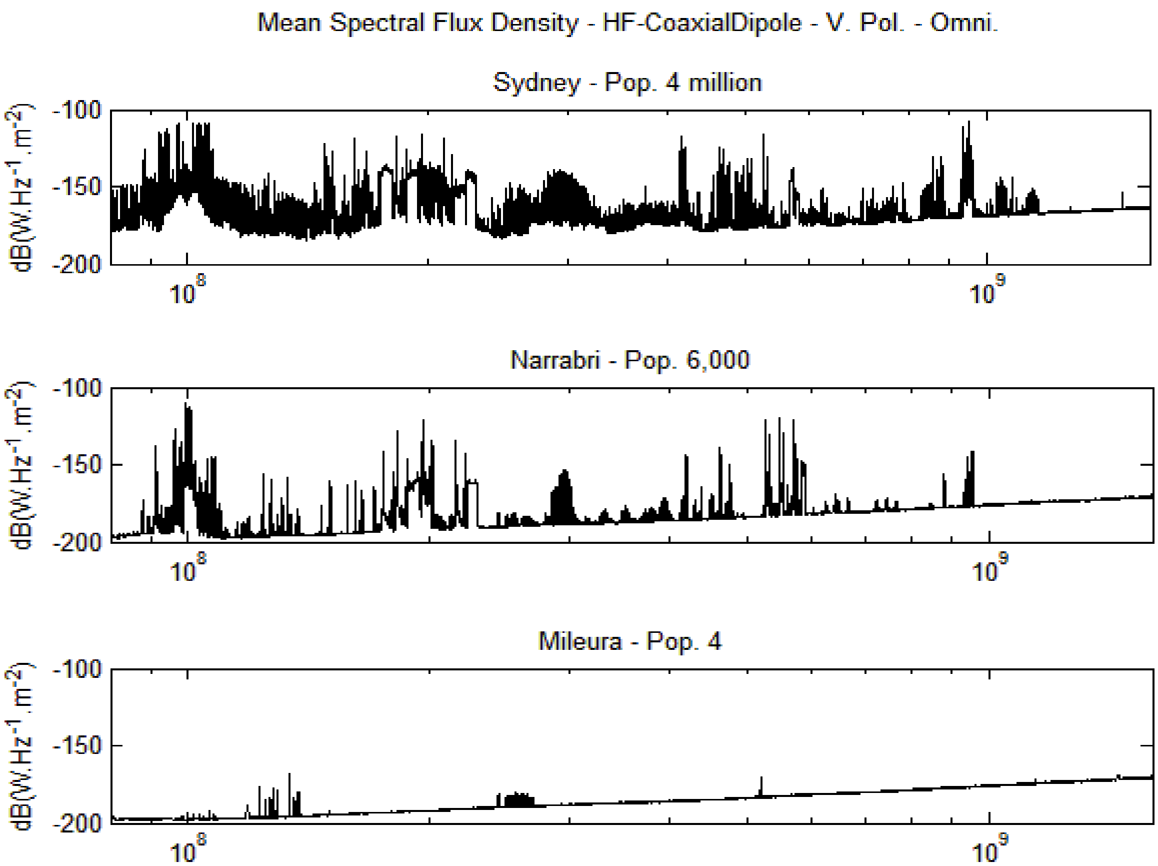


Figure 1.2: Recordings of ATNF personnel (Beresford 2006)

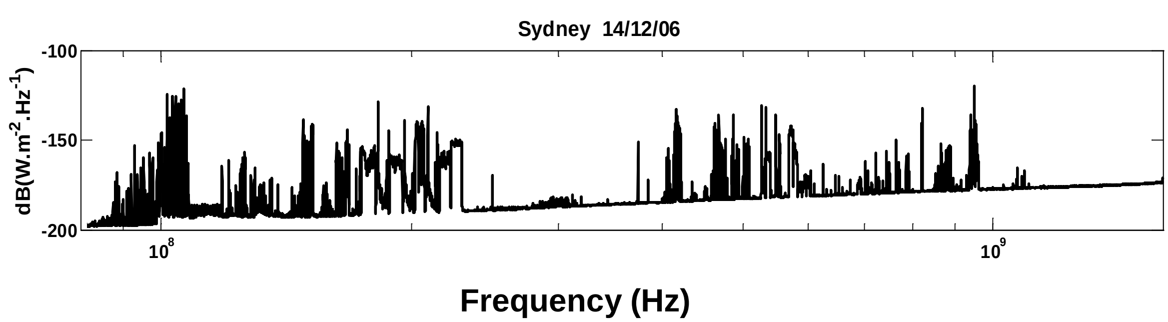


Figure 1.3: Recording taken in training at ATNF, Sydney

Figure 1.4 below gives a diagram equivalent to figure 1.2 above for the New Zealand situation, measured in the course of this project. Each location cannot necessarily be deemed typical for urban, suburban and rural locations as each location has transmission characteristics that could be regarded as unique to the location. For example, Sky Tower transmissions influence the Auckland City and the Mount Wellington diagrams below while the Karaka diagram is influenced by the Auckland International Airport radar.

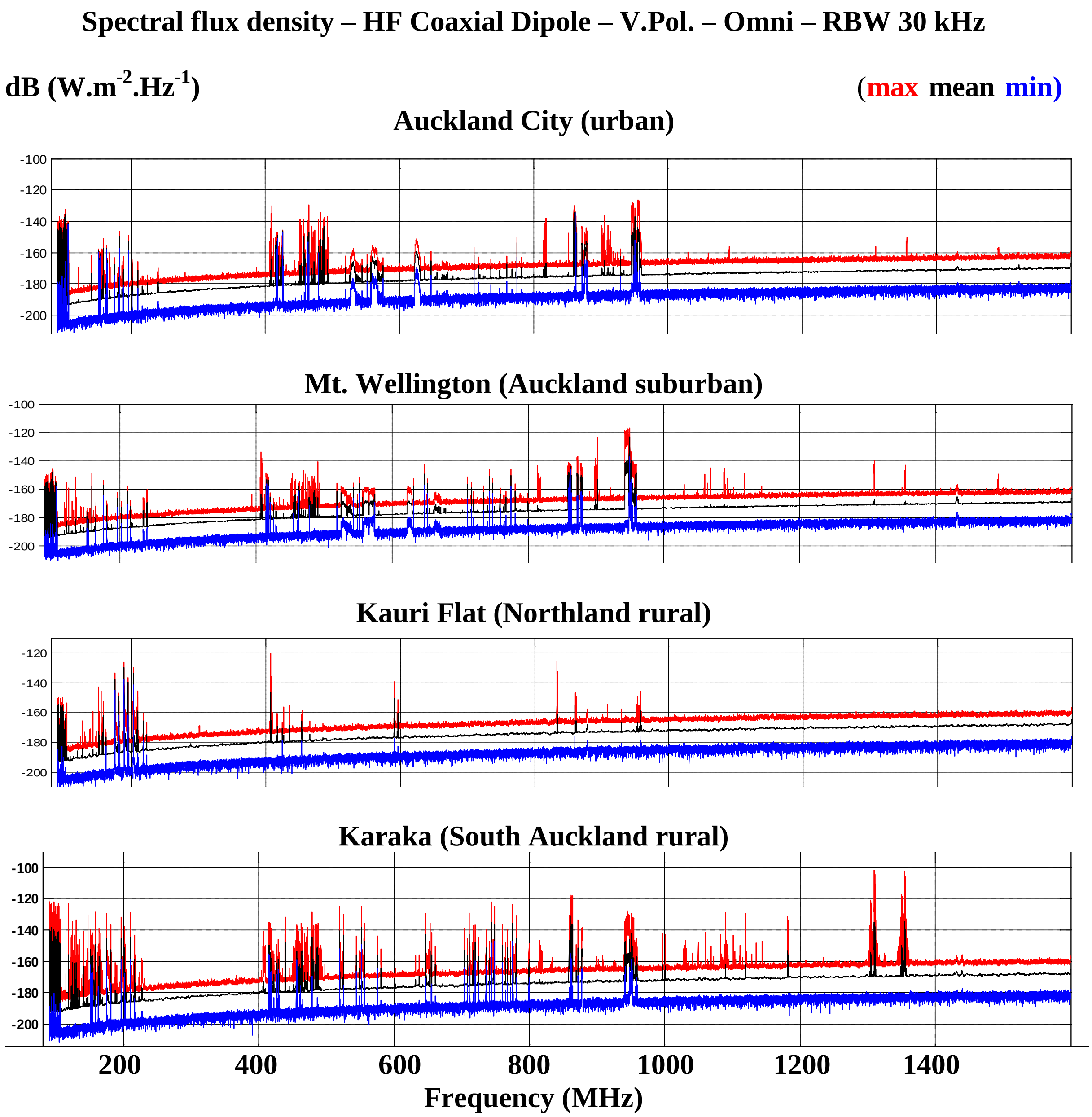


Figure 1.4: Recordings in New Zealand 80 – 1600 MHz

2. Methodology

It was known from the commencement of the project that the quality of results would be dependent on the quality of equipment obtained. It has only been the development of high speed and high capacity computer power, combined with the recent developments of spectrum analyser and radio receiver equipment that permits the notion of spectrum trend monitoring on a broad scale. The scope of the project was intended to investigate the frequency spectrum between 30 MHz and 30 GHz. Equipment capable of wideband spectrum scanning and high capacity recording was not available initially however the SKA component of the project produced substantial interest from ATNF, Sydney who, with Neo Vista Systems Incorporated (NVSI), Sydney, provided a suitable spectrum analyser, control and recording software and a coaxial dipole antenna. They also provided a Miteq LNA and a noise source for equipment calibration. ATNF also provided Matlab analysis software being used for potential SKA site RFI analyses. AUT provided a log periodic antenna which was used for higher frequencies as well as a Minicircuits LNA, cabling and connectors as required. Thus it was possible to make measurements in a range of frequencies from 80 MHz to 10 GHz although it was not possible to access all frequencies within the above range primarily because of ancillary equipment limitations. However this was not perceived to be impeding on the project.

In general, the experimental methodology concerned attempts to fully characterise the radio environments measured, as close to the radio noise floor as was reasonably practicable. Inter-modulation effects caused by powerful transmissions in city environments required filtering and attenuation, though the filter addition was normally enough attenuation. It was the filter frequency range limits, coupled with the LNA limits that lead to measurements being obtained primarily in the following frequency ranges;

80 – 1600 MHz
1340 – 4000 MHz
5500 – 8500 MHz

The project scope required measurements taken in city, suburban and rural locations within New Zealand which necessitated considerable logistical effort. The equipment required transportation and was of some bulk and fragility. A van and driver were obtained for the purpose and measurements were recorded in the following areas;

AUT Akoranga Campus
AUT Wellesley Campus (inner city readings)
Albany Heights
Whangaparoa Peninsula
Warkworth Satellite Station
Harrison Rd and Boakes Rd (suburban readings), Mt. Wellington
Kauri Flat (rural readings) and Hihi beach, Northland
Karaka (rural readings), South Auckland
Raurimu, Central Plateau
Awarua (rural readings), Southland

2.1 Equipment Used

Equipment used for each measurement has been recorded in the antenna line of the max mean min charts (c.f. accompanying disc) on the “NZRFI Directories 2007 2008” drive that this work accompanies, as exampled in figure 3.15. These charts also record number of sweeps, RBW, polarisation and bearing of each measurement. For most measurements, the spectrum analyser video bandwidth (VBW) was set at one third of RBW (if 3, 30, 300 kHz) on the advice of ATNF. Where RBW 100 and 1000 kHz were used, VBW was set to 30 or 300 kHz respectively. Table 2.1 and Figure 2.1 below show the main equipment used and general layout.

Item	Frequency	Gain (dB)
R&S FSU 26 spectrum analyser	20 Hz – 26.5 GHz	20*
R&S HK014 coaxial dipole antenna	80 – 1600 MHz	2
R&S HL050 log periodic antenna	0.85 – 26.5 GHz	8.5
Laptop computer with external drive		
Miteq AFS3-00100800-14s4s LNA	100 -8000 MHz	28†
Minicircuits Zx60-4016E+ LNA	20 – 4000 MHz	16 - 17
Minicircuits VHF1340 filter	1.34 – 4 GHz	(1)
Minicircuits VHF5050 filter	5.5 – 8.5 GHz	(2)
Noise diode HP346C	0.01 – 26.5 GHz	13 - 15
6 dB attenuators	DC – 1500 MHz	(6)
H&S MF141 cables		(0 - 12)
LMR 400 cables		(0-6)

Table 2.1: Main Equipment Used

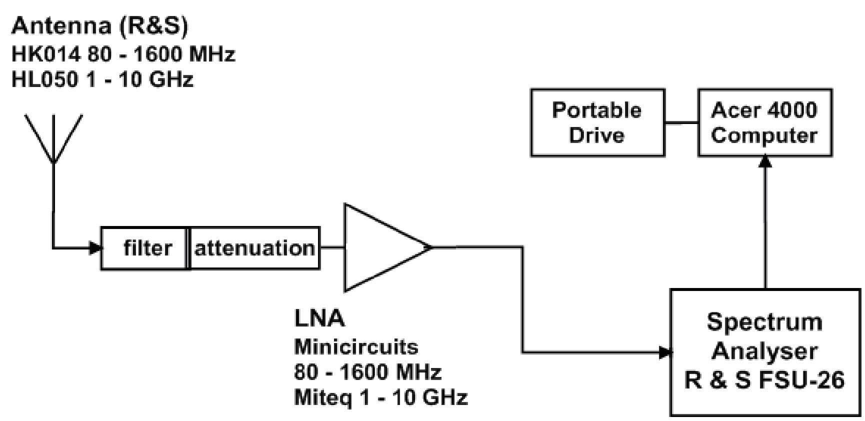


Figure 2.1: Equipment Layout

* 20 dB with preamplifier set on for all measurement and no internal attenuation (noted when used).
† From manufacturer's data ~ Gain less Noise Figure.

There is commercially available equipment that could be purchased to broaden the measurement range significantly, and it will be required if regular trend monitoring is intended. Table 2.2 below lists some equipment that could be used for trend monitoring and could be used with the software obtained for this work.

Item	**Range (GHz)**	**Gain (dB)**
R&S FSU50 Spectrum Analyser	0 - 50	
HL033 R&S antenna	0.08 – 2	6.5
HL024A11S1 R&S antenna	1 - 18	7
AC090 R&S antenna	0.85 - 40	15-40
Miteq Low Noise Amplifiers		
AU1291	0.0001 - 0.5	60
AFS44-00102000-30-10p-44	0.1 - 20	33
AMF-6F-18004000-37-8P	18 - 40	31
JSW4-40006000-60-OA	40 - 60	12
JDM2W-55006700-50-10P	55 - 67	20

Table 2.2: Useful Trend Measurement Equipment

2.2 Noise Generation

The predominant noise generators in the measurement system studied in this work were the low noise amplifiers (LNA) and the spectrum analyser used. This noise is thermal noise generated in the electronic components. These sources produced a random additive white Gaussian noise clearly seen in recordings taken, and illustrated in figure 2.2 below, particularly in the portion between 200 and 400 MHz.

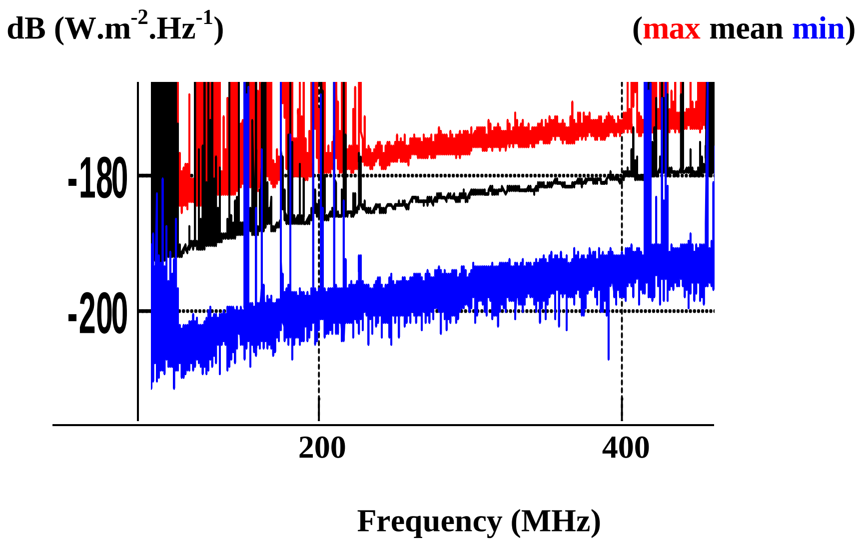


Figure 2.2: Random additive white Gaussian noise generated by instrumentation

Noise is also generated by thunderstorms, though none were noted in the course of this field work, power lines and automotive ignition. High tension wires did pass within one kilometre of suburban measurements recorded but available equipment did not permit recordings at the 50 – 60 Hz frequency level that would have been expected to generate the most noise. Similarly, no obvious effects were noted because of the proximity of automobiles, though antennae were mounted at some height above road level which mitigated effects produced. (Lee 1993).

While such effects are interesting, this work was primarily a study of method for the measurement of radio environments close to the noise floor and resources were not available to develop an accurate picture of each contributor. This can be achieved with future measurements.

2.3 Noise Figures of Devices Used

Table 2.3 below gives dB losses of devices used. Cable losses increased substantially with higher frequencies. These figures can be used in calculation of measuring system noise figures and temperatures by using the Friis formula below to show the effect of each device in the measuring circuit.

$$T_e = T_1 + T_2/G_1 + T_3/G_1G_2 + T_4/G_1G_2G_3 + \ldots$$ (Haykin 2001)

For an impedance matched linear two port device, the noise power is defined as:

$$N_d = GkT_eB$$

G = gain, k = Boltzmann constant, T_e = equivalent noise temperature, B = bandwidth.

Thermal noise: $N_t = kTB$

T is taken as 293 K by convention in defining noise factors and figures.

Total output noise:

$$\begin{aligned} N_{out} &= GN_t + N_d \\ &= Gk(T + T_e)B \end{aligned}$$

The noise figure of the device is ratio of noise out to the noise out assuming the device to be noiseless:

$$F_d = N_{out}/(N_{out} - N_d) = (T + T_e)/T$$

$$T_e = T(F_d\text{-}1)$$

For impedance matched, two port devices in cascade, the first device has a noise input N_1 plus device noise $(F_1 - 1)N_1$ and an output:

$$G_1N_1 + G_1(F_1\text{-}1)N_1 = F_1N_1G_1$$

The second device has as an input, the output of the first device plus the noise of the second device $(F2 - 1)N_1$.

The output noise power from the second device is $F_1N_1G_1G_2 + (F_2 - 1)N_1G_2$.

The overall noise figure is the actual output over noiseless output:

$$F = (F_1N_1G_1G_2 + (F_2 – 1)N_1G_2)/N_1G_1G_2$$

$$= F_1 + (F_2 – 1)/G_1$$

The noise figure equation extends to all cascaded devices:

$$F = F_1 + (F_2 – 1)/G_1 + (F_3 – 1)/G_1G_2 + (F_4 – 1)/G_1G2G3 + \ldots$$

(Haykin 2001)

Device	Range	Loss (dB)
Spectrum Analyser (DANL = -174)		16
6 dB attenuators	DC – 1500 MHz	6
H&S MF141 cables		Up to 12
LMR 400 cables		Up to 6
Miteq AFS3-00100800-14s4s LNA	100 -8000 MHz	1.4
Minicircuits Zx60-4016E+ LNA	20 – 4000 MHz	3.9
Minicircuits VHF1340 filter	1.34 – 4 GHz	1
Minicircuits VHF5050 filter	5.5 – 8.5 GHz	2

Table 2.3: Losses of devices used

For circuits used in these measurements where losses in cable and attenuator losses are equated as noise figures, $F = 10^{dBloss/10}$:

F_{sa} (spectrum analyser) = $10^{1.6} = 39.8$

F_{MF141} (cable) = $10^{1.2} = 15.8$ (worst case)

F_{LMR400} (cable) = $10^{0.6} = 4$ (worst case)

F_{AFS3} (LNA) = $10^{0.14} = 1.4$

F_{4016} (LNA) = $10^{0.39} = 2.5$

With its 20 dB preamplifier on, $G_{\mathrm{sa}} = 10^2 = 100$

$G_{\mathrm{MF141}} = 1/L = 1/15.8 = 0.06329$

$G_{\mathrm{LMR400}} = 1/L = 1/4 = 0.25$

$G_{AFS3} = 10^{2.8} = 631$

$G_{4016} = 10^{2} = 100$

For the instrumentation circuits used in these experiments listed at the beginning of Appendix A, the noise figure equation above gives the following noise figures for the circuits of the appendix figures (antennae and attenuation fitted prior to LNAs are ignored);

For the circuits of figures A1 - A7, B1 - B7 and C1 - C7 below;

$$F_{sys} \quad = \quad 1.4 + \frac{4-1}{631} + \frac{15.8-1}{631 \times 0.25} + \frac{39.8-1}{631 \times 0.25 \times 0.06329} \quad = \quad 5.4$$

Circuits of figures A8 – A9, B8 – B9 and C8 – C9 below;

$$F_{sys} \quad = \quad 2.5 + \frac{4-1}{100} + \frac{16.8-1}{100 \times 0.25} + \frac{39.8-1}{100 \times 0.25 \times 0.06329} \quad = \quad 27.7$$

Circuits of figures A10 – A14, B10 – B14 and C10 – C14 below;

$$F_{sys} \quad = \quad 1.4 + \frac{4-1}{631} + \frac{39.8-1}{631 \times 0.25} \quad = \quad 1.7$$

Circuits of figures A15 – A17, B15 – B17 and C15 – C17 below;

$$F_{sys} \quad = \quad 1.4 + \frac{15.8-1}{631} + \frac{39.8-1}{631 \times 0.06329} \quad = \quad 2.4$$

Circuits of figures A18 – A21, B18 – B21 and C18 – C21 below;

$$F_{sys} \quad = \quad 2.5 + \frac{4-1}{100} + \frac{39.8-1}{100 \times 0.25} \quad = \quad 4.1$$

These figures reveal problems encountered with the H&S MF141 cable which did not perform to specification and raised the system noise figure considerably. They also demonstrate clear preference for the AFS3 LNA which had a much better noise figure than the 4016 LNA. Noise produced by the measuring system affected the output values by an order of 20 dB above the theoretical noise floor calculation.

2.4 Locations Measured

Substantial recordings were taken at most of the sites but many were taken during developmental stages and are not considered suitable for presentation in this work. The data is available in SQL database format and can be retrieved in the future. It was deemed necessary to record as much as possible while equipment was available but not all equipment required was available in the early project stages; hence the most complete result sets have been produced from Auckland city and suburban data.

Three equipment sets were used at each location and in order to sweep the entire azimuth, the directional antenna was aimed in six directions for the 1.34 – 4 and 5.5 – 8.5 GHz recordings, giving a directional component to the signal strengths. Vertical and horizontal polarisation sweeps were recorded so that twenty four pointings were taken at each location for the two high ranges. As the 80 – 1600 MHz antenna was omni-directional, only vertical and horizontal polarisation sweeps were taken in this range. These were repeated for varying resolution bandwidth (RBW) to determine the effect on readings and to gauge the level of economy that could be achieved in the future.

2.4.1 Auckland City and Suburban Measurements

The published measurements from Boakes Road, Mount Wellington (suburban area) and those from AUT Wellesley Campus, Auckland City (urban area) were taken when all required equipment was available. The equipment at these locations suffered from substantial inter-modulation effects because of their close proximity to powerful transmitters, particularly those on the Sky Tower in Victoria Street West, Auckland City which were visible from both locations. Filters and appropriate attenuation were used to minimise these effects. Figures 2.3 and 2.4 below indicate the measuring positions and directions scanned in Auckland City and the suburb of Mount Wellington.

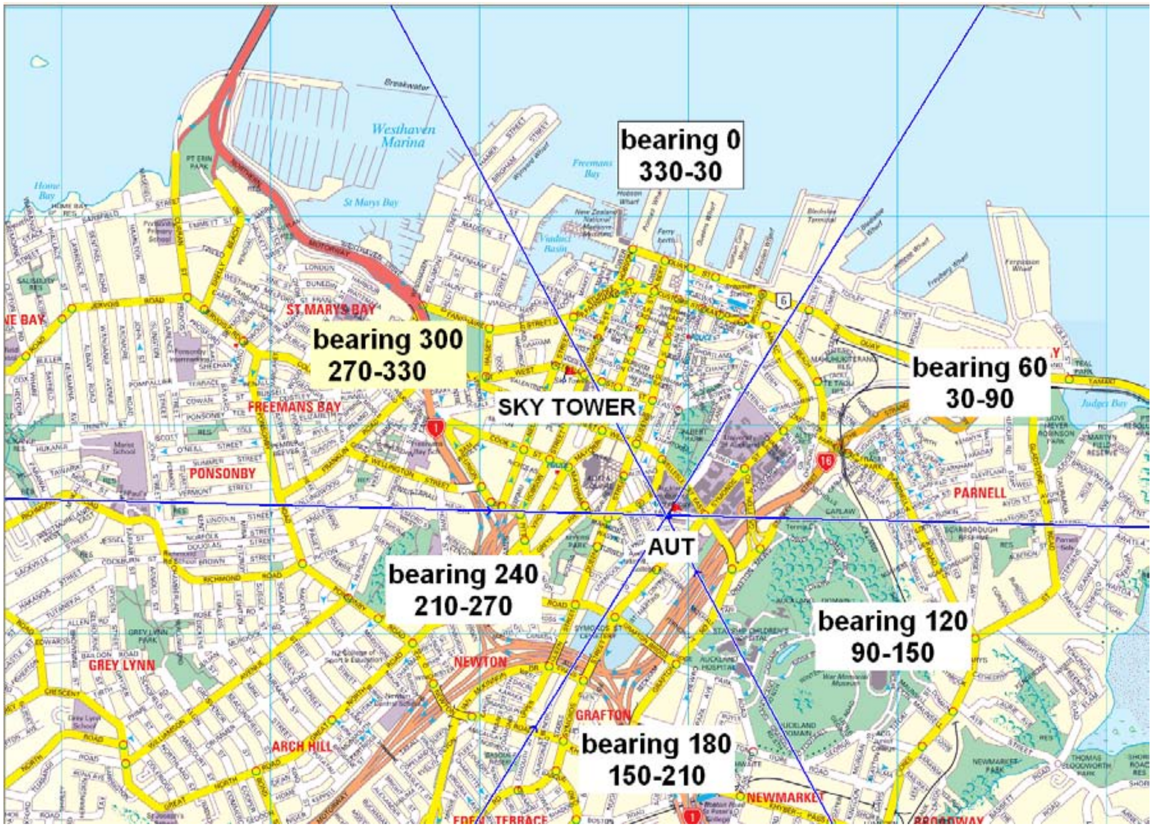


Figure 2.3: Auckland inner city site and bearings (degrees)

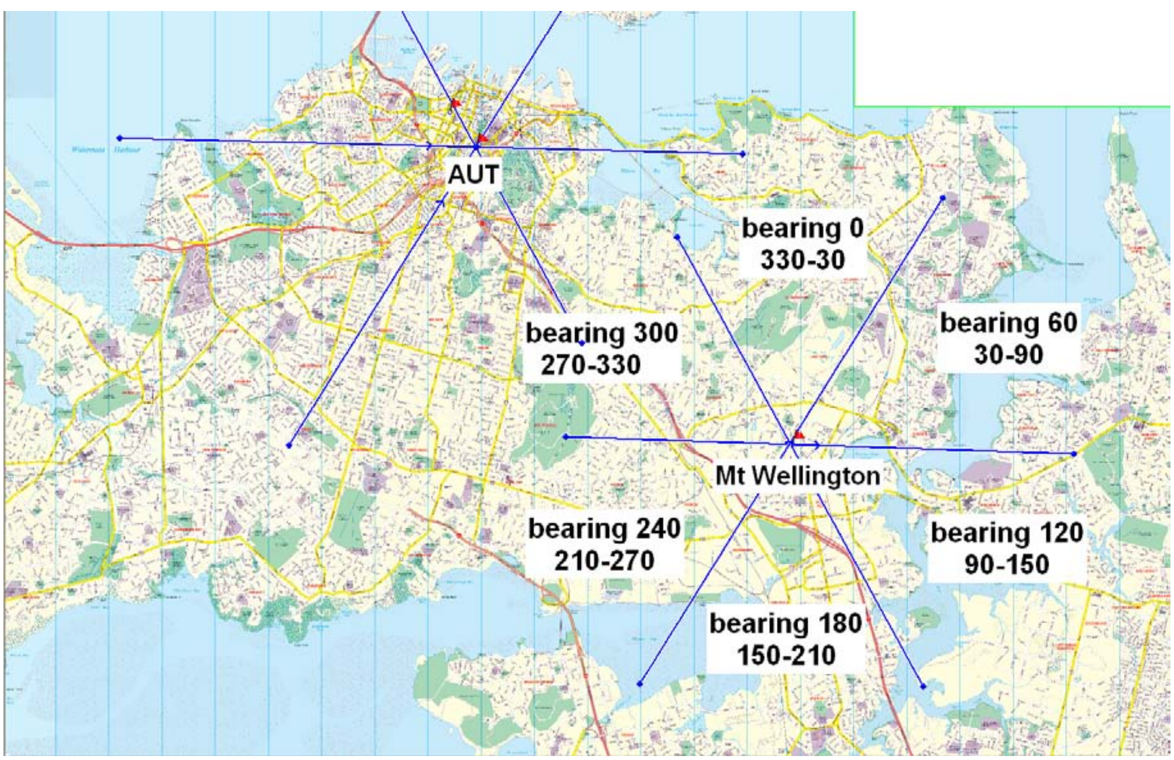


Figure 2.4: Auckland suburban site and bearings (degrees)

2.4.2 Rural Measurements

Rural locations were measured early in the course of the project. As there were no observed inter-modulation effects, filters were not required. There were some cabling problems however and the best readings from three sites have been included in this work. Of major interest was the site of Awarua near Invercargill as this is a proposed site for a remote SKA telescope station. Recordings from Kauri Flat in Northland and Karaka in South Auckland have also been presented here. Each of these locations are relatively close to towns or cities, but more remote sites would have required power supplies, such as the generator used at Warkworth, which was beyond budget constraints and would have caused logistical difficulties. Between them however, the three locations were regarded as typical rural locations of New Zealand and each had readily available power supplies.

Figure 2.5: HK014 on mast and HL050 on tripod at Awarua

Figure 2.5 above is a picture of the Venture Southland radio shack on the Awarua Plains, one of the potential SKA remote station sites. The HL050 directional antenna is mounted on the tripod on the roof and the HK014 omni-directional is the highest antenna in the picture, with guy ropes attached.

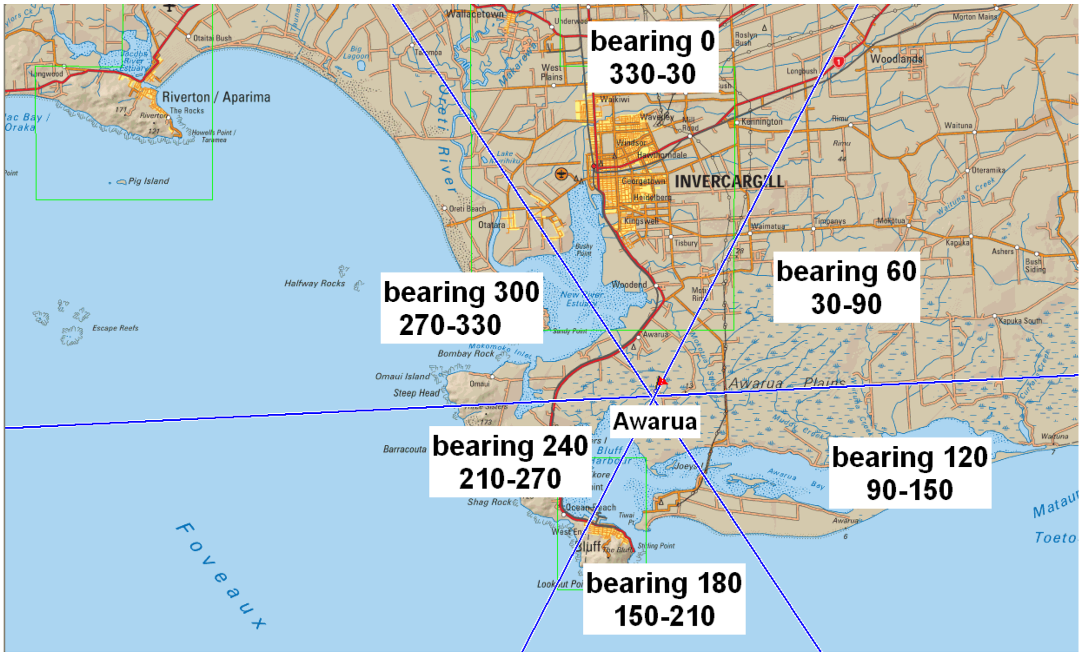


Figure 2.6: Southland rural site and bearings (degrees)

Figure 2.6 above gives the location of the Awarua site and indicates the bearing fields for the directional HL050 antenna. This was pointed in each of the directions indicated for vertical and horizontal polarisation. Figure 2.7 below gives the location and bearings for measurements taken at Kauri Flat and Karaka. At Karaka, only the coaxial dipole antenna was available and no measurements were recorded above 1600 MHz. Filters were not required in the rural locations as it was expected that there would not be local transmitters in close proximity to measurement sites. It is not suggested that there are no transmissions of interest however as the Awarua Plains site is 13 km from the centre of Invercargill and 7 km from the Tiwai Point aluminium smelter. The Karaka site is 11 km distant from Auckland International Airport and the Kauri Flat site is 16 km from Kaitaia. Kauri Flat was the location with the least RFI, where mobile phone reliability is very limited.

Figure 2.7: Karaka site South Auckland and Kauri Flat site

2.5 Control, Data and Analysis Software

Software was made available to the AUT Institute for Radiophysics and Space Research by ATNF and NVSI, because of the shared interest in the bid to host the SKA telescope. The software was designed specifically for the purpose of collecting and presenting radio frequency interference (RFI) information at telescope station sites proposed for the SKA, which coincidentally was required for a similar frequency range as this work. At the commencement of the project, the availability of equipment and software were not known and a substantial debt of gratitude is owed to Australia which, it is hoped will be repaid with research efforts on the new Warkworth telescope and the SKA in future.

2.5.1 Spectrum Analyser Control Software (Labview)

The spectrum analyser remote control software consisted of a virtual instrument built in Labview by NVSI, Sydney. The software allowed for the addition of component identifiers and measurement parameters such as frequency range, sweeps or stop time, RBW, video band width (VBW) and attenuation at the spectrum analyser, though front end attenuation was used in preference when required. Figure 2.8 below shows the parameter entry screen.

Once a measurement started, sweep progress and uncalibrated flux level readings could be viewed in the virtual instrument and on the spectrum analyser screen. The virtual instrument could deal with peripheral tasks such as data transfer and backups, but these features were not needed and standard backups have been sufficient. The software is proprietary and was given to AUT for SKA purposes.

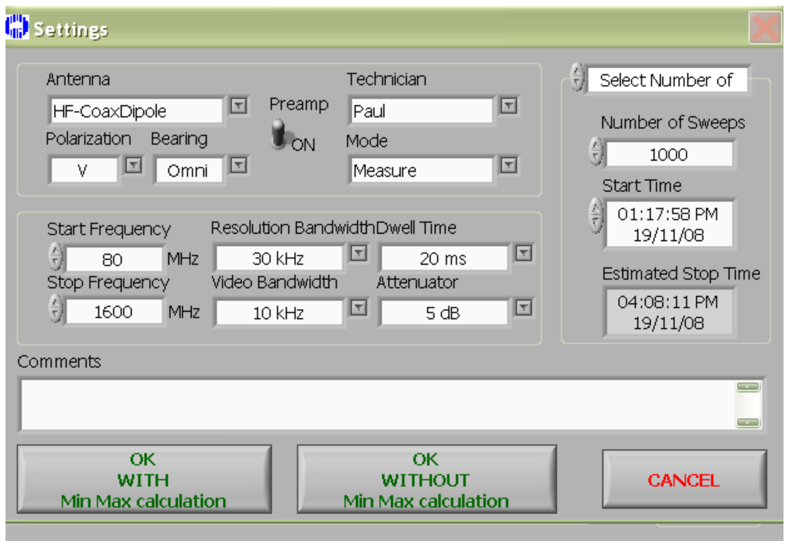


Figure 2.8: Virtual Spectrum Analyser Parameter Screen

2.5.2 Database Software (SQL)

Each measurement was recorded into a SQL database with structure as per figures 2.9 and 2.10 below. The database created a table of each sweep of each measurement, recording the data and time of creation of each table in the directory as in figure 2.9. Each table then recorded the sweep number, sweep frequency and amplitude of the signal present at the receiver. The sweep frequencies were increments of RBW from start to stop frequency parameters that were set in the virtual instrument screen as in figure 2.8 above. Each table name is created from the commencement date and time of recording of the sweep, as per the recording computer clock (t separates date and time), plus the sweep number (x) in the format t_yyyymmddthhmmss_x. Commencement (NZST or NZDT) and measurement parameters were logged with each run.

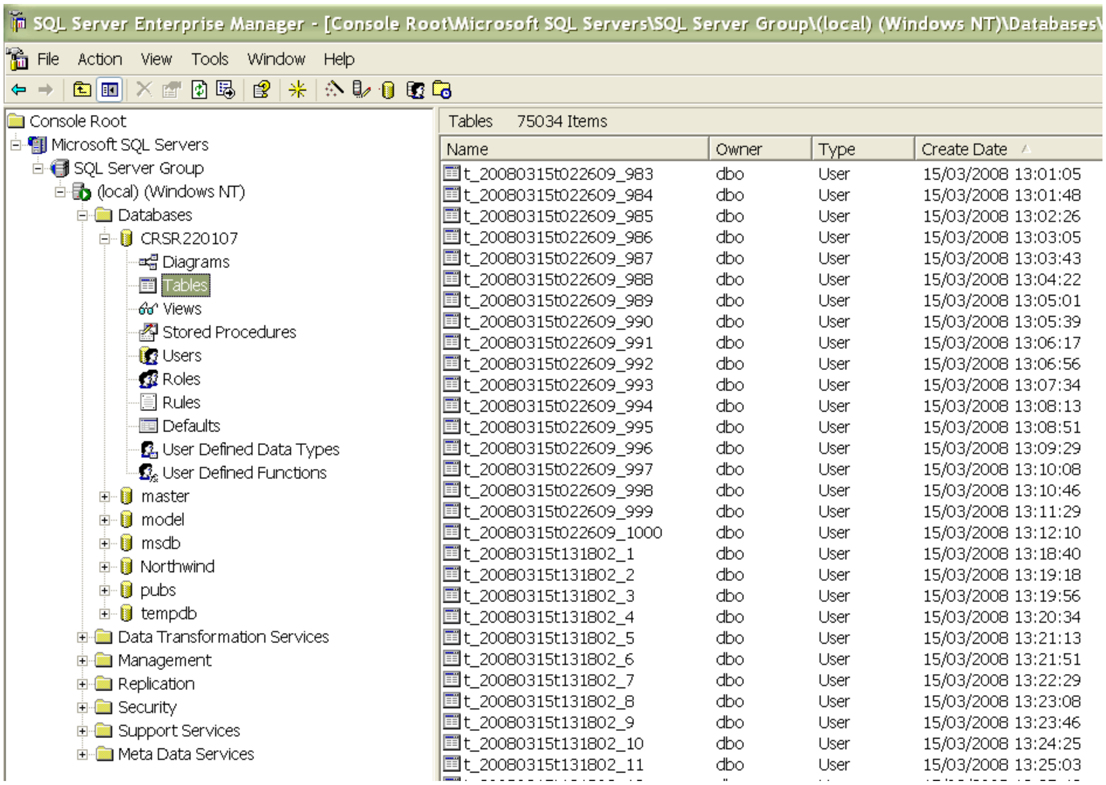
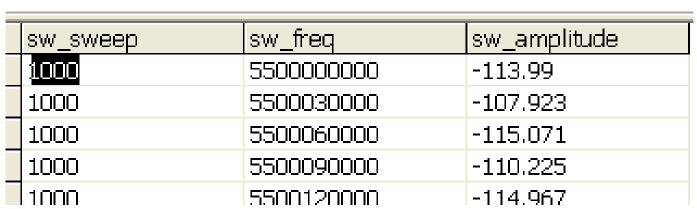


Figure 2.9: SQL database structure for two measurement portions



sw_sweep	sw_freq	sw_amplitude
1000	5500000000	-113.99
1000	5500030000	-107.923
1000	5500060000	-115.071
1000	5500090000	-110.225
1000	5500120000	-114.967

Figure 2.10: Example of measurement data table

2.5.3 Analysis Software (Matlab)

Code to calculate and plot a graph flux density against frequency was provided by ATNF, Sydney. This code, which was also for SKA purposes, was in Matlab. Copies of the summary result charts are found in appendices A, B and C. The appendix A charts of “max, mean, min”, were produced in the field from code known as “rfiquicklook”. This was provided with the virtual instrument and the database when the ATNF equipment was made available, and was run soon after the main measurements. The “max, 90th percentile, median” charts of appendix B and the “Band Occupancy Fraction” charts of appendix C were also produced using Matlab code, which was made available through remote access to the ATNF intranet system after connection of the external drive containing the measurement data to the Sydney system, where it remained for several months.

2.6 Calibration

This section describes a calibration/correction procedure that could be applied to data taken in the field. We consider both the practical (noise diode on/off) approach of section 2.6.1 below, and the theoretical estimation of the correction factor in section 2.6.2. It is shown that the correction factor required is minimal in terms of the appendix chart scales.

2.6.1 Calibration Procedure

Antenna gain and spectrum analyser gain were derived from the manufacturer documentation but the system requires calibration to account for the spectrum analyser preamp and LNA gains as well as cable and filter losses. This can be achieved with hot noise diode, Y factor measurements requiring the disconnection of the antenna and connection of a noise diode that is switched on and off. When off, T is assumed 290 K and when on the diode generates $T_{\text{hot}} \rightarrow$ 10,000 K (Beresford 2006). Additive Gaussian noise T_u (u unknown) input to the system as kT_uB gives total power to the spectrum analyser (sa) as:

$$P_{sa} = G(T_{hot} + T_u)kB \Leftrightarrow G_t = \frac{P_{sa}}{k(T_{hot} + T_u)B}$$

G gain, *k* Boltzmann constant, *B* bandwidth

T_{hot} is known from noise diode characteristics and the Y factor measurement is used to determine T_{u}.

This measurement method uses a receiver noise figure given by;

$$F = \frac{\text{ENR}}{\text{Y - 1}} \text{ where the Y factor}$$

$$Y = \frac{P_{saThot}}{P_{saT290}} = \frac{P_{diode\ on}}{P_{diode\ off}} = \frac{k(T_{hot} + T_u)B}{k(290 + T_u)B}$$

$$= \frac{\mathrm{T_{hot} + T_u}}{\mathrm{290 + T_u}}$$

$$Y\text{-}1 = \frac{T_{hot} + T_u - (290 + T_u)}{290 + T_u} \qquad \Rightarrow T_u = \left(\frac{T_{hot} - 290}{Y\text{-}1}\right) - 290$$

ENR is the noise source data of the manufacturer and values are interpolated by Matlab to account for frequency variations. P_{sa} are the spectrum analyser readings at T_{hot} where the noise source is on and connected in place of the antenna, and T_{290} where the noise source is off.

receiver temperature is; $T_r = 290(F\text{-}1)$

system gain is given by; $G_t = \dfrac{P_{saThot}}{k(T_{hot} + T_r)B}$

where; $\mathrm{ENR(dB)} = 10\log_{10}\left(\dfrac{\mathrm{T_{hot}} - 290}{290}\right)$

Power at antenna terminals is given by: $P_a = \dfrac{P_{sa}}{G_t}$

Antenna effective collecting area is: $A_e = \dfrac{G_a \lambda^2}{4\pi}$ G_a = antenna gain.

Received flux per bandwidth (W/m^2/Hz) = $\dfrac{4\,\pi.P_{sa}}{B\,G_a\,G_t\lambda^2}$ (Beresford 2006)

A theoretical approach to the calibration is described in section 2.6.2 below.

2.6.2 Measured and Actual Power Levels

The full analysis Matlab code (used for appendices B and C charts) requires a Y factor calibration method as described in section 2.6.1 above, whereby the antenna is replaced with a noise source that is then switched on and off in order to provide a calibration ratio that accounts for LNA noise and cable, attenuator and filter insertion losses in data taken. The field measurement code used to create the charts of appendix A, calibration required only the diode on table.

Our RFI measurements are presented as plots of Spectral Flux Density $S_\upsilon(\upsilon)_{dB}$ in dB (W m^{-2}Hz^{-1}). The data output by the Spectrum Analyser is in the form of power readings P_{SA} (the power seen at the input terminals of the Spectrum Analyser) that must be used to derive $S_\upsilon(\upsilon)$;

$$S_\upsilon(\upsilon) = \frac{P_{SA} 4\pi}{G_{ANT} G_{SYS} B \lambda^2}$$

where;

G_{ANT} = antenna gain (relative to isotropic),

G_{SYS} = gain from rest of system (LNA, cable losses, insertion loss of filters, attenuators and spectrum analyser (SA) preamp gain),

B = RBW (resolution bandwidth of SA),

λ = measurement wavelength

These parameters are known except for $\boldsymbol{G_{SYS}}$. It is standard practice to determine this through use of a Noise Diode and a Y Factor measurement as discussed in section 2.6.1 above. However, $\boldsymbol{G_{SYS}}$ can be derived from the following consideration:

It can be shown that (Beresford 2006);

$$G_{SYS} = \frac{P_{SA\_DIODE\_ON}}{k(Thot + Tsys)B}$$

where;

$P_{SA\_DIODE\_ON}$ = power seen by spectrum analyser when noise diode is switched on

$k = 1.38 \times 10^{-23}$ J/K = Boltzmann's constant

T_{HOT} = noise temperature of noise Diode when switched on

T_{SYS} = noise temperature contributed by rest of system (LNA, losses, SA).

An estimate of T_{SYS} is given below to show the effect on measurements.

The noise diode has an ENR_{dB} of approximately $+13.5\,dB$ (section 2.1)

$$\Rightarrow ENR = 10^{\frac{13.5}{10}} \approx 22.4$$

$$\therefore ENR = \frac{T_{HOT} - 290}{290} = 22.4$$
$$\Rightarrow T_{HOT} = 290(22.4 + 1) \approx 6782\,K$$

Items that contribute to T_{SYS} are the LNA, losses in cables and the noise contributed by the spectrum analyser itself.

$$NF_{LNA} \approx 1.5\,dB \Rightarrow F_{LNA} = 10^{0.15} \approx 1.4$$
$$= 1 + \frac{T_{LNA}}{290} \Rightarrow T_{LNA} \approx 116\,K$$

Assuming a representative figure for the cable and filter losses of $L_{dB} = 15\,dB$ the effective noise temperature of the loss is;

$$L = 10^{1.5} \approx 31.6$$
$$\Rightarrow T_{losses} = (L - 1) \times 290 = (31.6 - 1) \times 290 \approx 8874\,K$$

The spectrum analyser noise contribution is as follows;

$$NF_{SA} \approx 16\ dB \Rightarrow F_{SA} = 10^{1.6} \approx 39.8$$
$$\therefore F_{SA} = 1 + \frac{T_{SA}}{290} \Rightarrow T_{SA} \approx (290 \times 39.8) - 290 \approx 11252\ K$$

These components are in cascade hence (Haykin 2001);

$$T_{SYS} = T_{LNA} + \frac{T_{losses}}{G_{LNA}} + \frac{T_{SA}}{G_{LNA}G_{losses}} = T_{LNA} + \frac{T_{losses}}{G_{LNA}} + \frac{LT_{SA}}{G_{LNA}} \qquad (G_{losses} = L^{-1})$$

The quoted gain of the LNA is $G_{dB} = +28\ dB \Rightarrow G = 10^{2.8} \approx 631$

$$T_{SYS} = 116 + \frac{8874}{631} + \frac{31.6 \times 11252}{631} \approx 694\ K$$
$$694\ K << 6782\ K \Rightarrow T_{SYS} << T_{HOT}$$

Therefore the correction required for the spectral density plots is minimal;

$$10\log_{10}\left[\frac{T_{HOT}}{T_{HOT} + T_{SYS}}\right] = 10\log_{10}\left[\frac{6782}{6782 + 694}\right] \approx -0.4\ dB$$

This factor is difficult to discern in the plotted charts and has not been incorporated but signal level accuracy will be improved with future application of the methodology presented in this work.

3. Measurements

This section describes measurement logistics and results, focusing on the method of recording results for future reference. There are in the order of 50 GB of results in computer storage and this thesis concentrates on efforts to bring these into perspective, as well as describing methodology. This paper presents the results in the holistic sense, while the details are described in below.

3.1 Production of NZRFI Directories 2007 2008

The set of sub-directories and documents contained within the directory entitled “NZRFI Directories 2007 2008” that this work accompanies, comprise radio frequency interference (RFI) measurements recorded in New Zealand during 2007 and 2008;

- On the roof of the School of Engineering, WS block, AUT University, St Paul Street (off Symonds Street), Auckland. This location is referred to as “Auckland City” throughout.

- On the roof of a residence in Boakes Road, Mount Wellington, Auckland, referred to as “Mount Wellington”.

- On the roof of the Venture Southland radio shack on the Awarua Plains, at the northern end of Awarua Siding Road, Southland, referred to as “Awarua”.

- Off Far North Road (Imms Road), Kauri Flat, Northland, referred to as “Kauri Flat”.

- Off Clark Road, Te Hihi, South Auckland, referred to as “Karaka”.

The directories are the products of a study to determine appropriate methodology for the measurement of man made radio frequency interference in New Zealand. The measurements themselves represent a characterisation of the New Zealand radio frequency environments within urban, suburban and rural areas of New Zealand, for radio frequencies between 80 MHz and 8.5 GHz as determined in the period 2007 – 2008. The methodology discussed in this work, that these measurements accompany, is intended to apply to the frequency range of 30 MHz to 30 GHz, although measurement in the frequency domain wider than these records requires equipment that was not available at the time that these were taken.

This chapter describes navigation through the directories and charts, which are intended as a tool by which anyone may gain knowledge of the radio frequency environment in New Zealand. They are also intended as a starting point against which future studies can be compared for any location in order to allow the monitoring of trends in radio spectrum usage within New Zealand.

3.2 Measurement Locations

Location maps and photographs are included in the directories. Maps have directional indicators to show the orientation of the HL050 directional antenna used in scans of frequencies above 1 GHz. The HK014 omni-directional antenna frequency range was 80 - 1600 MHz. The positions described below are not derived from Global Positioning System (GPS) methods owing to privacy concerns, but are estimated from topographic locality maps. Measurements were recorded at antennae positioned close to the locations given in table 3.1 below.

Location	East	South	Altitude (m)
Auckland City	174º46’	36 º51’	80
Mt Wellington	174º50’	36º54’	40
Awarua	168º23’	46º32’	25
Kauri Flat	173º12’	34º59’	50
Karaka	174º50’	37º06’	45

Table3.1: Location Coordinates and Altitude above Sea Level

3.3 NZRFI Directories 2007 2008 Contents

Most files within the directories are charts requiring, as a minimum, Matlab Student Version 7.1.0.124 (R14) with Service Pack 3 produced by The MathWorks. At the professional level, Matlab Version 7.5.0.342 (R2007b) or later should be used. Earlier versions may open the files but this cannot be guaranteed.

NZRFI Directories 2007 2008 contains the following:

1. A subdirectory "Measurement of the Radio Frequency Environment in New Zealand" with this report containing summary charts and 20 MHz band chart descriptions, with measurement methodology. The summary charts within this document are of three types in the appendices as per figure 3.3 below:

    - Appendix A, the key reference, with figures A1 to A21 These are spectral flux density plots of maximum, mean and minimum power levels recorded per resolution bandwidth (RBW) within frequency ranges scanned for all measurements published within the directories.
    - Appendix B with figures B1 to B21, of spectral flux density plots with maximum, 90th percentile and median levels per RBW recorded for all measurements published in the directories.
    - Appendix C with figures C1 to C21 of spectral occupancy fraction (0-1) charts across each frequency range measured, for the duration of each measurement.

    Appendix A is the key reference for the directories, as these charts were plotted not long after each measurement was recorded. They identify the key equipment and measurement parameters for all records taken at each location. Figures A1 to A21 each show copies of up to six charts that reference each record published in the study. These have been designed to give readers the ability to absorb the substantial amount of information contained in the directories and to assist in navigation through them. It is suggested that appendix A is consulted before further exploration through the directories.

2. Five numbered sub directories of locations measured as displayed in figure 3.1 below, each containing;

    - Position sub directories with maps and photographs of positions at which measurements were taken (e.g. subdirectory “position Karaka” in figure 3.1).

    - Figure number sub directories containing a summaries sub directory, with the individual charts from which the files of appendices A, B and C were compiled (e.g. “figure A21 full range charts” in figure 3.1 below), and up to six measurement sub directories containing 20 MHz bandwidth charts (section 3.6.4 below) for each frequency range scanned and recorded (e.g. “20070506t182514 20 MHz bands” of figure 3.1 below).

    - Each full range measurement has been subdivided to 20 MHz bandwidths (section 3.6.4 below) across the full measurement range, excepting three measurements with corrupted data. Figure 3.2 below has an example of the 20 MHz band file listing of measurement table 20071027t204012 for the frequency range of 1000 – 1020 MHz.

    - The table short cuts indicated in the type list in figure 3.2 are short cuts used by the Matlab code to access all the 20 MHz band charts used to produce two of the full range summary charts. They have been retained in the directories to indicate their purpose and they may be useful in the future. The three types of full range summary charts developed are given in figure 3.3 below. The max mean min chart was designed for field use and is not constructed with the 20 MHz band charts of the figure 3.2 listing.

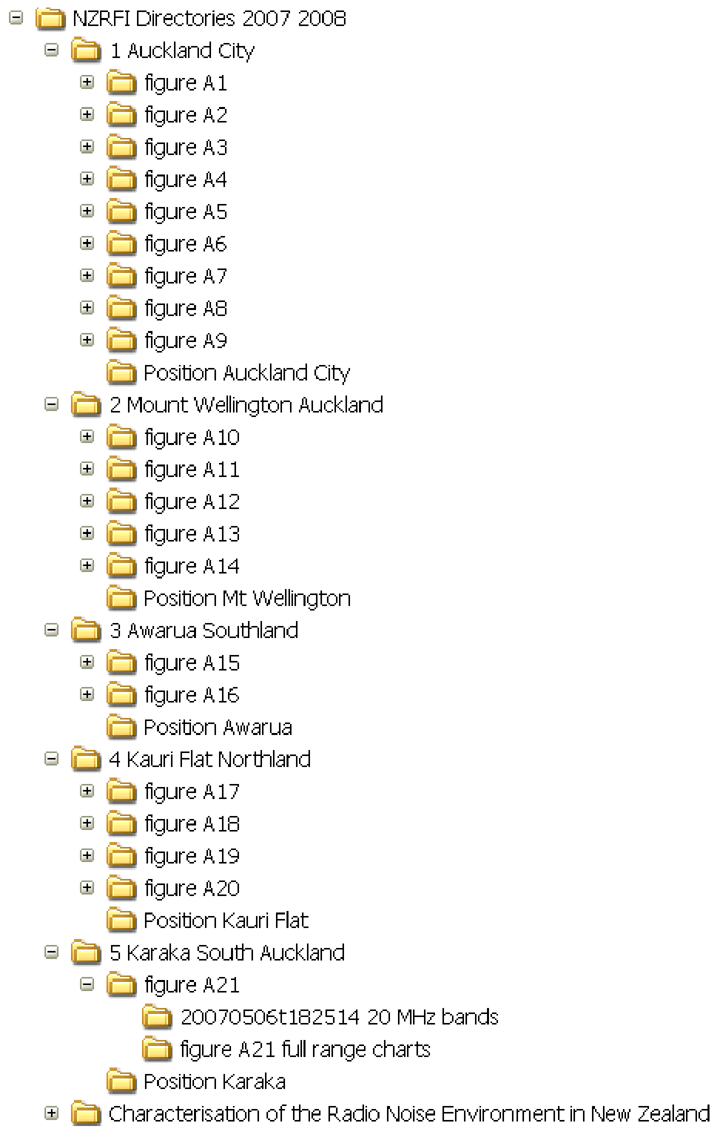
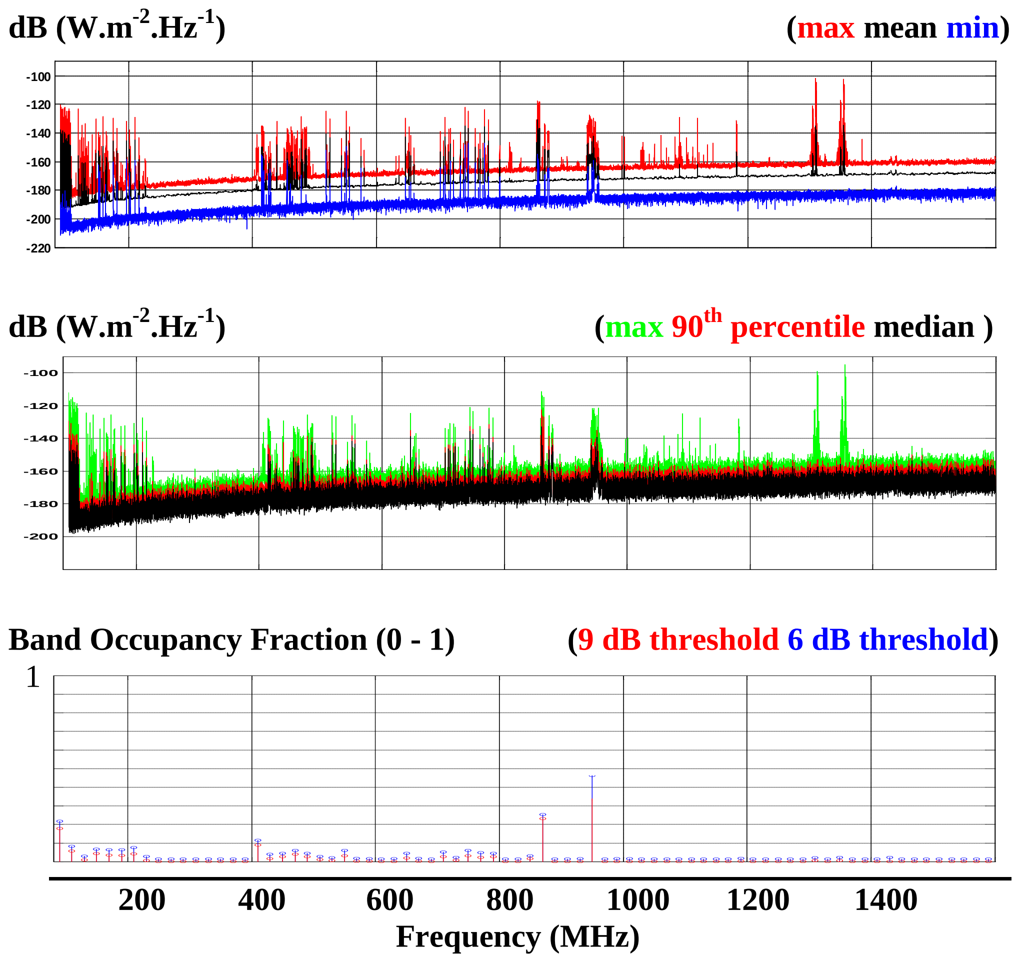


Figure 3.1: NZRFI Directories 2007 2008 Structure

Name	Size	Type
processRFIt_20071027t204012_1000_1020	687 KB	Microsoft Office Access Table Shortcut
processRFIt_20071027t204012_1000_1020_max_mean_uncal	17 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_occupancy	10 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_residuals	11 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_spectrogram_minus_mean_fit	783 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_spectrogram_raw	542 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_spectrogram_threshold_6dB	12 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_spectrogram_threshold_9dB	7 KB	MATLAB figure file
processRFIt_20071027t204012_1000_1020_statistics	20 KB	MATLAB figure file

Figure 3.2: Sample 20 MHz File Listing



Tables
20070506t182514 max mean min
20070506t182514 max 90 med
20070506t182514 occupancy

Antenna:	HK014
dB scales:	-220 to -90
Polarisation:	Vertical
Sweeps:	2172
RBW : VBW:	30 : 10 kHz
Bearing:	Omni-directional

1825 hours 060507 to 2000 hours 070507

Figure 3.3: Full Range Summary Charts for Karaka

The charts generated by the Matlab code can be enlarged by Matlab software to read measurements down to RBW frequencies across the entire frequency scanned for each measurement. Section 3.6.4 below gives examples of the figure 3.3 charts magnified to a 20 MHz bandwidth in Matlab. The large number of charts has been generated primarily for the purpose of demonstrating the methodology involved and justifying recommendations. The summaries have been generated to report the measurements themselves and to demonstrate how a substantial volume of information of this nature, can be usefully absorbed, relatively quickly by practitioners in the field of radio engineering, their clients and whoever else may be interested. Section 3.6.4 also discusses the 20 MHz bandwidth charts generated by the analysis software used. Those presented are for table 20070506t182514 which is the Karaka data summarised in figure 3.3 above. The 20 MHz bandwidth was chosen because ATNF selected this in order to analyse RFI at potential SKA sites however any bandwidth is selectable through the software.

3.4 File and Directory Names

The names of all directories and files specific to individual measurements include table names with date and time formats indicating the measurement commencement either in New Zealand Standard Time (NZST) or New Zealand Daylight Time (NZDT) format yyyymmddthhmmss. The t is a separator of date and time and names normally include a descriptor of the file or sub-directory as can be seen in figure 3.4 below, which is a subdirectory file listing with names indicating the measurement start date and time as well as the summary contained within the chart.

Name	Size	Type
20071027t204012 max 90 med	1,075 KB	MATLAB figure file
20071027t204012 max mean min	1,158 KB	MATLAB figure file
20071027t204012 occupancy	19 KB	MATLAB figure file
20071028t233320 max 90 med	1,074 KB	MATLAB figure file
20071028t233320 max mean min	1,158 KB	MATLAB figure file
20071028t233320 occupancy	19 KB	MATLAB figure file
20071029t232407 max 90 med	1,074 KB	MATLAB figure file
20071029t232407 max mean min	1,158 KB	MATLAB figure file
20071029t232407 occupancy	19 KB	MATLAB figure file
20071030t191204 max 90 med	1,074 KB	MATLAB figure file
20071030t191204 max mean min	1,159 KB	MATLAB figure file
20071030t191204 occupancy	19 KB	MATLAB figure file
20071031t233456 max 90 med	1,075 KB	MATLAB figure file
20071031t233456 max mean min	1,160 KB	MATLAB figure file
20071031t233456 occupancy	19 KB	MATLAB figure file
20071102t024424 max 90 med	1,075 KB	MATLAB figure file
20071102t024424 max mean min	1,160 KB	MATLAB figure file
20071102t024424 occupancy	19 KB	MATLAB figure file

Figure 3.4: figure 15A full range charts file listing

Individual sweep commencement times were logged by the SQL database directories that store the measurements, and measurement stop times can be found from these. The SQL files are not included in these directories, and table 3.2 below is useful as a guide in determining measured periods, with the RBW used for these measurements.

In the period that these records were taken, NZDT occurred between 0300 hours on 30th September 2007 (20070930t030000) and 0200 hours on 6th April 2008 (20080406t020000). The t is a separator only and the file and directory names normally include a descriptor to indicate what the file concerns. These were allocated by the code in the computer logging the data, using the internal clock. Only the measurements at Karaka were recorded during NZST for this work. All others are NZDT.

3.5 Measurement Times

Table 3.2 below shows measurement time spans achieved at various RBW. A RBW of 3 kHz requires much time to gather data sets suitable for results hence 3 kHz was used on a few occasions only for comparison. While this is the best RBW to use in terms of approaching the noise floor, the probability of a given frequency being used is low to the point that it is unlikely if not a continuous signal. The time required for enough sweeps to catch the signals present makes it impractical to use 3 kHz RBW for trend monitoring on a wide scale. Measurement commencement times were used to name tables and charts, and measurement duration can be estimated from table 3.2.

RBW kHz)	Sweep time/GHz (s)	1000 sweeps/GHz sweep time (hrs)
3	420	120
10	50	14
30	13	4
100	7	2
300	2	0.5
1000	1	0.25

Table 3.2: Approximate Measurement Times for RBW used

3.6 Analysis and Results

This section discusses the main results summaries presented. Two separate Matlab codes were used to construct the summaries charts of appendices A, B and C. The charts in appendix A were constructed with ATNF code known as “rfiquicklook”, which was designed to allow viewing in the field as measurements were recorded. This code was available when the equipment was obtained. Appendices B and C charts were constructed from code that summarised the 20 MHz band charts, not available until remote access to the ATNF intranet was obtained, after the field work was completed. Code availability was not known of beforehand and a calibration step required was omitted during the field research. The calibration step is discussed further in sections 2.6 above and 3.6.6 below.

Filter use had not been deemed necessary when measurements in rural locations were recorded as there was no evidence of inter-modulation occurring. Inter-modulation effects were ghost signals appearing in scans, often at harmonic frequency levels, caused by transmitter proximity or electrical noise that drove amplifier and spectrum analyser overloads. Inter-modulation effects were obvious in the city centre and it was necessary to attenuate signals received at the monitoring antennae. To eliminate inter-modulation effects, band pass filters and/or attenuators were added to the signal path before the LNA and antenna cables. By adding these at the front end, unwanted signals were filtered before amplification stages and by adding the LNA before the cables, wanted signals were amplified before cables could reduce signal power, thus producing a more reliable measure. There was attenuation available in the spectrum analyser as well, but this was used only after front end attenuation could not be added. Attenuation was added to levels required for the inter-modulation effects to disappear from scans. Levels added were recorded on all “max, mean, min” charts.

It was hoped to compare the performance of the omni-directional coaxial antenna (HK014) and the log periodic (HL050) directional antenna, but they were not equivalent systems. The HK014 was certainly much easier to use as no turning was required, however the noise floor of this system was substantially higher than that of the HL050, as different amplification and attenuation were used. Additionally, the gain of the HK014 was 2, while that of the HL050 was 8.5 and the recordings for this showed far greater activity in the overlapping ranges from 1340 – 1600 MHz, than those of the HK014 as can be seen in appendix A, figures A1 – A9. In terms of a method for trend monitoring, a good omni-directional antenna system with the gain achieved by the log periodic system would be cheaper but the increased power levels received from all directions would require better filtering or attenuation. The directional system shows the directional component of the signals, but its use is unwieldy if signals from all directions are required. For spectrum management purposes, the use of a directional antenna and only one direction measurement may be adequate. The beam width of the directional antenna used was 60º.

3.6.1 Auckland City Urban Results

The city area required the most work in terms of attenuation because of transmitter proximity. Signals were measured at the top of the School of Engineering of AUT, Wellesley Street campus. This site had a clear view across the city centre to the Sky Tower in Victoria Street West where, as at 1/12/08 approximately 340 transmitting licences were valid for operating via equipment at less than 1 GHz in the tower, plus a further 100 licences operating to 38 GHz and two more at higher frequencies (NZMED 2008). The measurements in appendix A were recorded in March 2008. The monitoring antennae were positioned directly opposite the Sky Tower across the city centre at 820 m distance. There were apartment blocks behind AUT that rose above the monitoring position and these reflected substantial signal levels, as can be seen in the appendix summaries containing azimuthal displays of the maximum (max), mean and minimum (min) signal levels (appendix A), max, 90th percentile (90) and median (med) levels (appendix B) and band occupancy fractions from 0 – 1 (appendix C). While a more ideal city environmental characterisation may have been obtained at the top of the apartment buildings, it is considered that the position chosen was more realistic in practical terms as it better characterised the environment for the average positioning of antennae in general use. This characterisation was intended as a starting point, and other locations can be characterised with this method for future comparisons.

RBW used in 1.34 – 4 GHz directional recordings, were 30 kHz and 300 kHz and full azimuthal recordings were taken. The 30 kHz RBW shows a great deal more activity taking place than the 300 kHz. The appendix A figures useful for comparison are figures A1 – A2 at 30 kHz and figures A3 – A4 at 300 kHz respectively. The only difference in equipment parameters between the respective bearings of each pair was RBW 30:300 and number of sweeps 1000:2500. Figures A1 and A3 are vertical polarisation while figures A2 and A4 are horizontal. Signal power levels are lower for the 300 kHz RBW shots owing to averaging over the longer bandwidth. The disadvantage of the 30 kHz RBW is that it took approximately 8 times as long as the 300 kHz to collect and analyse. A 30 kHz RBW is far more accurate than 300 in terms of signals present. The same comparison can be made for the 5.5 – 8.5 GHz, figures A5 and A7, recorded at RBW 30 kHz and 1000 kHz respectively. These are full azimuth, vertical polarisation recordings. Figure A9 presents signal power levels for the HK014 antenna at 3, 10, 30 and 300 kHz RBW. The 3 kHz data does not encompass many sweeps because of time constraints and the fact that data was unreliable in the analysis software.

3.6.2 Mount Wellington Suburban Results

While Mt. Wellington is a typical Auckland suburb, it is difficult to regard it as a typical New Zealand suburb. It is located close to the industrial areas of Penrose and East Tamaki, and high tension power lines ran east from the Otahuhu power station, 500 m away from the location monitored. The monitoring location was a typical residence. The monitoring antennae were mounted on a tripod on top of the car port. The upper portion and mast of the Auckland Sky Tower were visible from this location, and the sheet steel of a roof was located a few metres from the antenna. A more ideal characterisation may have been gained from the top of Mt. Wellington, but the most common visible antennae used in the vicinity were television antennae and the monitoring antennae were located in a typical television aerial position.

The band pass filters provided adequate attenuation in these measurements with the HL050 antenna and attenuation was only required on the HK014 (80 – 1600 MHz) measurements on which filters were not used. RBW 300 kHz was selected for all Mt. Wellington measurements as at this time it was felt that this was the best compromise between scan time available and activity detected. These were recorded in February 2008, before the inner city measurements. Figures A10 – A14 show the suburban measurements and there is less activity, although it is still a busy area owing to the proximity of industry. Activity in the 5.5 – 8.5 GHz band is substantially less than the inner city levels, as can be seen in figure A12 for Mt. Wellington. The frequency range of figure A12 was set to be 5.5 – 10 GHz and the LNA response roll off can be seen above 8.5 GHz. Signals of greater power than the floor level can still be seen.

3.6.3 Awarua, Kauri Flat and Karaka Rural Results

The rural Measurements of Awarua, Kauri Flat and Karaka were taken before the Auckland measurements, in 2007, October, September and May respectively. These were made while equipment was still being procured and familiarisation was taking place. Some cabling problems are apparent in the results. Neither filtering nor attenuation was necessary as there was insufficient local transmitter activity to cause any inter-modulation. Appendix A figures A15 – A21 show rural activity which was far less than the Auckland measurements as expected. Cable faults can be seen in figures A15 and A16 of Awarua as well as figure A17 of Kauri Flat.

3.6.4 20 MHz Band Charts

Figures 3.5 to 3.12 below show the set of 20 MHz bandwidth charts generated by the ATNF analysis software for the Karaka measurement of table t_20070506t182514 from 1300 to 1320 MHz. 20 MHz bandwidth was used by ATNF for SKA sites. The band can be set as required. Within NZRFI Directories 2007 2008, there are eight charts per 20 MHz band of all measurements that the code was capable of processing. Two data sets were corrupted before they could be processed and the two 3 kHz RBW sets taken would not run. The Matlab file names are used as captions for each of the 20 MHz band charts shown in this section except for the two zoomed charts not created by this procedure (figures 3.6 and 3.10). There are substantial numbers of 20 MHz band charts in RFI Directories 2007 2008 and it has not been possible to spend much time making use of them as yet. The obvious radio astronomical application is to study the charts near observing frequencies in order to determine the locality of interference in frequency and time, to aid filtering and observing decisions. This section serves to identify to chart types. There are too many to include all sets on one disc but a range of full measurement sets are included as follows;

1. Table t_20080304t134343, figure A1 (Auckland City). Bearing 0 North across the city from the roof of AUT School of Engineering, 1000 sweeps@30 kHz RBW, 1.34 – 4GHz.
2. Table t_20080315t022609, figure A5 (Auckland City). Bearing 0 North across the city from the roof of AUT School of Engineering, 1000 sweeps@30 kHz RBW, 5.5 – 8.5 GHz.
3. Table t_20080319t023912, figure A8. Omni-directional from the roof of AUT School of Engineering, 2914 sweeps@30 kHz RBW, 80 – 1600 MHz.
4. Table t_20080210t205400, figure A10 (Mt. Wellington). Bearing 300 North West towards Auckland City centre, 2500 sweeps@300 kHz RBW, 1.34 – 4 GHz.
5. Table t_20080217t220154, figure A12 (Mt. Wellington). Bearing 300 North West towards Auckland City centre, ~2000 sweeps@300 kHz RBW, 5.5 – 8.5 GHz.
6. Table t_20080227t002050, figure A14 (Mt Wellington). Omni-directional, 1000 sweeps@30 kHz RBW, 80 – 1600 MHz.
7. Table t_20071027t204012, figure A15 (Awarua). Bearing 0 North towards Invercargill, 1000 sweeps@100kHz RBW, 1 – 5 GHz.
8. Table t_200709247t210248, figure A18 (Kauri Flat). Omni-directional, 1002 sweeps@30 kHz RBW, 80 – 1600 MHz.
9. Table t_20070506t182514, figure A21 (Karaka). Omni-directional, 2172 sweeps@30 kHz RBW, 80 – 1600 MHz.

Figure 3.5 below charts maximum, ninety percentile and median signal levels. It also plots 6 and 9 dB occupancy threshold levels, which were used by the code in the calculation and plotting of channel occupancy charts. The code calculates the Matlab data tables in NZRFI Directories 2007 2008 which are then used to produce the summary charts of maximum (max), ninety percentile (90^{th} percentile) and median spectral density levels as per figure 3.6 below (which is figure B21 zoomed to 1300 to 1320 MHz). These are given in appendix B, and the channel occupancy fraction charts are in appendix C. The threshold levels refer to 6 and 9 dB levels above the occupancy threshold, defined as a 5^{th} order polynomial fit to the median in empty channels of the band (Beresford 2006). The 9 dB levels were produced to provide more robustness to occupancy levels by avoiding system noise pollution. Empty channels were used to avoid underestimation of occupancy because of the presence of many interferers within a band.

Figure 3.7 below plots uncalibrated maximum and minimum levels as well as the 5th order polynomial fit of the median level of empty channels, plus the 6 and 9 dB thresholds The Residual plots of figure 3.8 below shows the power above the noise floor within each band.

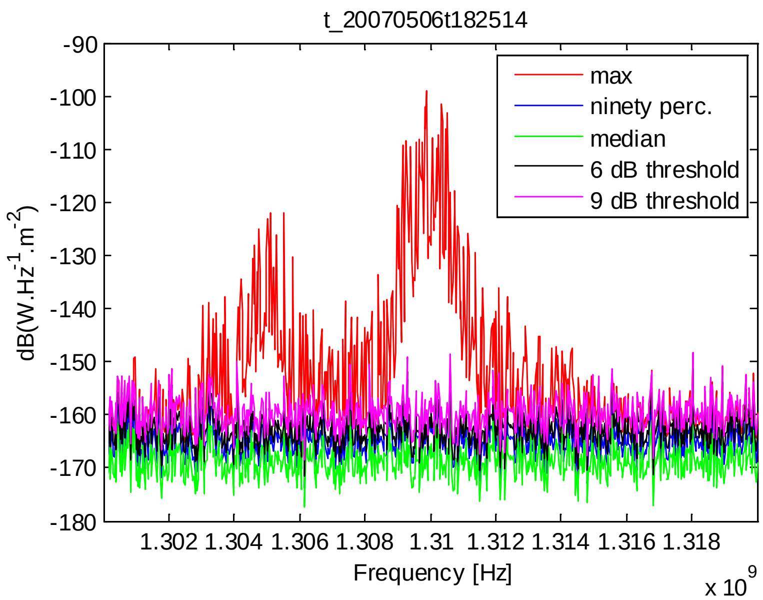


Figure 3.5: t_20070506t182514_1300_1320_statistics

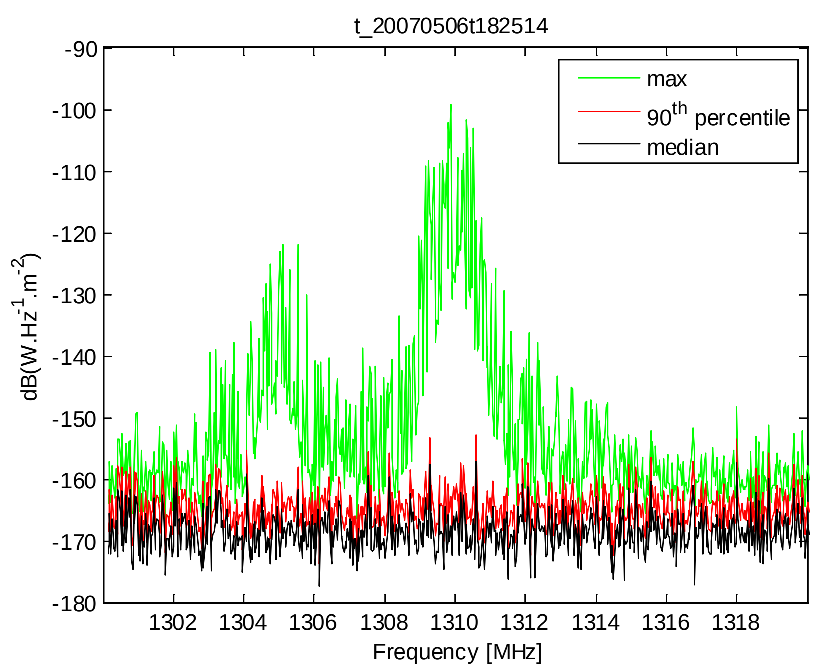


Figure 3.6: Max 90 Med plot magnified to 1300 - 1320 MHz

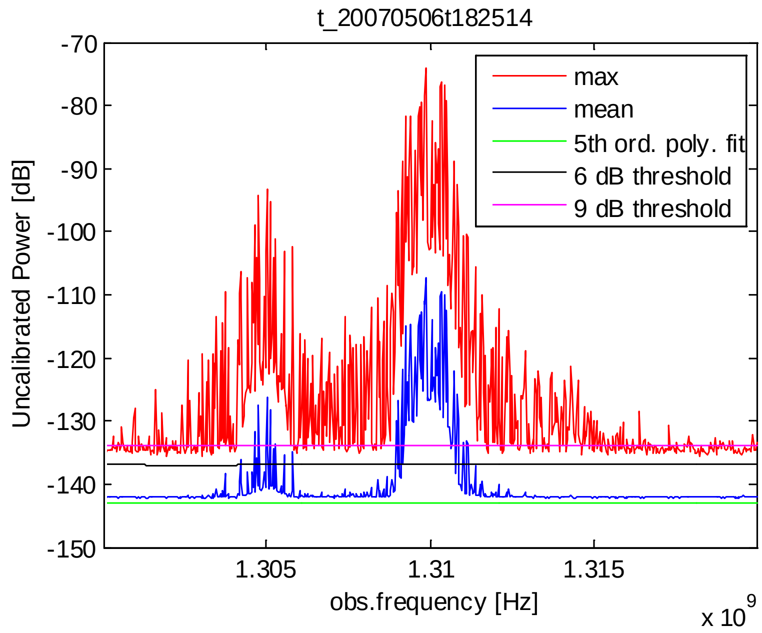


Figure 3.7: t_20070506t182514_1320_1340_max_mean_uncal

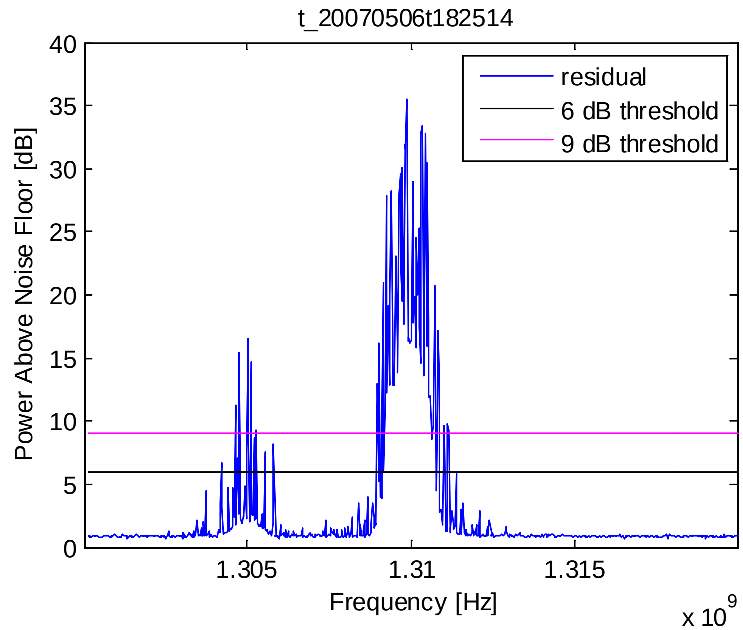


Figure 3.8: t_20070506t182514_1320_1340_residuals

The channel occupancy plots of the type in figure 3.9 below were summarised across all measurements (except for the corrupt and 3 kHz RBW data), and were used to produce occupancy summaries given in appendix C. These are occupancies 6 and 9 dB above A 5th order polynomial fit to the mean power level within empty channels of the band. The difference between the 20 MHz band chart and the summary chart is that the band chart gives occupancy across each RBW used in a measurement. The comparison is seen in figure 3.10 below which is the summary chart for the same measurement (i.e. figure C21) zoomed to the 1300 to 1320 MHz band.

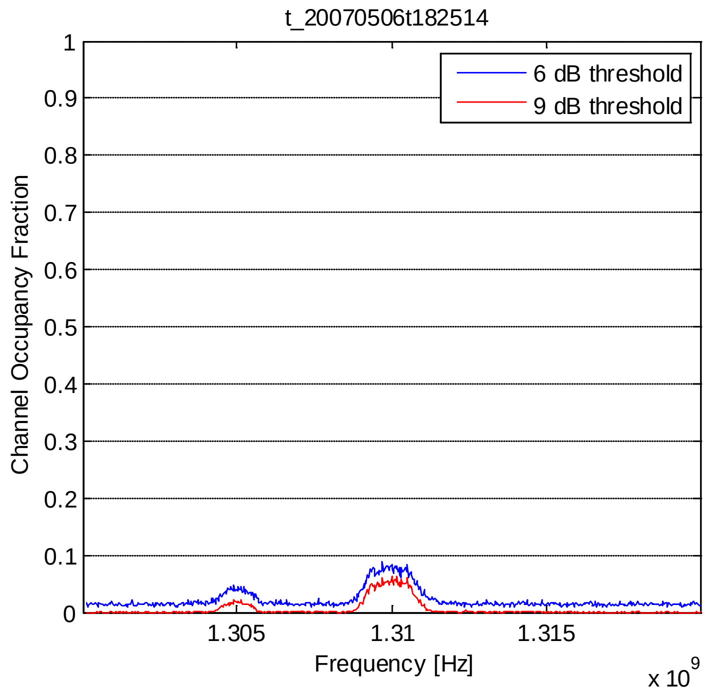


Figure 3.9: t_20070506t182514_1300_1320_occupancy

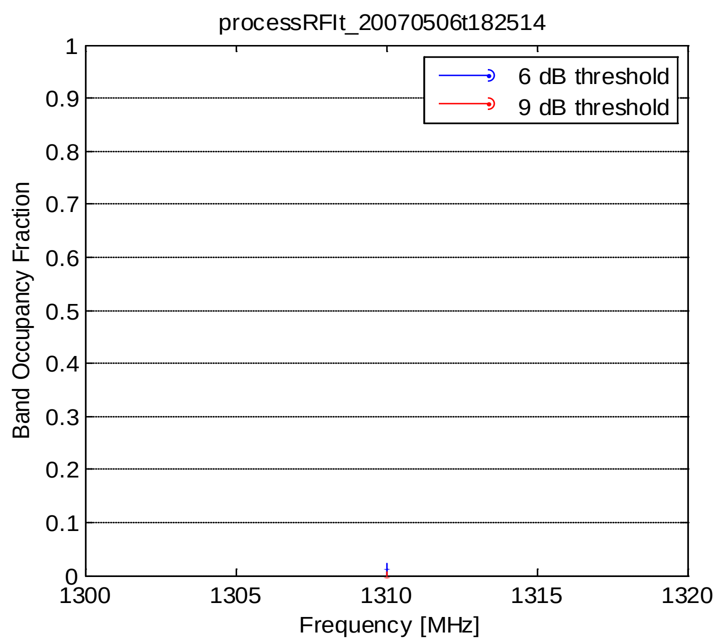


Figure 3.10: Occupancy Chart Magnified to 1300 – 1320 MHz

Figures 3.11 to 3.14 are 20 MHz spectrograms giving a presentation of the temporal characteristics of the measurement, with the spectrum analyser scan number plotted in the vertical axes. Figures 3.11 and 3.12 are the raw spectrogram and raw spectrogram minus the mean noise respectively but it is the threshold spectrogram figures 3.13 and 3.14 that give the best indication of what happens in time, particularly figure 3.14 of the 9 db threshold spectrogram This threshold has machine noise subtracted so that only received signals from external sources are plotted.

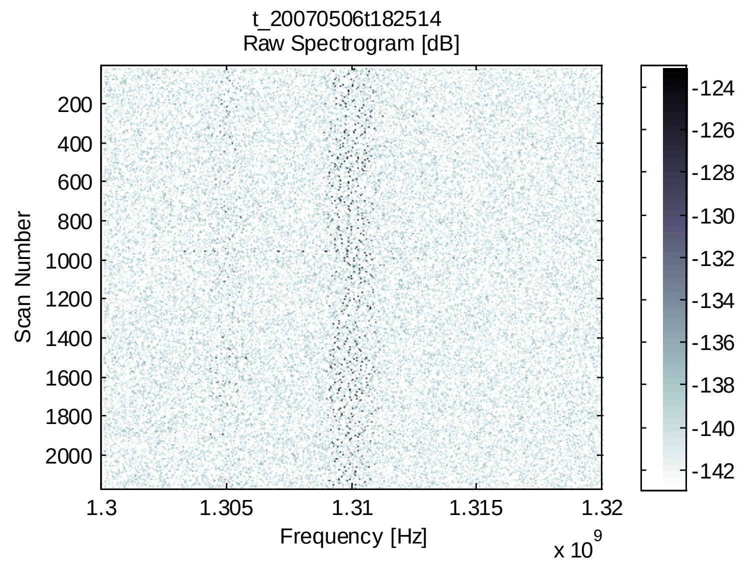


Figure 3.11: t_20070506t182514_1300_1320_spectrogram_raw

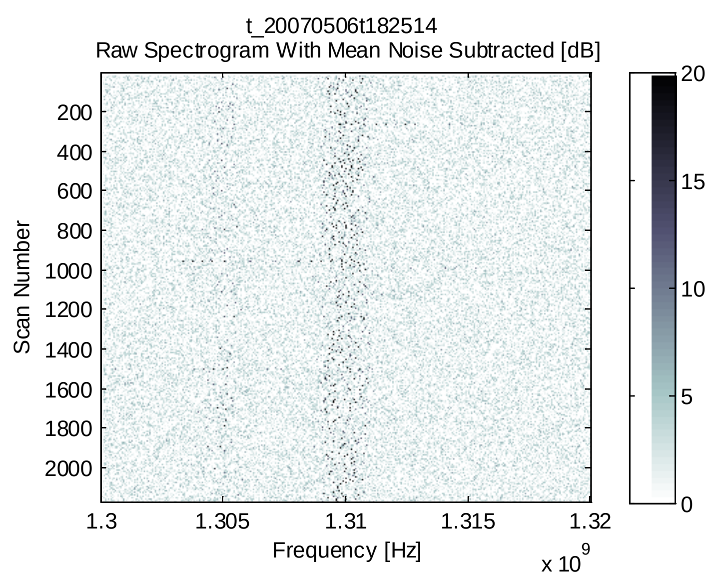


Figure 3.12: t_20070506t182514_1300_1320_spectrogram_minus_mean_fit

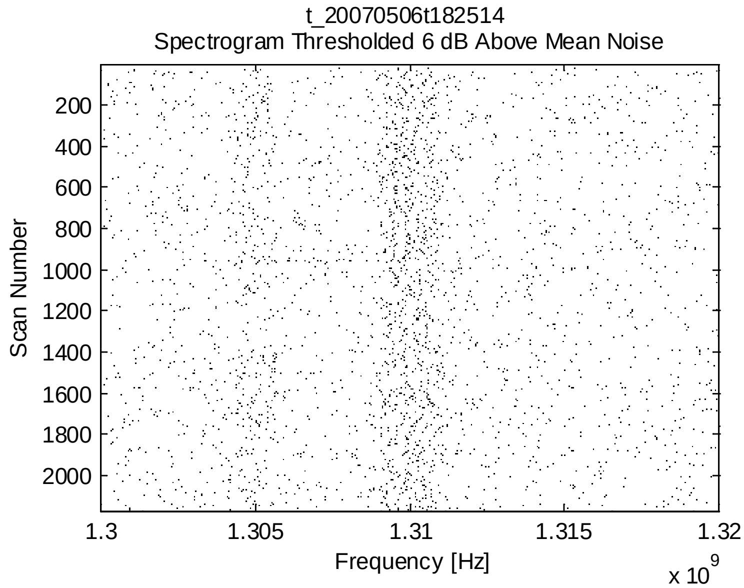


Figure 3.13: t_20070506t182514_1300_1320_spectrogram_threshold_6dB

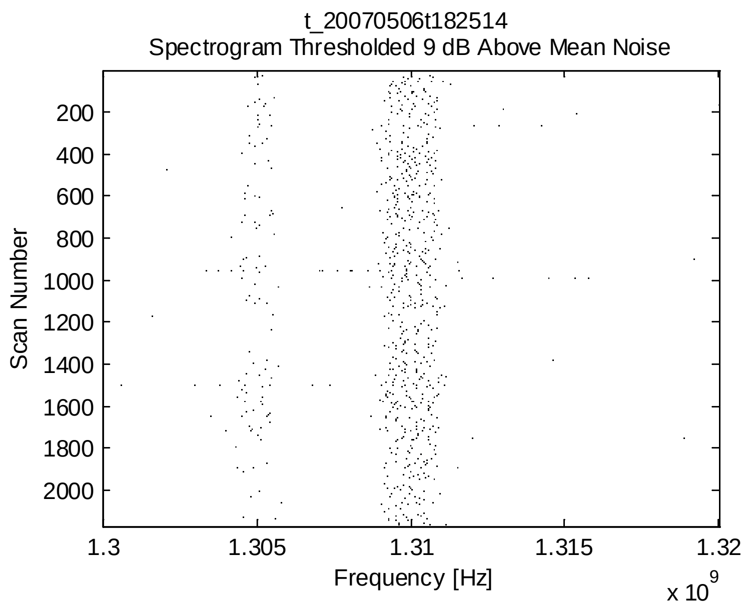


Figure 3.14: t_20070506t182514_1300_1320_spectrogram_threshold_9dB

3.6.5 rfiquicklook Charts

All full range max mean min charts of appendix A were constructed with the ATNF code "rfiquicklook". For each measurement, these charts record the measuring equipment used in the antenna line from the antenna to the spectrum analyser (FSU), with FSU settings recorded at the end of the line. The charts also record the table name, sweep count, RBW, technician, polarisation and bearing. The full size charts with details are contained in the compact disc that accompanies this work, but they are not a part of the 20 MHz band code. The rfiquicklook charts can be magnified to RBW frequency levels as required (with Matlab) as per figure 3.15 below. The full size max 90 med and occupancy charts of appendices B and C do not have the equipment details recorded, but full size versions are also on the disc. All of these require as minimum, Matlab Version 7.5.0.342 (R2007b) or Matlab Student Version 7.1.0.124 (R14) with Service Pack 3 produced by The MathWorks.

3.6.6 Problems Encountered

There were two problems encountered in the course of the project that have been minimised with better familiarisation with procedure and experience. These errors do not render results unusable and they form a part of the methodology development.

The first involved the ripple of figures A15 - A17. This was caused by coaxial cable wear at connectors that then required re-connecting. The problem highlighted the need to run the rfiquicklook code in the field immediately after recording a measurement. While spectrum analyser screen checks were made, they did not reveal the problem during the measurements. Familiarisation of equipment and process was taking place during the course of these measurements at Kauri Flat and Awarua.

The second problem concerns the omitted calibration step affecting the measurements, The rfiquicklook code generating the charts of appendix A, only required a calibration with the noise diode on to subtract the spectrum analyser settings for pre amplifier and internal attenuation. There was no step to calibrate with the diode off. The full analysis code requires a diode on and a diode off calibration. However, it has been shown in section 2.6.2 that the correction factor is not significant to the scale of charts plotted and can be corrected at the software level in future if required.

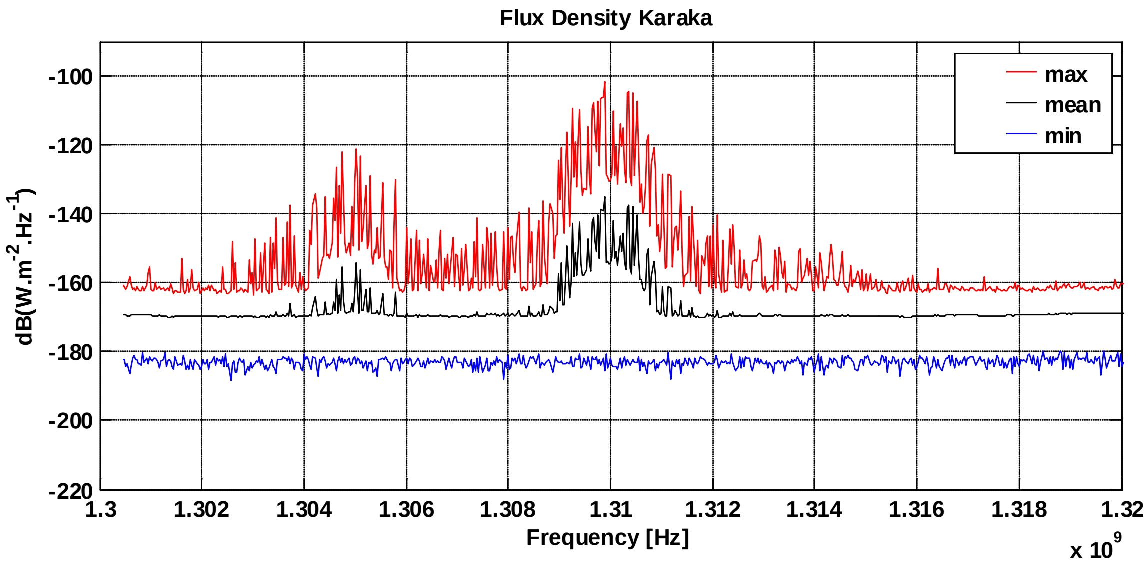


Table Name:	**t_20070506t182514**
Antenna:	**HF-CoaxDipole 1 m LMR400 cable Minicircuits 4016 LNA 10.1 m LMR400 cable FSU preamp on attn 0**
Sweeps:	**2172 060507 1825 - 070507 2000**
Resolution Bandwidth:	**30 kHz**
Technician:	**Paul**
Polarization:	**V**
Bearing:	**Omni**

Figure 3.15: figure A21 rfiquicklook chart zoomed to 1.3 – 1.32 GHz

4. Conclusion

The methods worked through for this project could be consolidated into an expedient process for data capture and analysis, for comparison with other locations. This could be achieved with a more suitable selection of equipment and streamlining of software used. ATNF are examining ways of consolidating the software and this work could be investigated in the future. In terms of equipment, if broad band LNA devices are used, measurement sets could be taken in two bands, one from 30 MHz to 5 GHz and the other from 5GHz upwards. In city locations, filtering and/or attenuation are required, but if the low frequency signals are filtered off (up to the bottom of the range to be measured) the level of attenuation required can be reduced. Strong signals received may cause inter-modulation effects though they may not be obvious in the range being measured. High gain omni-directional antennae are suggested unless the directional component is required. An LNA is necessary and should be installed, with filters and attenuators, at the front end of antenna lines in order to condition and amplify signals before they are passed through the cables. Any spectrum analyser preamplifier should be left on unless the antenna and LNA gains render this unnecessary. Low loss cables should be used. For trend purposes, the resolution bandwidth recommended is 10 kHz to 30 kHz if time permits. If time does not permit RBW 100 kHz to 300 kHz could be used. Generally speaking, the high and low RBW requires proportionally longer measurement time to raise the probability of signal capture and averaging. For spectrum usage monitoring, there is no real need to characterise the RFI environment in all directions. A single direction towards the main signal activity is adequate, or else omni-directional antennae could be used. These may require some additional filtering or attenuation owing to the additive power levels from all directions.

The inner city measurements were conducted in the busiest transmission environment and the level of low frequency radio signals were substantial, and caused the most serious inter-modulation. These signals, to the bottom of each range measured, should have been filtered off at AUT and at Mount Wellington. They were filtered off most measurements, but not the 80 – 1600 MHz range measurements. Attenuation was used which resolved the problem. The low frequency signal power did not appear sufficient to interfere with rural measurements.

4.1 Recommendation for Future Development

1. Examine more of the radio spectrum 30 MHz to 30 GHz.

These were the band limits specified in the project requirements but the equipment available did not permit investigation to this extent. Te software used in this investigation could be applied to equipment capable of measuring activity within this range as well as less than 30 MHz, where there are likely to be many more interferers and higher than 30 GHz where there is likely to be much empty spectrum required for future development.

2. Build a full working system at the AUT Warkworth telescope as RFI data will be required there on a continuing basis.

This application is required immediately and access to ATNF staff, facilities and software is still available. ATNF have indicated substantial willingness to assist AUT Institute of Radio Astronomy and Space Research in all endeavours to install and commission the new Warkworth telescope.

3. Streamline data taking and analysis procedures and software.

This work was conducted with no prior knowledge of the ATNF designed RFI monitoring system. Now that substantial experience has been gained in its use, further development and customisation for the New Zealand environment could be carried out efficiently.

4. Further process data for summarised temporal characteristics and process other location data collected.

Temporal analysis is required for spectrum planning purposes. No code was available for automatic processing and time did not permit a manual analysis. All charts in this work are averages over the entire scan time periods as are the 20 MHz band charts in "NZRFI Directories 2007 2008". Modification to the Matlab code that will summarise temporal characteristics is recommended.

5. Investigate varying resolution bandwidth and measurement time to derive the probability function of signal capture with high and low RBW as well as short and long measurement timing.

Lengthening the integration time within the RBW used will have the effect of averaging out more of the random noise signals, giving much clearer pictures of actual signals as well as a lower random noise level but this decreases the probability of a man made signal being present, if it is not a continuous signal. This can be offset with longer scan time.

6. Determine the drop in inter-modulation effects with the filtering of low frequency signals to the bottom of the frequency range being measured.

It may be possible to eliminate the need for attenuators provided that signal input is conditioned specifically to the frequency range of interest. This will increase time required if a wide frequency band is to be investigated but will improve receiver sensitivity for narrow frequency range.

7. Examine other locations such as inner city street level locations for urban comparison, the top of Mount Wellington for suburban comparison and more remote rural locations.

This method is portable but time constraints prevented adequate location measurement to permit comparison to a statistically significant level.

8. Investigate noise contribution from automotive sources, high tension power lines and reflecting surfaces.

Comparisons can be made between other locations measured to gain initial impressions of noise contributors, or they could be determined directly with this methodology.

9. Investigate smaller bandwidth and low RBW.

Use of small bandwidth allows time to investigate at 3 or 1 kHz RBW.

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Appendix A: Maximum, Mean and Minimum Flux Density

Instrumentation circuits below refer primarily to appendix A figures as the instrumentation is recorded on the individual appendix A charts on the accompanying disc. The figure number sequence matches figure numbers in appendix B and appendix C as they use the same data tables. In a few cases the appendix A data tables became corrupted and could not be plotted with the 20 MHz analysis code, which are summarised in appendix B and C.

Auckland City Instrumentation Circuits

Figures A(B,C)1 – A(B,C)4; HL050 log periodic antenna, filter 1.34 - 4 GHz, LNA on Miteq AFS30010080014s4s, 10.1 m LMR400 cable, 5 m MF141 cable, FSU preamp on attenuation 0.

Figures A(B,C)5 – A(B,C)7; HL050, 5.5 - 10 GHz filter, LNA on Miteq AFS30010080014s4s, 10.1 m LMR400 cable, 5 m MF141 cable, FSU preamp on attenuation 0 except on figure A7, with 10dB for tables t_20080309t203841, t_20080309t234713 and 5 dB for table t_20080310t152630.

Figure A(B,C)8; HK014 coaxial dipole antenna, attenuation 2 @ 6 dB, LNA on MinicircuitsZx60-4016E-S+ 16 dB gain, 10.1 m LMR400 cable, 5 m MF141 cable, FSU preamp on attenuation 0.

Figure A(B,C)9; HK014, attenuation 3 @ 6 dB, LNA on Minicircuits Zx60-4016E-S+ 16 dB gain, 10.1 m LMR400 cable, 5 m MF141 cable, FSU preamp on attenuation 0.

Mt Wellington Instrumentation Circuits

Figures A(B,C)10 – A(B,C)11; HF LPDA (HL050), filter 1340-4000 MHz, LNA on Miteq AFS30010080014s4s, 10.1 m LMR400 cable, 500 mm flexible cable, FSU preamp on attenuation 0.

Figures A(B,C)12 – A(B,C)13; HF LPDA, filter 5500 - 10000 MHz, LNA on Miteq AFS 30010080014s4s, 10.1 m LMR400 cable, 500 mm flexible cable, FSU preamp on attenuation 0.

Figure A(B,C)14; HK014, 2 attenuators @ 6 dB DC - 1500 MHz, LNA on Miteq AFS30010080014s4s 29 dB gain 100 - 1500 MHz, 10.1 m LMR400 cable, 500 mm flexible cable, FSU preamp on attn 0.

Awarua Instrumentation Circuits

Figures A(B,C)15 - A(B,C)16; HF LPDA, LNA on Miteq AFS30010080014S4S, 9 m H&S MF141 cable, FSU preamp on attn 0.

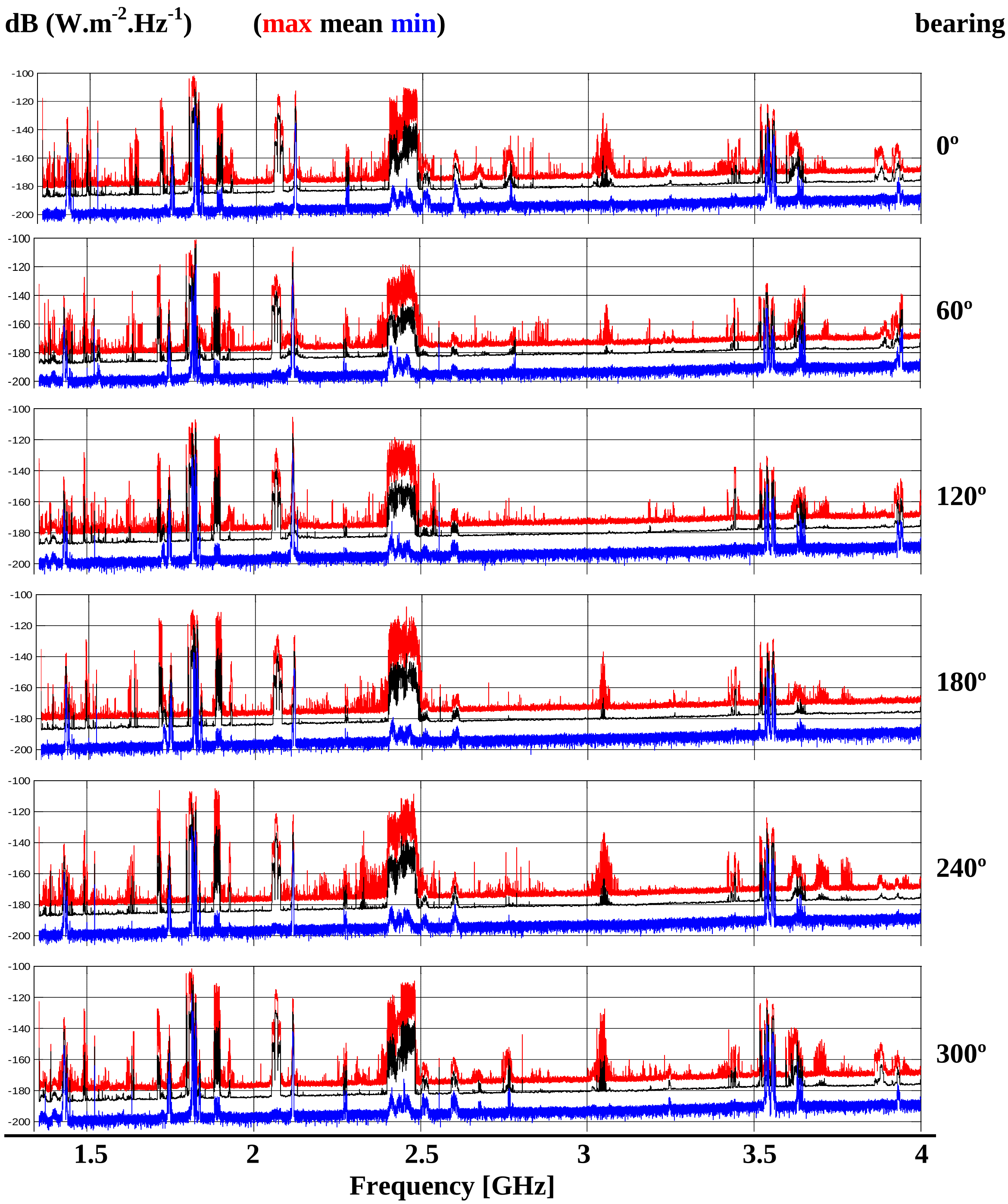
Kauri Flat Instrumentation Circuits

Figure A(B,C)17; HF LPDA, LNA on Miteq AFS30010080014S4S, 9 m H&S MF141 cable, FSU Preamp on attn 0.

Figures A(B,C)18 – A(B,C)20; Coaxial dipole (HK014), 1 m LMR400 cable, Minicircuits 4016 LNA, 10.1 m LMR400 cable, FSU preamp on attn 0.

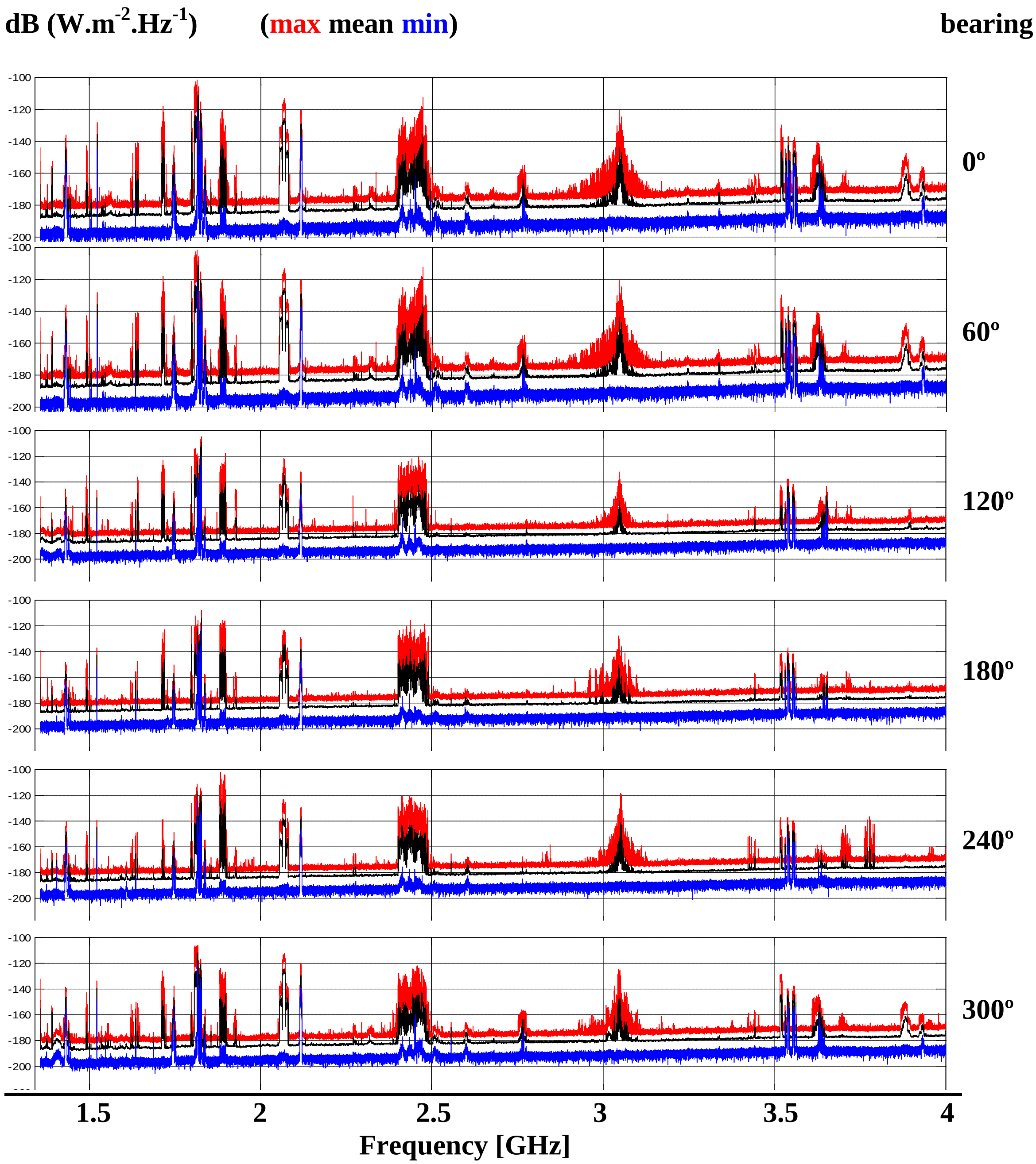
Karaka Instrumentation Circuits

Figure A(B,C)21; HK014 antenna, 1 m LMR400 cable, Minicircuits 4016 LNA, 10.1 m LMR400 cable, FSU preamp on attn 0.



Tables		
t_20080304t134343	Antenna:	HL050
t_20080305t140111	dB scales:	-200 to -100
t_20080306t003358	Resolution Bandwidth:	30 kHz
t_20080306t183456	Video Bandwidth:	10 kHz
t_20080307t062858	Polarisation:	Vertical
t_20080307t225516	Bearing:	As indicated
	Sweeps:	1000 at each bearing

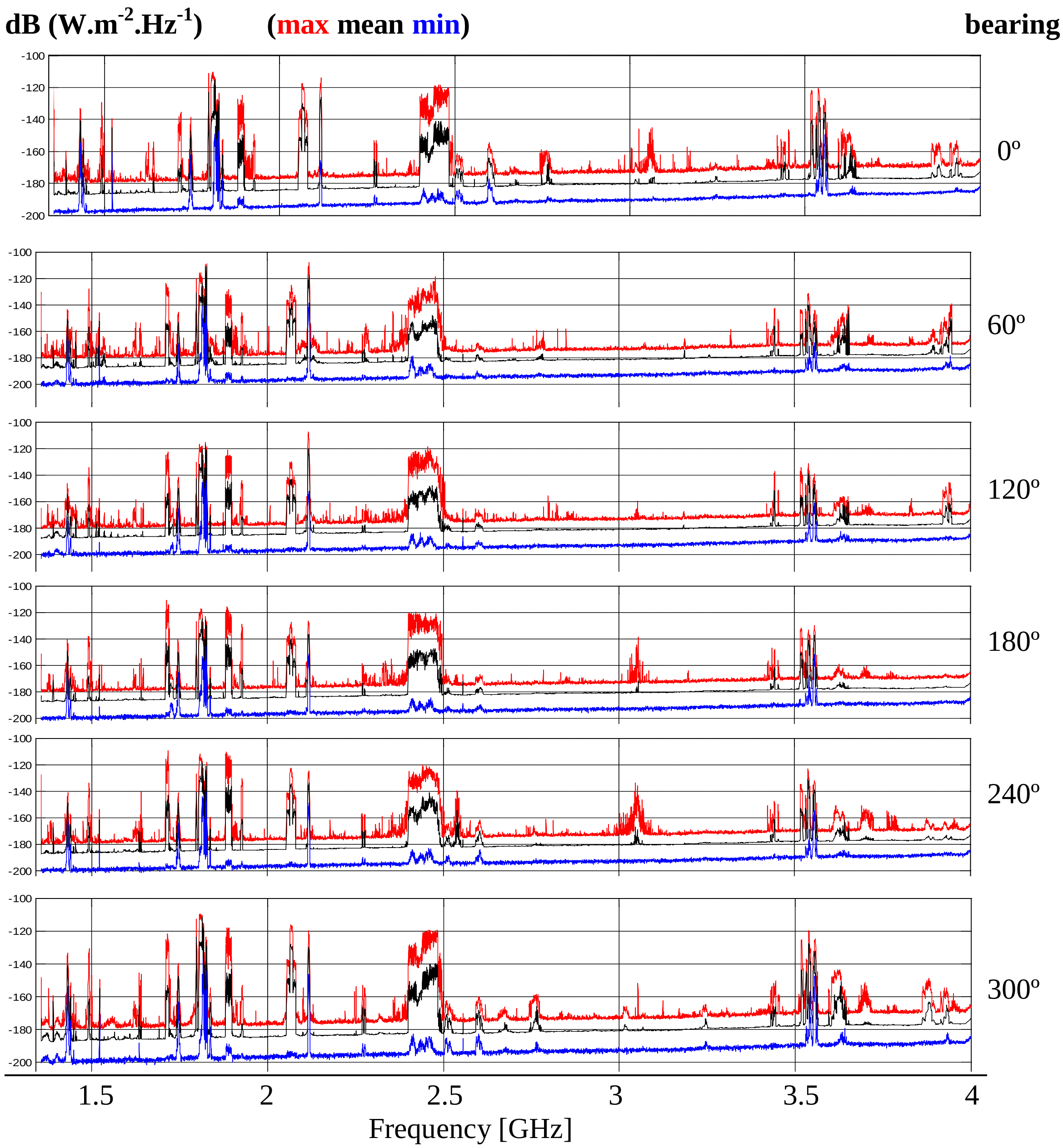
Figure A1: Vpol 30 kHz RBW 1.34 – 4 GHz at roof of AUT Auckland City



Tables
t_20080308t175831
t_20080308t210603
t_20080308t235945
t_20080309t030406
t_20080309t055643
t_20080308t150216

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	200 at each bearing

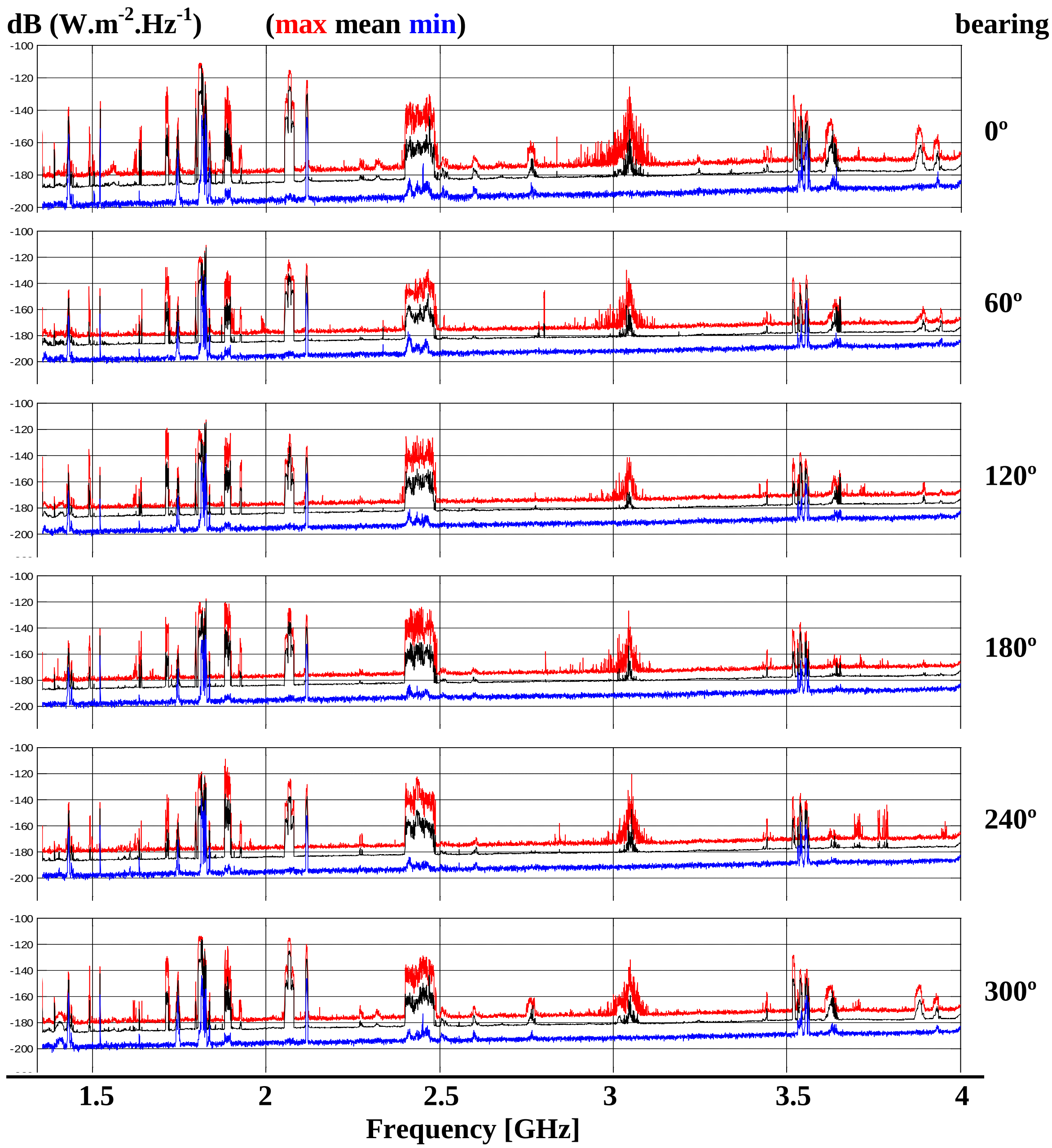
Figure A2: Hpol 30 kHz RBW 1.34 – 4 GHz at roof of AUT Auckland City



Tables
t_20080304t005604
t_20080305t111829
t_20080306t110054
t_20080306t141541
t_20080307t163433
t_20080307t194338

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	2500 at each bearing

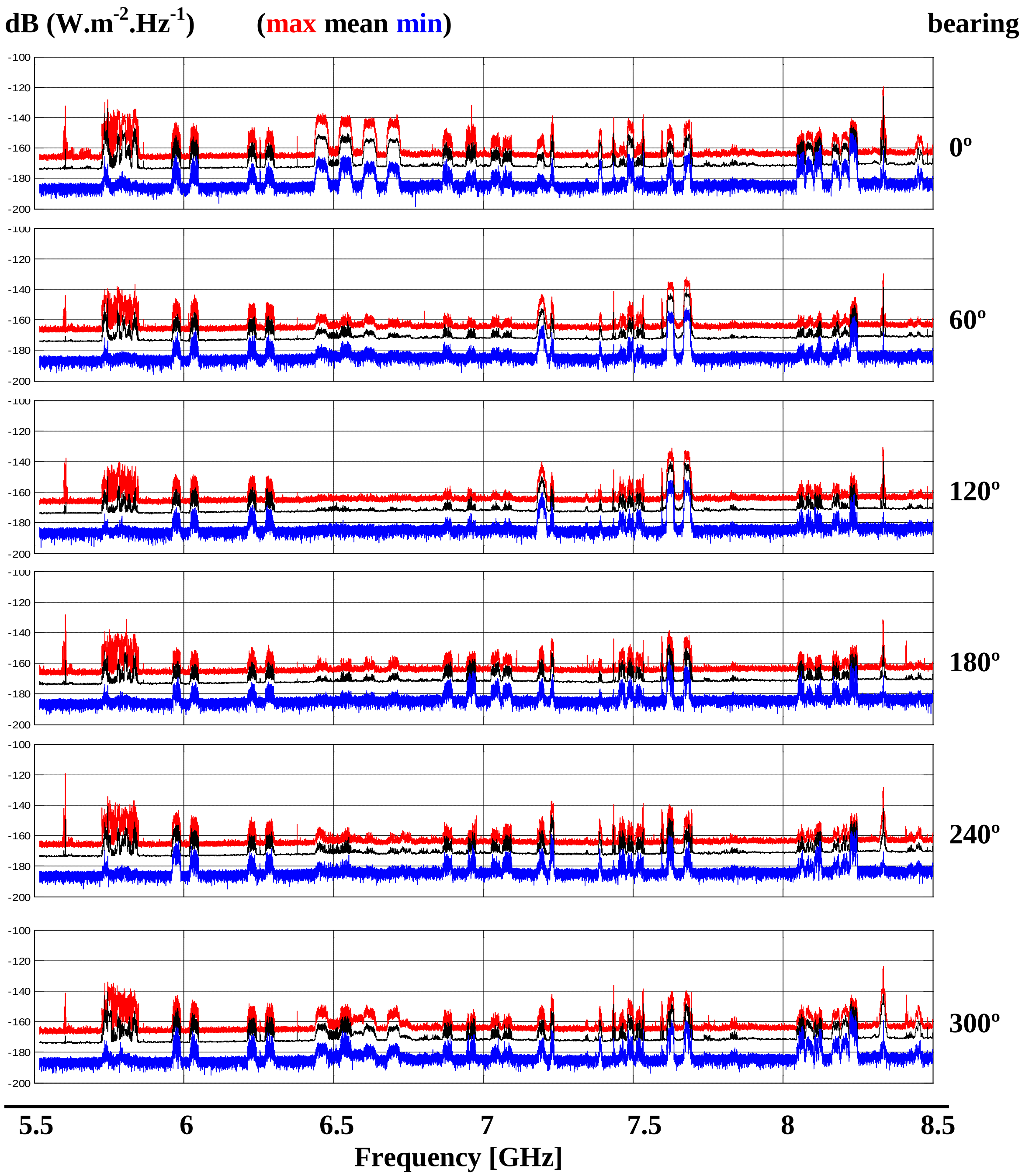
Figure A3: Vpol 300 kHz RBW 1.34 – 4 GHz at roof of AUT Auckland City



Tables
t_20080308t172216
t_20080308t202915
t_20080308t232659
t_20080309t022651
t_20080309t051556
t_20080308t142249

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

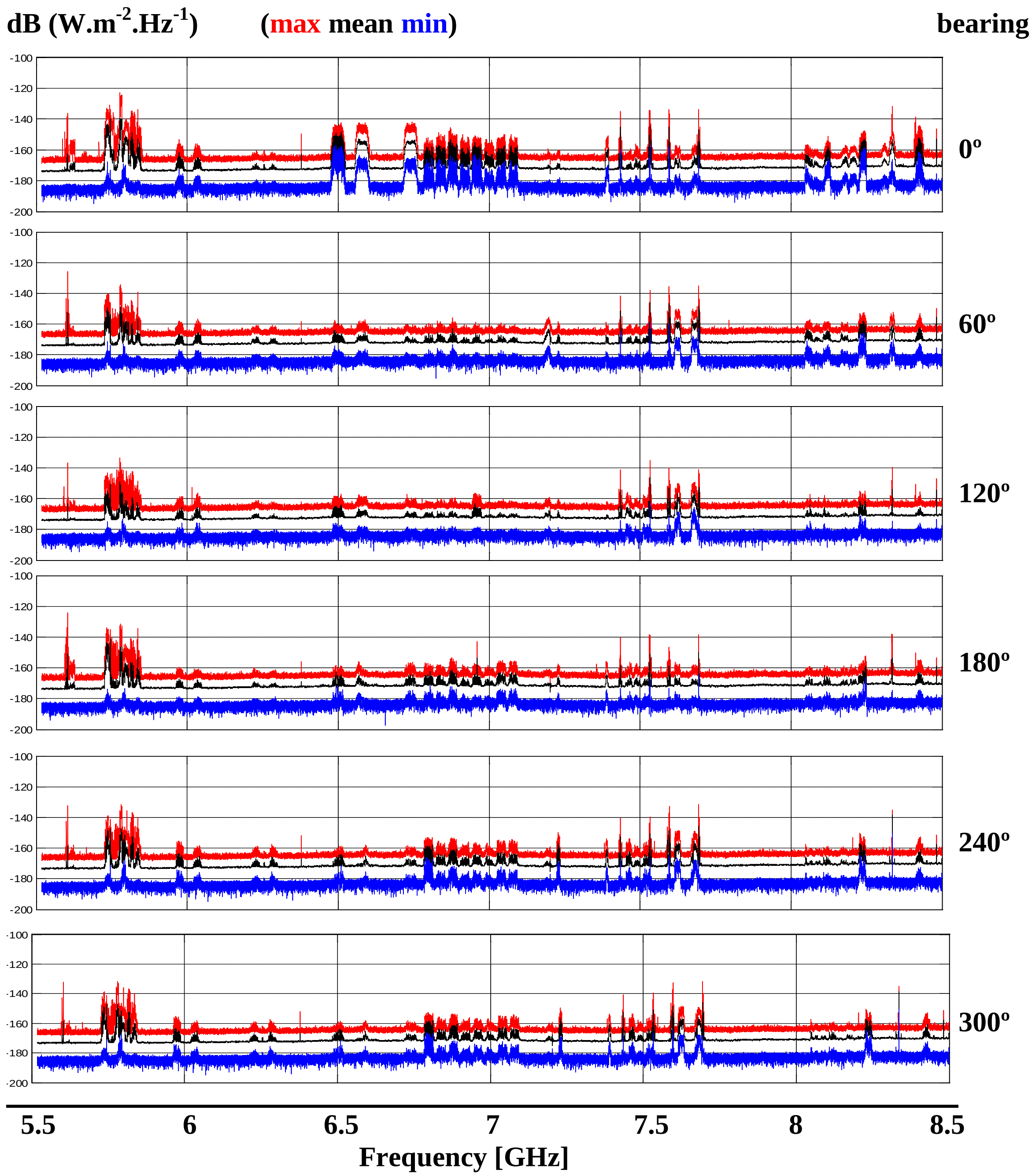
Figure A4: Hpol 300 kHz RBW 1.34 – 4 GHz at roof of AUT Auckland City



Tables
t_20080315t022609
t_20080315t131802
t_20080316t002335
t_20080311t135216
t_20080312t040914
t_20080312t152947

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	1000 at each bearing

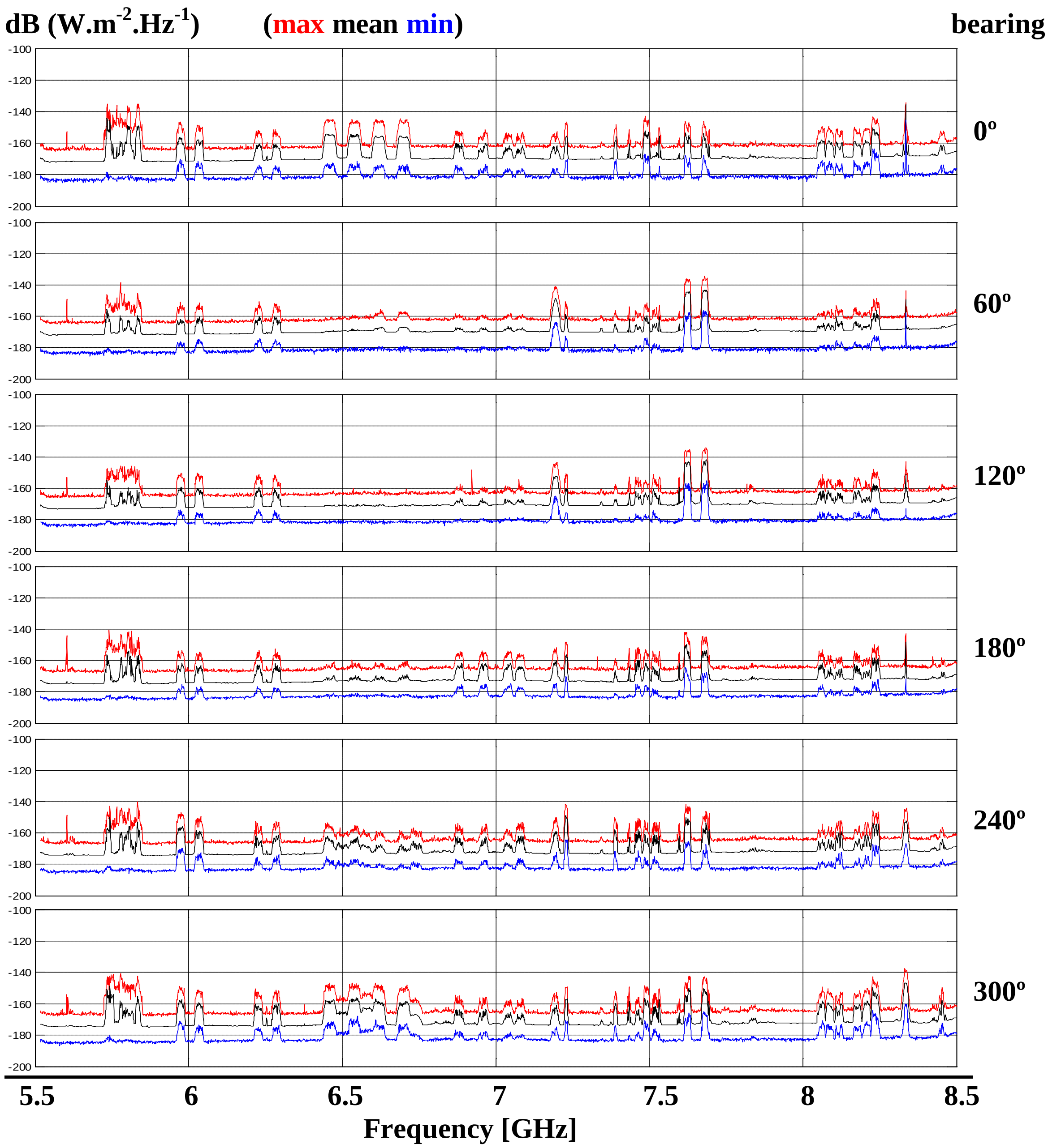
Figure A5: Vpol RBW 30 kHz 5.5 – 8.5 GHz at roof of AUT Auckland City



Tables
t_20080313t165414
t_20080313t223320
t_20080314t083456
t_20080314t140825
t_20080314t202216
t_20080313t112400

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

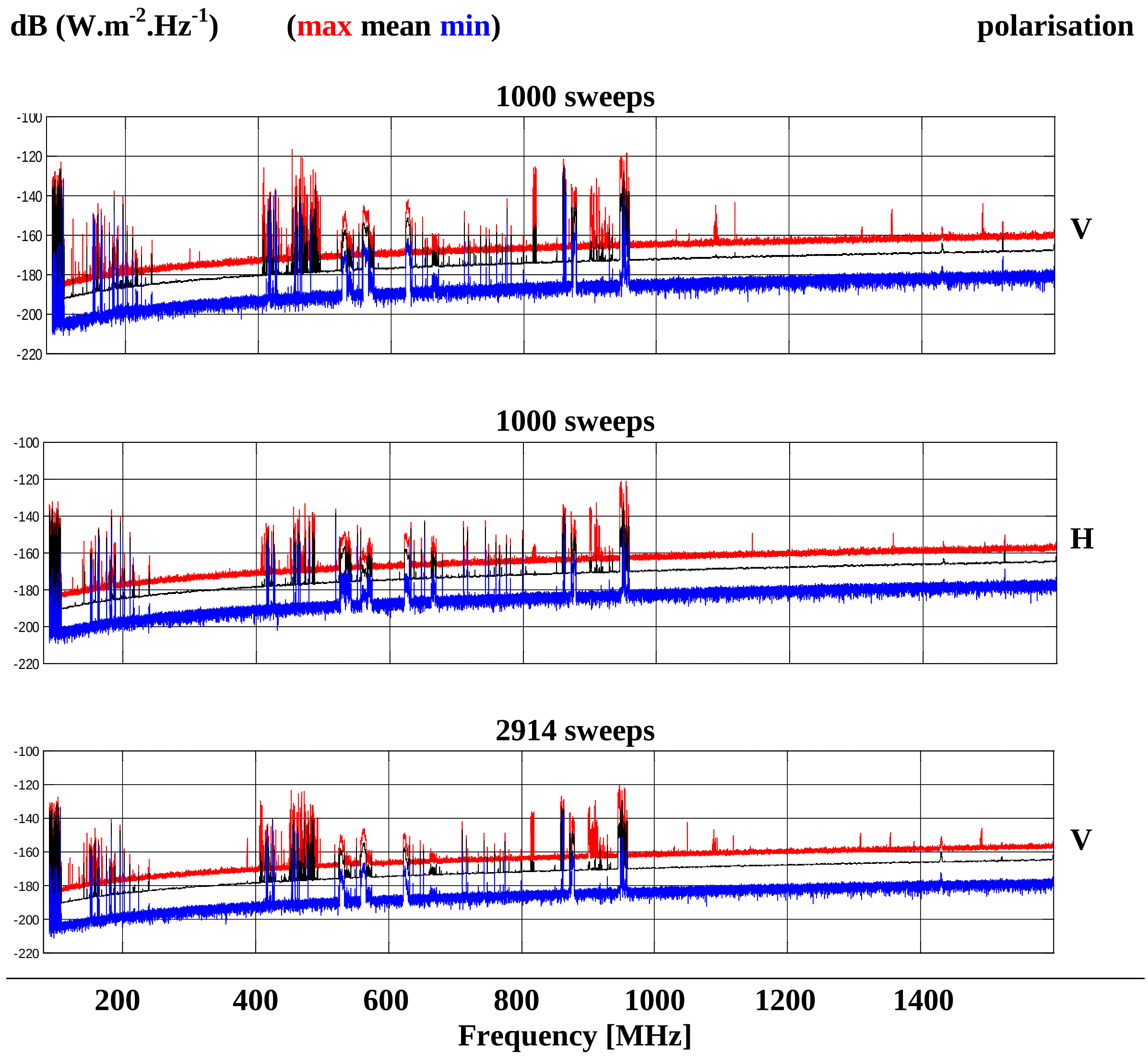
Figure A6: Hpol RBW 30 kHz 5.5 – 8.5 GHz at roof of AUT Auckland City



Tables	Attenuation
t_20080309t203841	10 dB
t_20080309t234713	10 dB
t_20080310t152630	5 dB
t_20080311t104940	0
t_20080312t010639	0
t_20080313t023628	0

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	1000 kHz
Video Bandwidth:	300 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	5000 at each bearing

Figure A7: Vpol RBW 1000 kHz 5.5 – 8.5 GHz at roof of AUT Auckland City

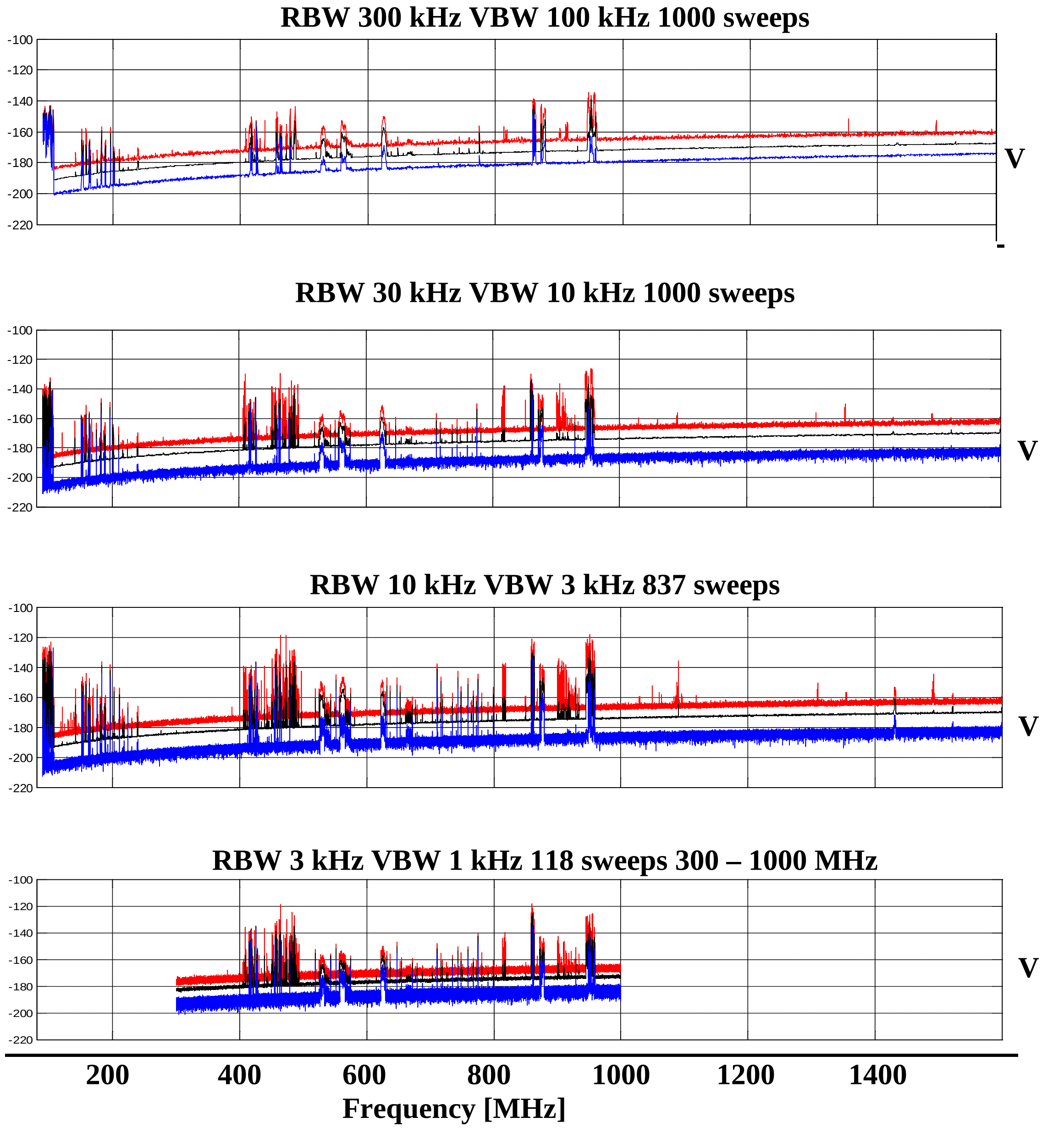


Tables
t_20080317t063338
t_20080318t202730
t_20080319t023912

Antenna:	HK014
dB scales:	-220 to -100
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

Figure A8: RBW 30 kHz 80 – 1600 MHz at roof of AUT Auckland City

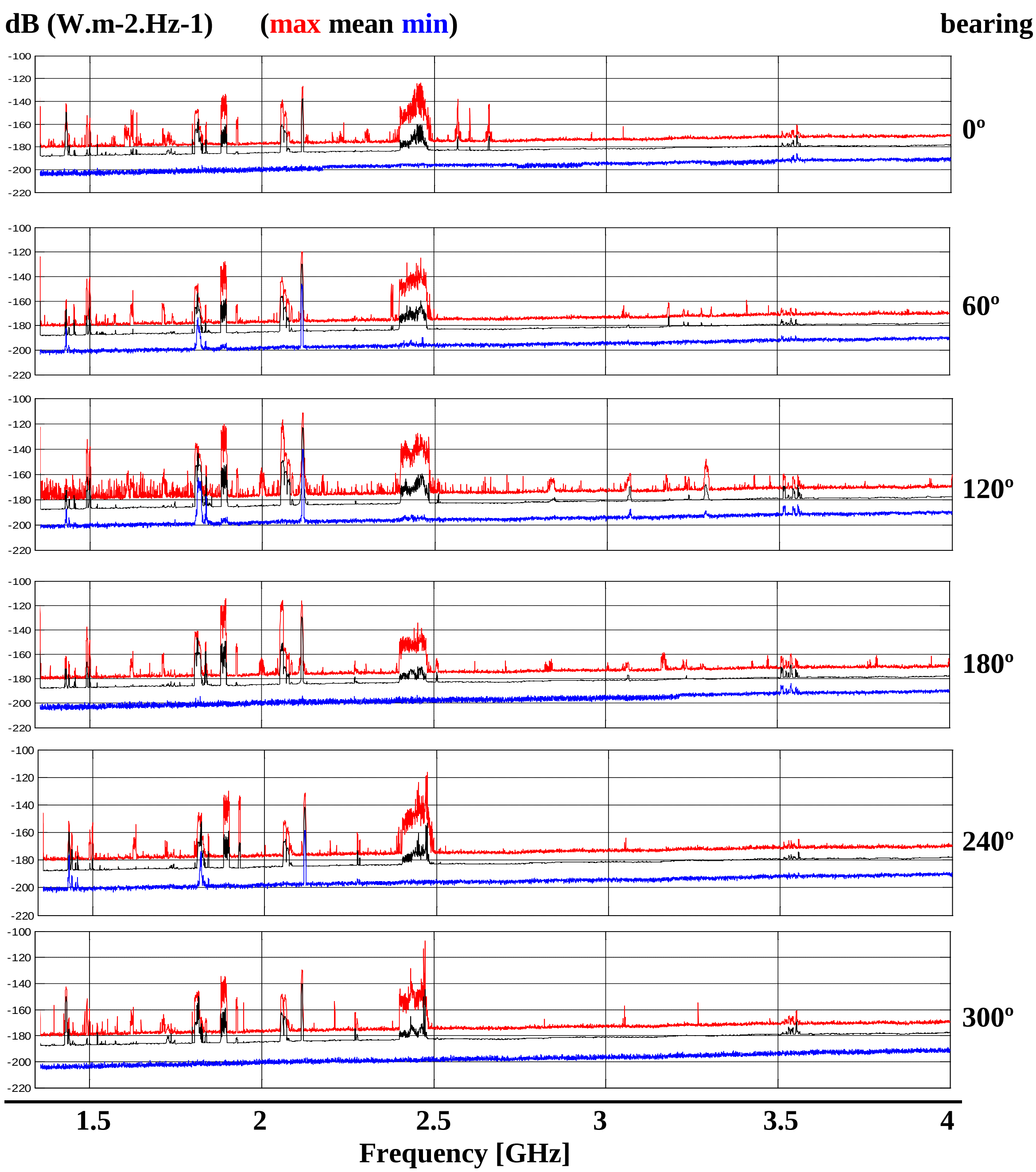
dB (W.m^{-2}.Hz^{-1}) (max mean min) polarisation



Tables
t_20080318t011904
t_20080318t113456
t_20080319t185706
t_20080318t020454

Antenna:	HK014
dB scales:	-220 to -100
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

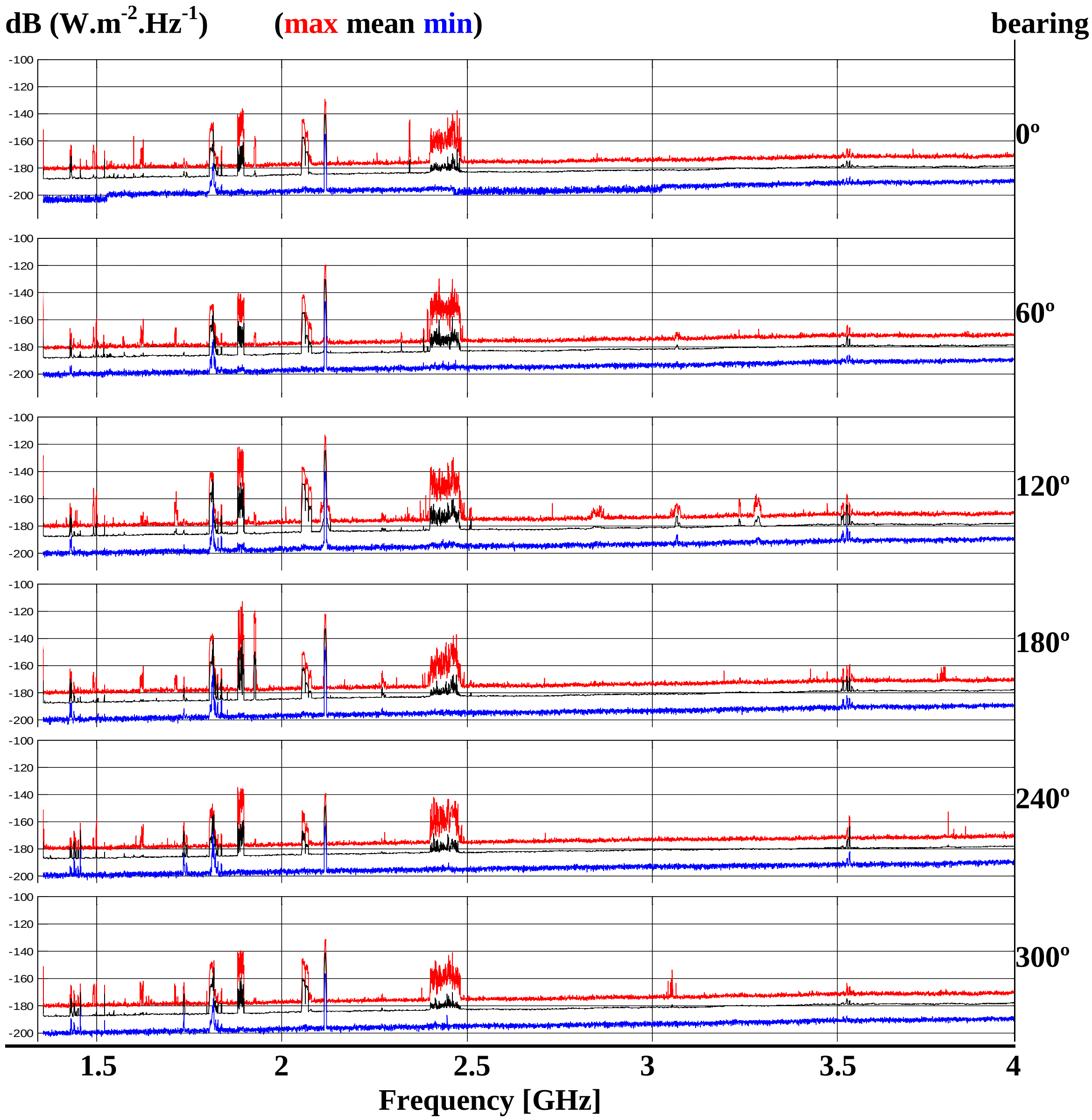
Figure A9: Varied RBW 80 – 1600 MHz at roof of AUT Auckland City



Tables
t_20080208t072311
t_20080208t194741
t_20080209t080720
t_20080209t201923
t_20080210t083740
t_20080210t205400

Antenna:	HL050
dB scales:	-220 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	~5000 at each bearing

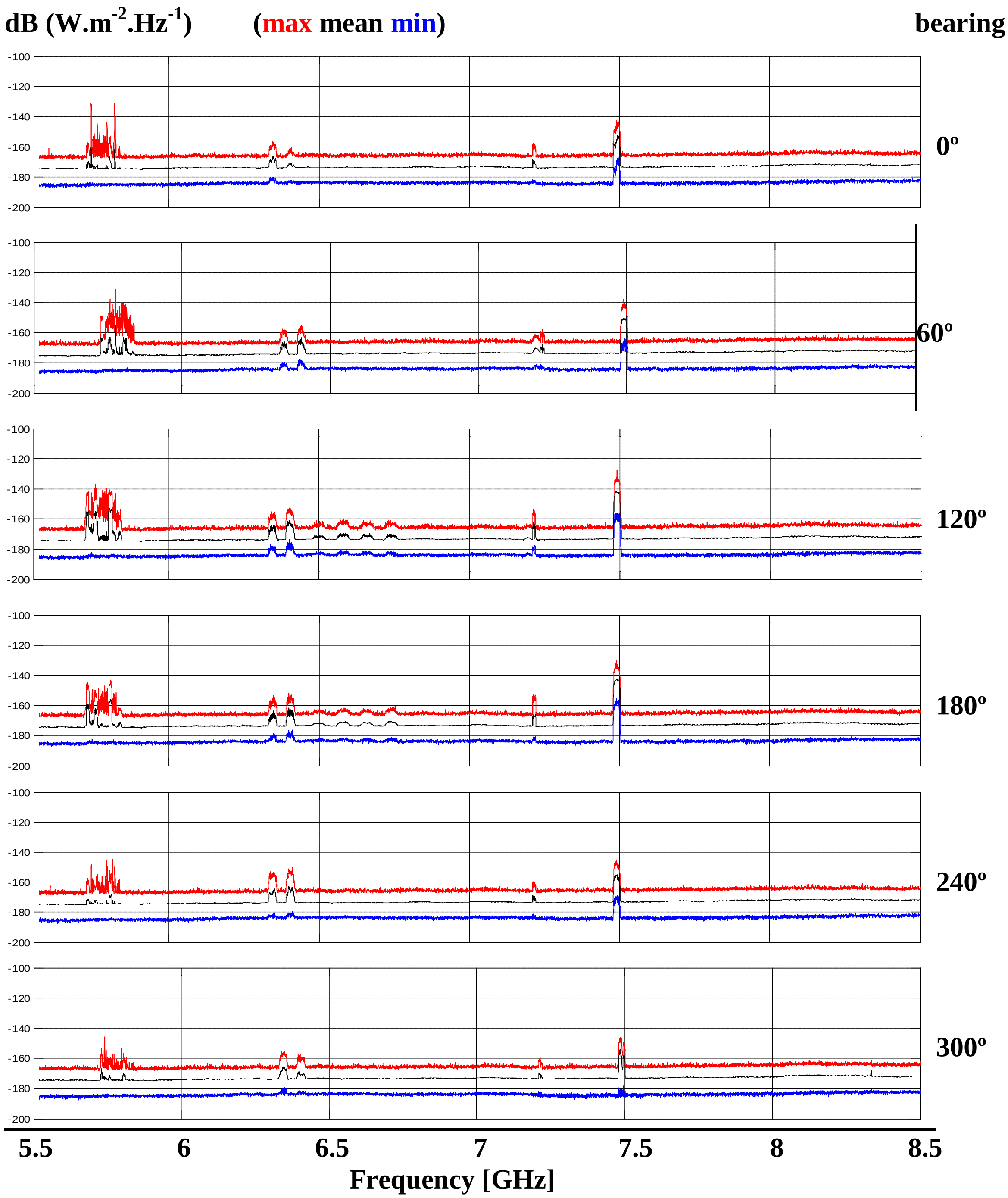
Figure A10: Vpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington residence



Tables
t_20080211t113433
t_20080211t140551
t_20080211t163138
t_20080211t190506
t_20080211t220709
t_20080211t091042

Antenna:	HL050
dB scales:	-220 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	479 at 240 º and 1000 at other bearings

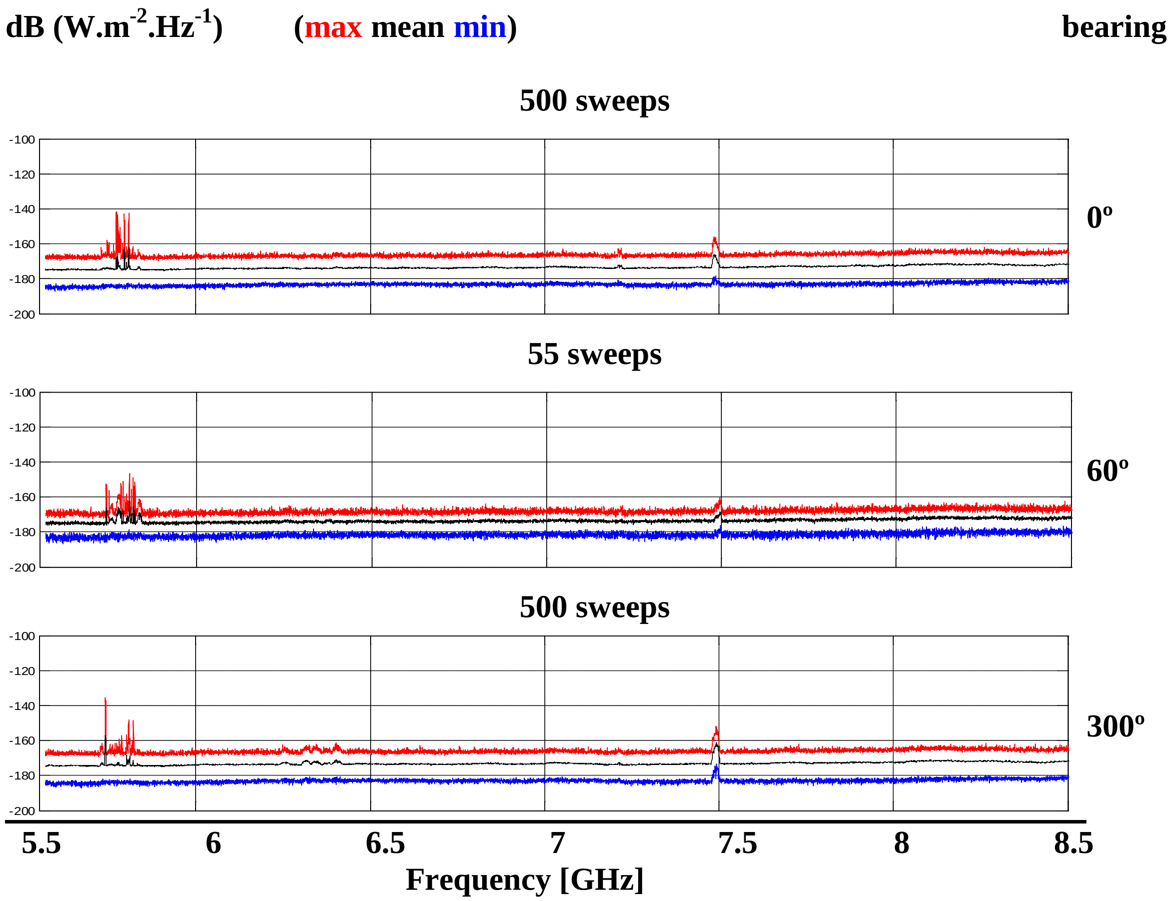
Figure A11: Hpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington residence



Tables
t_20080216t013935
t_20080216t123038
t_20080216t202327
t_20080217t041500
t_20080217t140530
t_20080217t220154

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	~2000 at each bearing

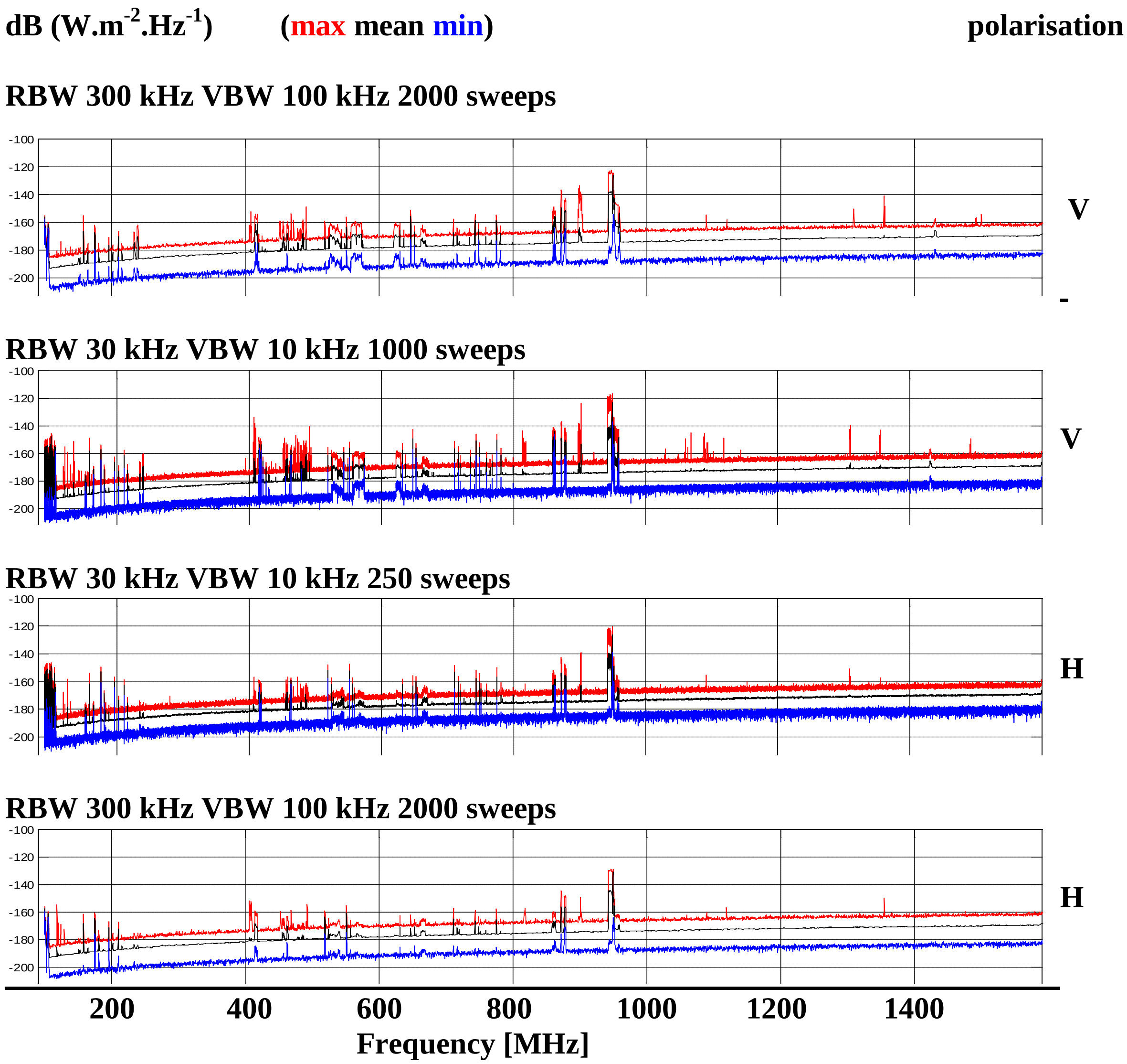
Figure A12: Vpol RBW 300 kHz 5.5 – 8.5 GHz at Mt Wellington residence



Tables
t_20080218t105805
t_20080218t130206
t_20080218t084115

Antenna:	HL050
dB scales:	-200 to -100
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	As indicated

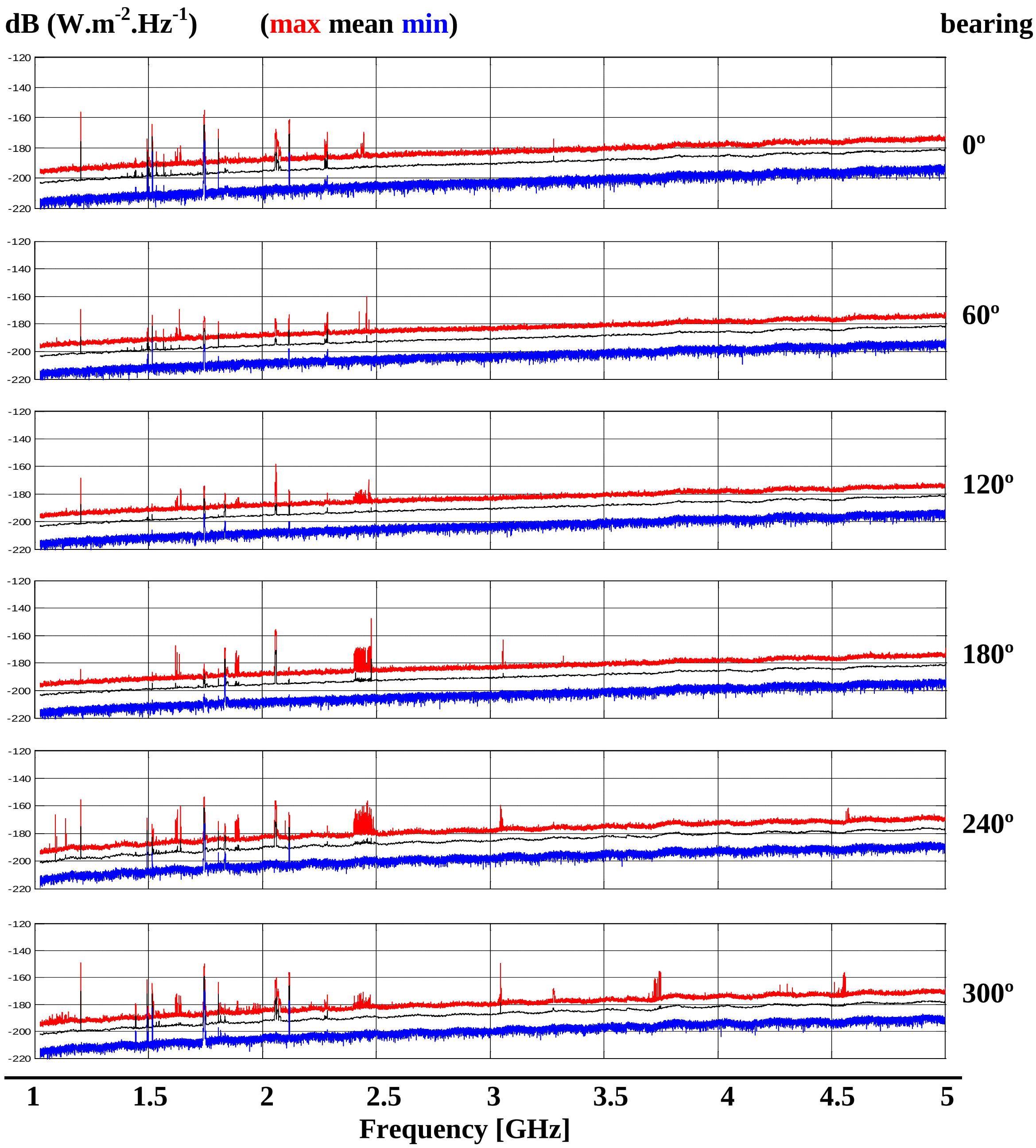
Figure A13: Hpol 300 kHz RBW 5.5 – 8.5 GHz at Mt Wellington residence



Tables
t_20080226t212253
t_20080227t002050
t_20080226t172605
t_20080226t143451

Antenna:	HK014
dB scales:	-200 to -100
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

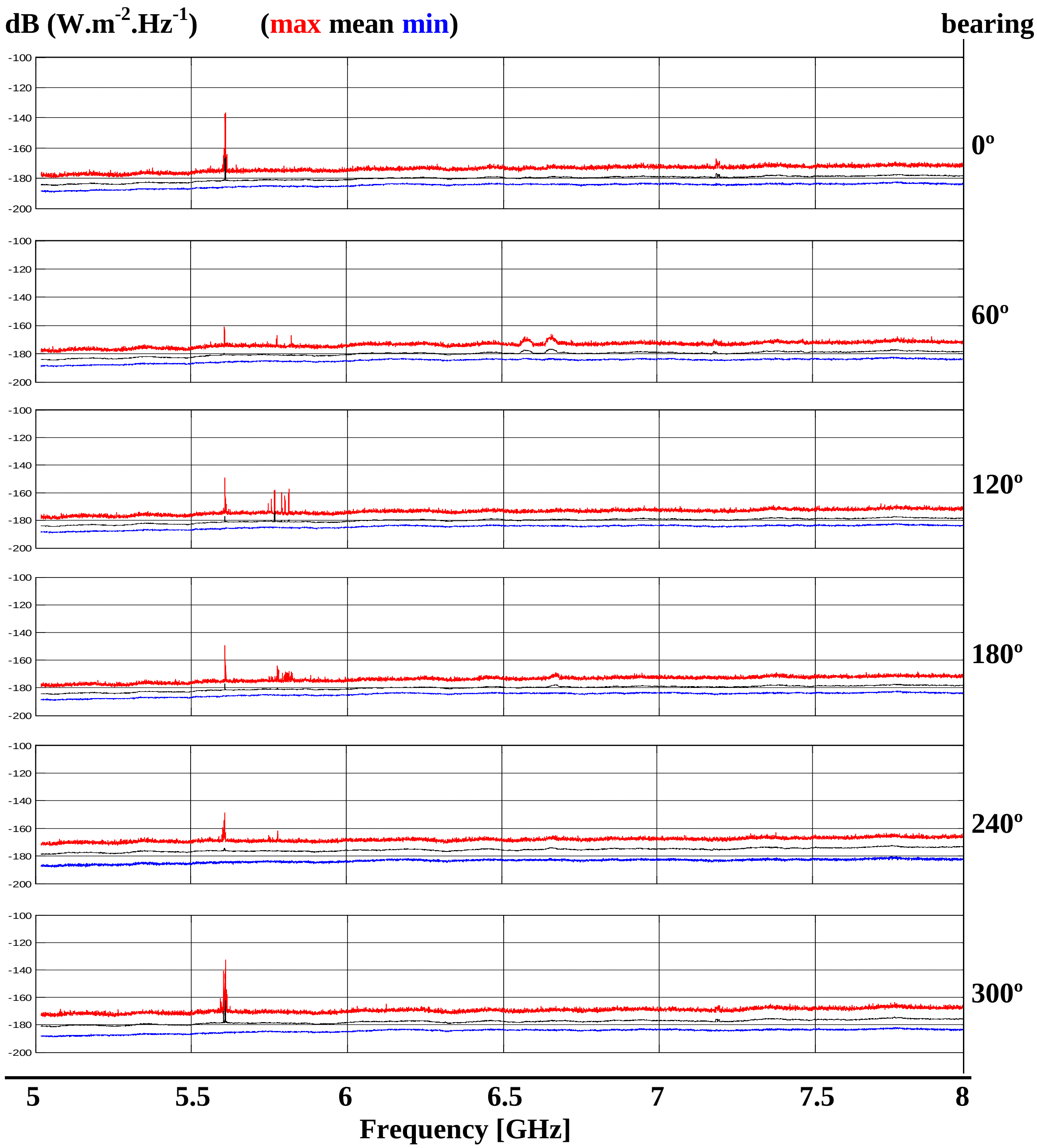
Figure A14: Varied RBW 80 – 1600 MHz at Mt. Wellington residence



Tables
t_20071027t204012
t_20071030t191204
t_20071029t232407
t_20071028t233320
t_20071029t024424
t_20071031t233456

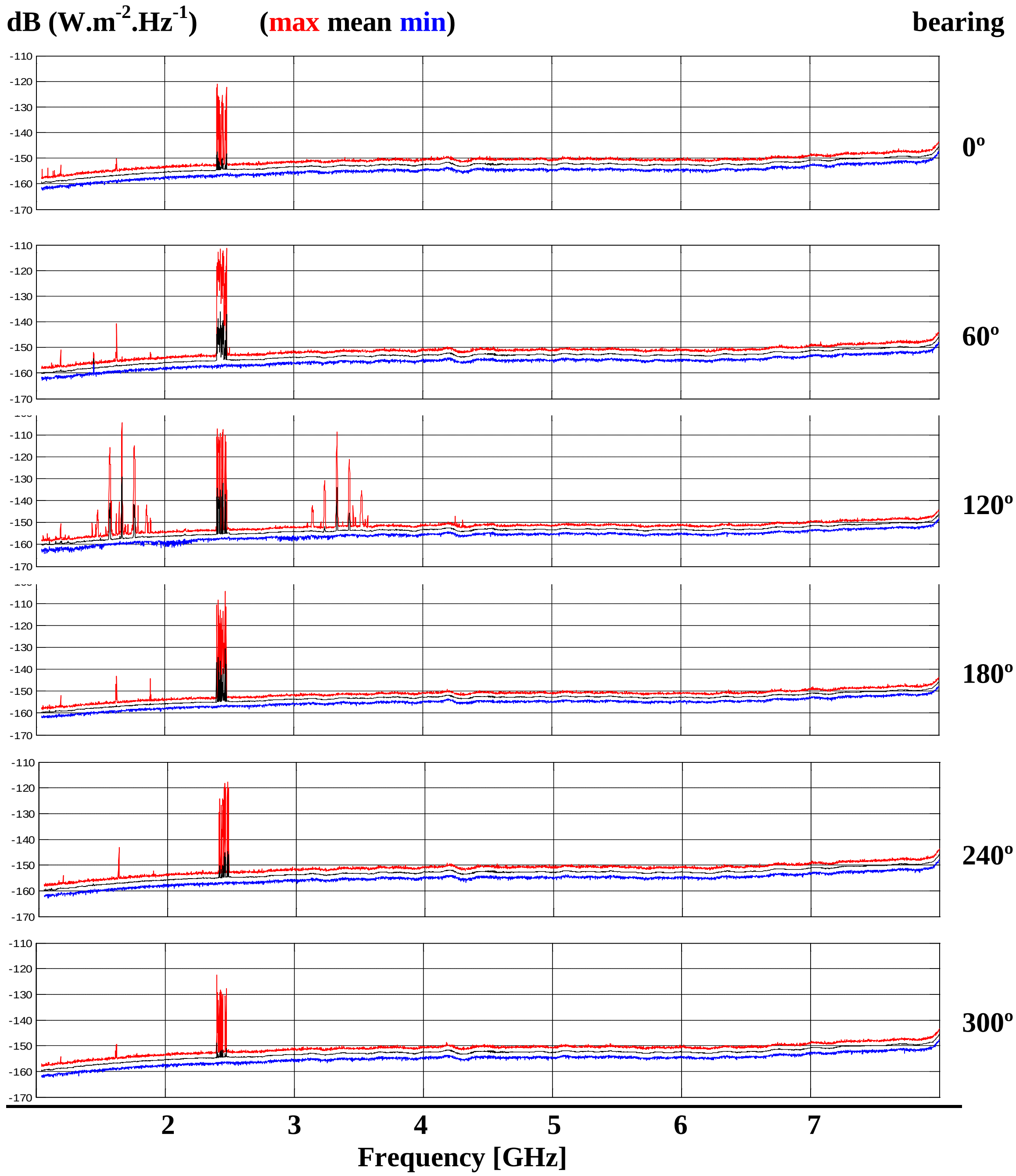
Antenna:	HL050
dB scales:	-220 to -120
Resolution band width	100 kHz
Video band width	30 kHz
Polarisation:	Vertical
Sweeps:	1000 at each bearing

Figure A15: Vpol 100 kHz RBW 1 – 5 GHz at Awarua Station



Tables		
t_20071028t104331	Antenna:	HL050
t_20071031t072027	dB scales:	-200 to -100
t_20071030t091040	Resolution band width	300 kHz
t_20071029t092057	Video band width	100 kHz
t_20071102t123835	Polarisation:	Vertical
t_20071101t094252	Bearing:	as indicated
	Sweeps:	1000 at each bearing

Figure A16: Vpol RBW 300 kHz 5 - 8 GHz at Awarua Station



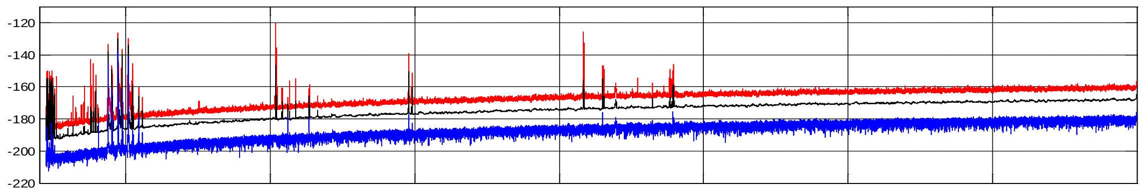
Tables
t_20070923t023029
t_20070923t123550
t_20070923t145555
t_20070925t162123
t_20070922t164353
t_20070922t222635

Antenna:	HL050
dB scales:	-190 to -110
RBW : VBW	1 MHz : 10 kHz
Polarisation:	Vertical
Bearing:	as indicated
Sweeps:	~500 at each bearing

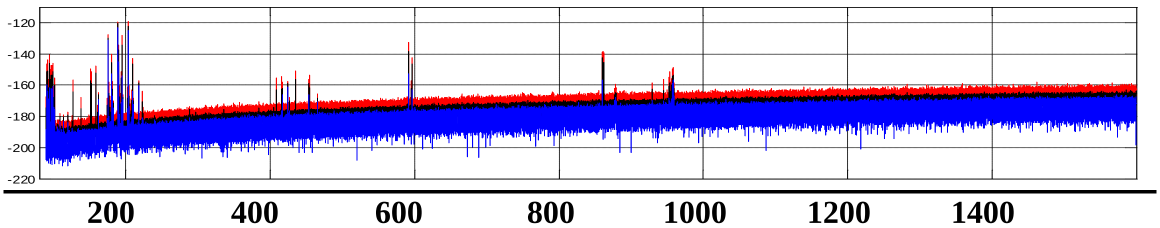
Figure A17: Vpol RBW 1 MHz 1 - 8 GHz at Kauri Flat Northland

dB (W.m^{-2}.Hz^{-1}) **(max mean min)**

North corner of house, RBW 30 kHz, 1002 sweeps



North corner of house, RBW 3 kHz, 7 sweeps

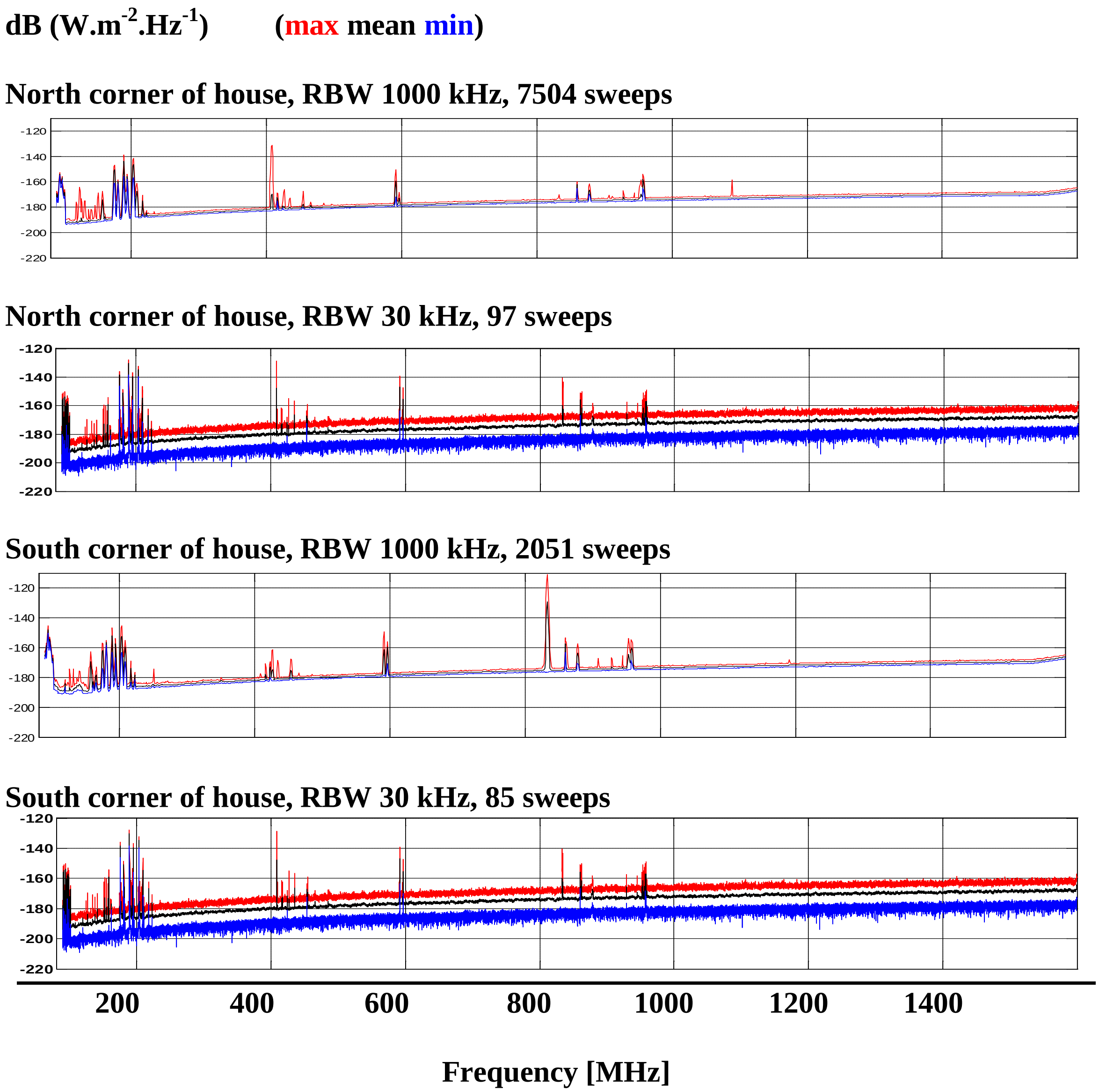


Frequency [MHz]

Tables
t_20070924t210248
t_20070924t150447

Antenna:	HK014
dB scales:	-220 to -110
RBW :	as indicated
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	as indicated

Figure A18: Various RBW 80 - 1600 MHz at Kauri Flat Northland

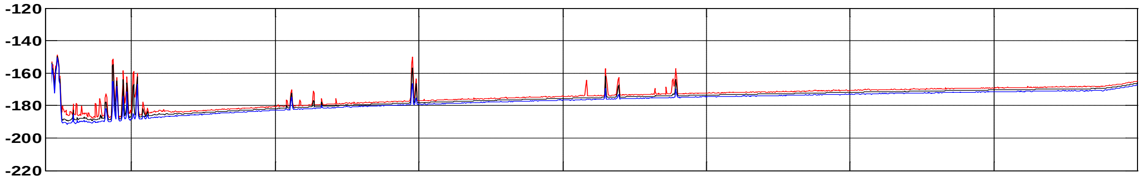


Tables		
t_20070923t051748	Antenna:	HK014
t_ 20070924t135111	dB scales:	-220 to -120
t_20070925t184807	RBW :	as indicated
t_ 20070925t200952	Polarisation:	vertical
	Bearing:	omni-directional
	Sweeps:	as indicated

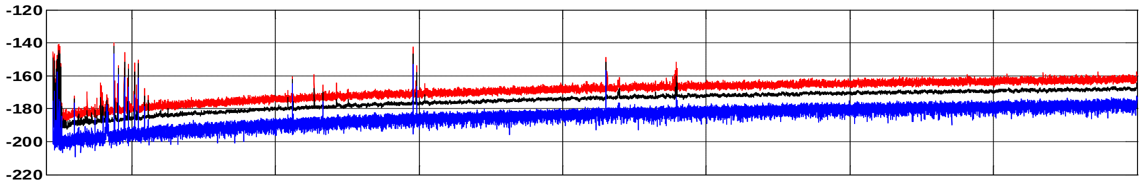
Figure A19: Various RBW 80 - 1600 MHz Vpol at Kauri Flat Northland

dB (W.m^{-2}.Hz^{-1}) **(max mean min)**

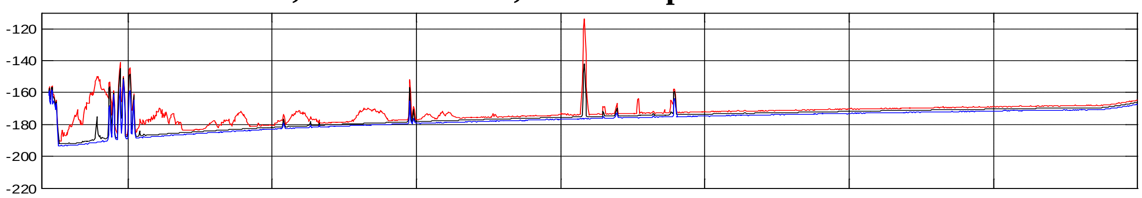
South corner of house, RBW 1000 kHz, 1880 sweeps



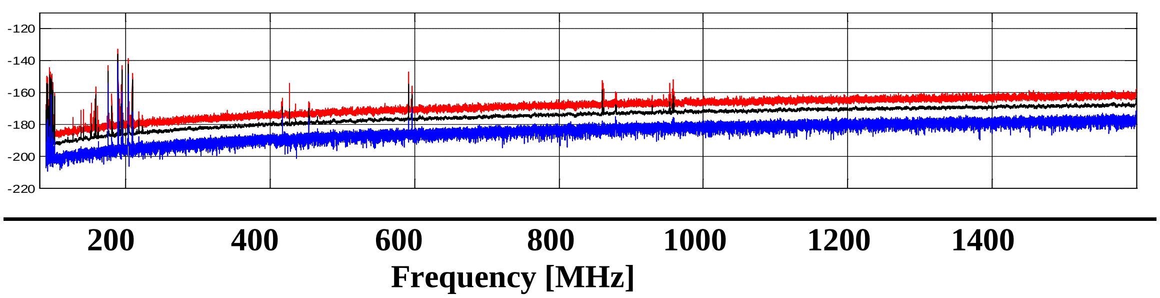
South corner of house, RBW 30 kHz, 88 sweeps



North corner of house, RBW 1000kHz, 6675 sweeps



North corner of house, RBW 30 kHz, 86 sweeps

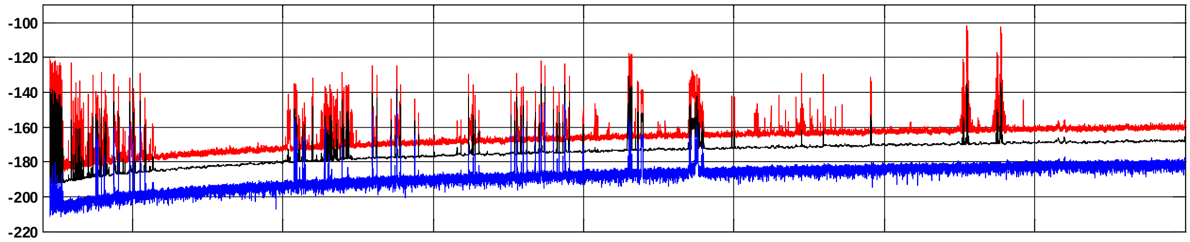


Tables
t_ 20070925t233402
t_ 20070926t004251
t_20070923t214627
t_20070924t163919

Antenna:	HK014
dB scales:	-220 to -120
RBW :	as indicated
Polarisation:	Horizontal
Bearing:	omni-directional
Sweeps:	as indicated

Figure A20: Various RBW 80 - 1600 MHz Hpol at Kauri Flat Northland

dB ($W.m^{-2}.Hz^{-1}$) **(max mean min)**



200 400 600 800 1000 1200 1400

Frequency (MHz)

Tables
t_20070506t182514

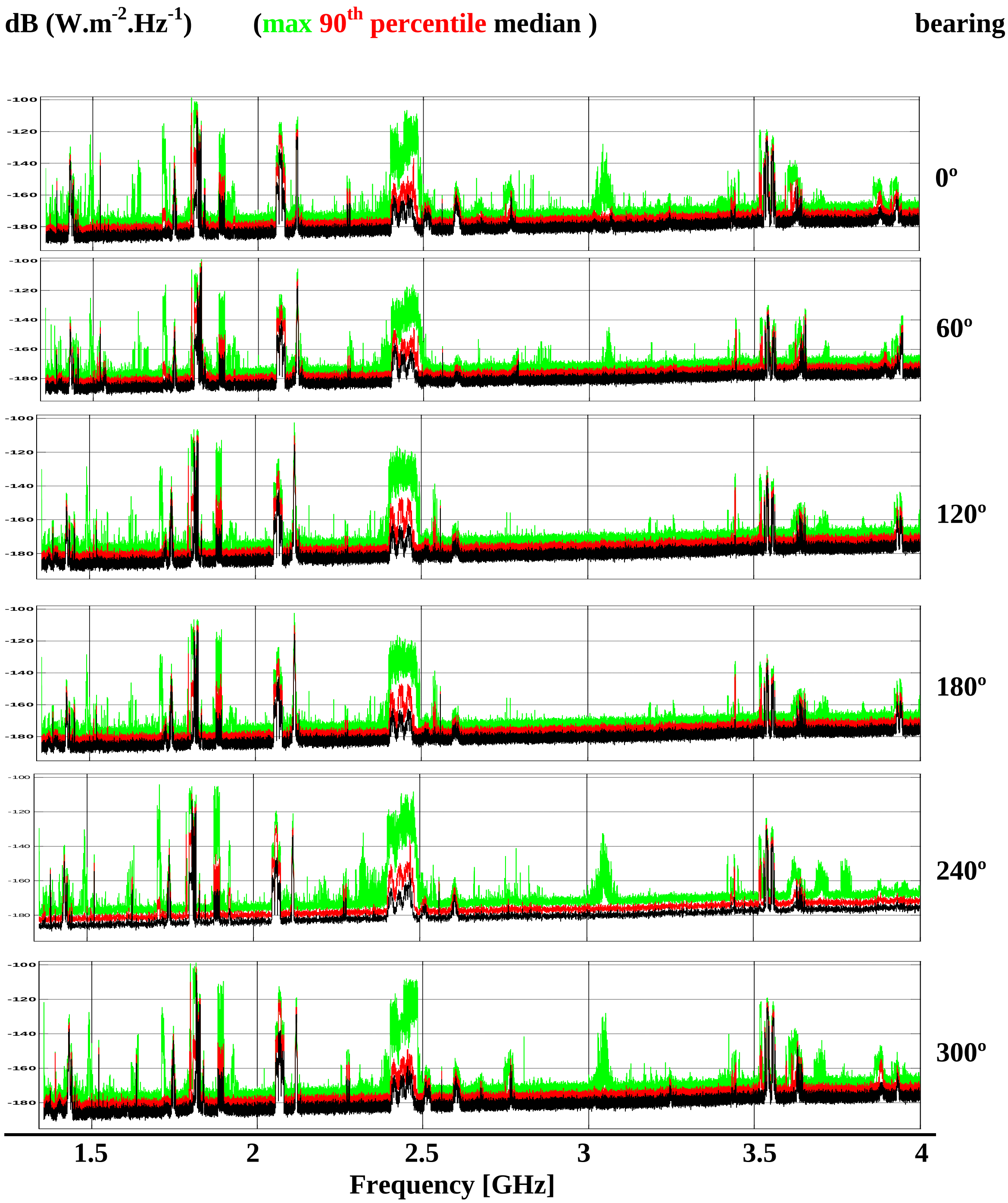
Antenna:	HK014
dB scales:	-220 to -90
RBW : VBW:	30 kHz : 10 kHz
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	2172
Recording:	1825 060507 to 2000 070507

Figure A21: Vpol 80 – 1600 MHz RBW 30 kHz near Karaka

Appendix B: Maximum, 90th Percentile and Median Flux Density

Figures B1 – B21 show the maximum, 90th percentile and median flux density levels of measurements. These charts (and those in appendix C) were required for SKA site selection considerations.

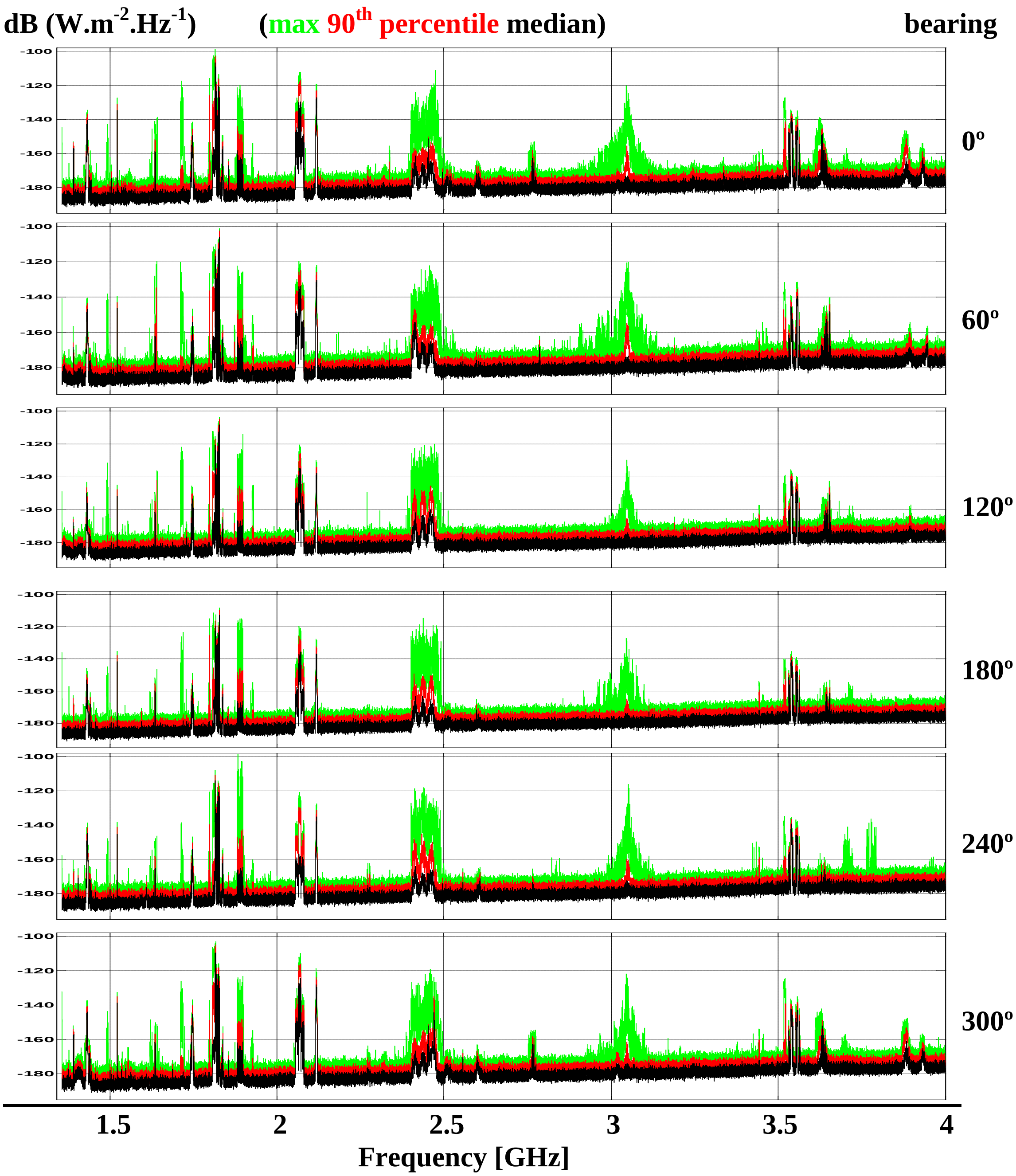
The figure number sequence matches figure numbers in appendix A and appendix C as they use the same data tables. In a few cases the appendix A data tables became corrupted and could not be plotted with the 20 MHz analysis code, which are summarised in appendix B and C.



Tables
t_20080304t134343
t_20080305t140111
t_20080306t003358
t_20080306t183456
t_20080307t062858
t_20080307t225516

Antenna:	HL050
Db scales:	-195 to -98
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	1000 at each bearing

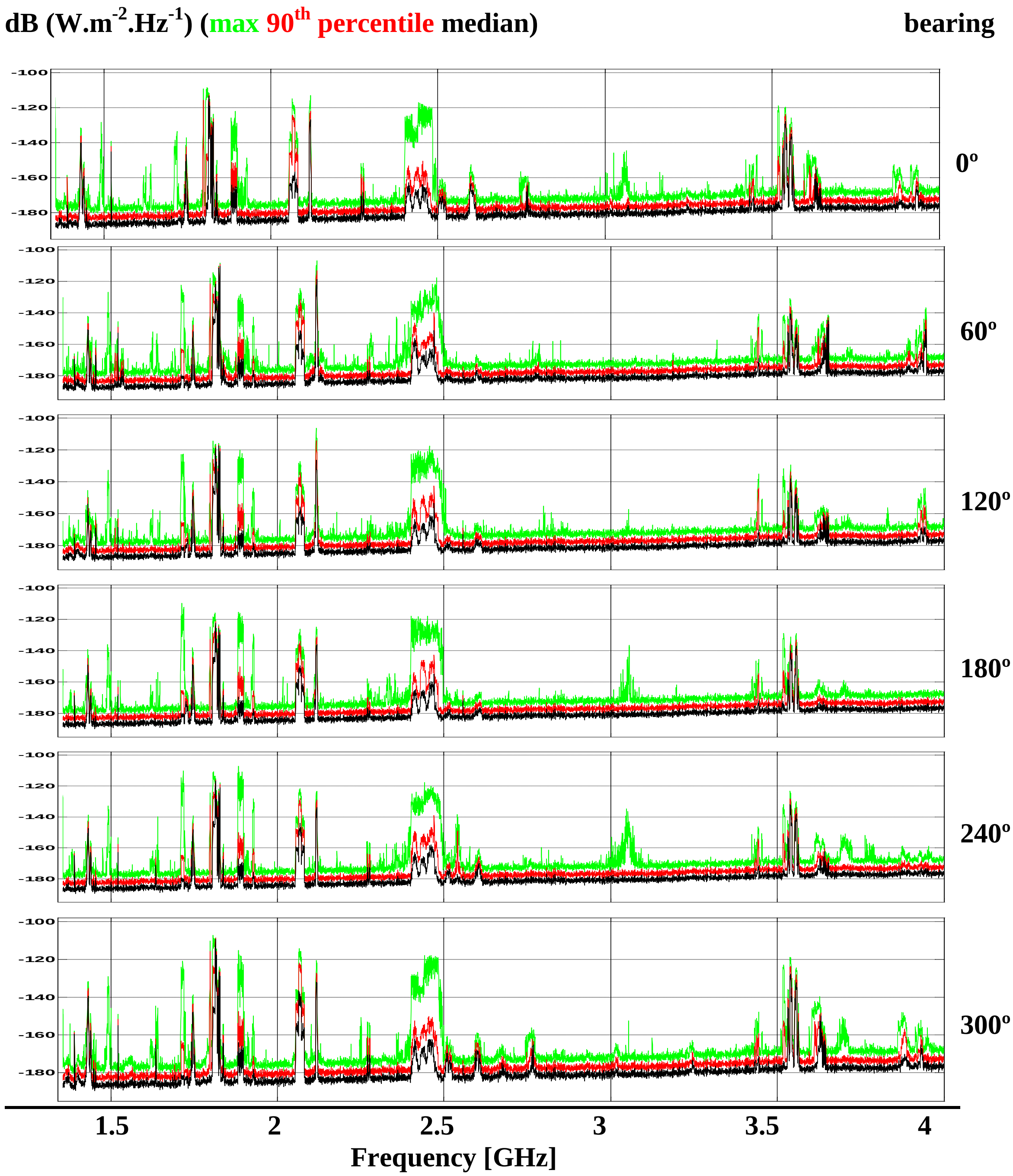
Figure B1: Vpol 30 kHz RBW 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080308t175831
t_20080308t210603
t_20080308t235945
t_20080309t030406
t_20080309t055643
t_20080308t150216

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	200 at each bearing

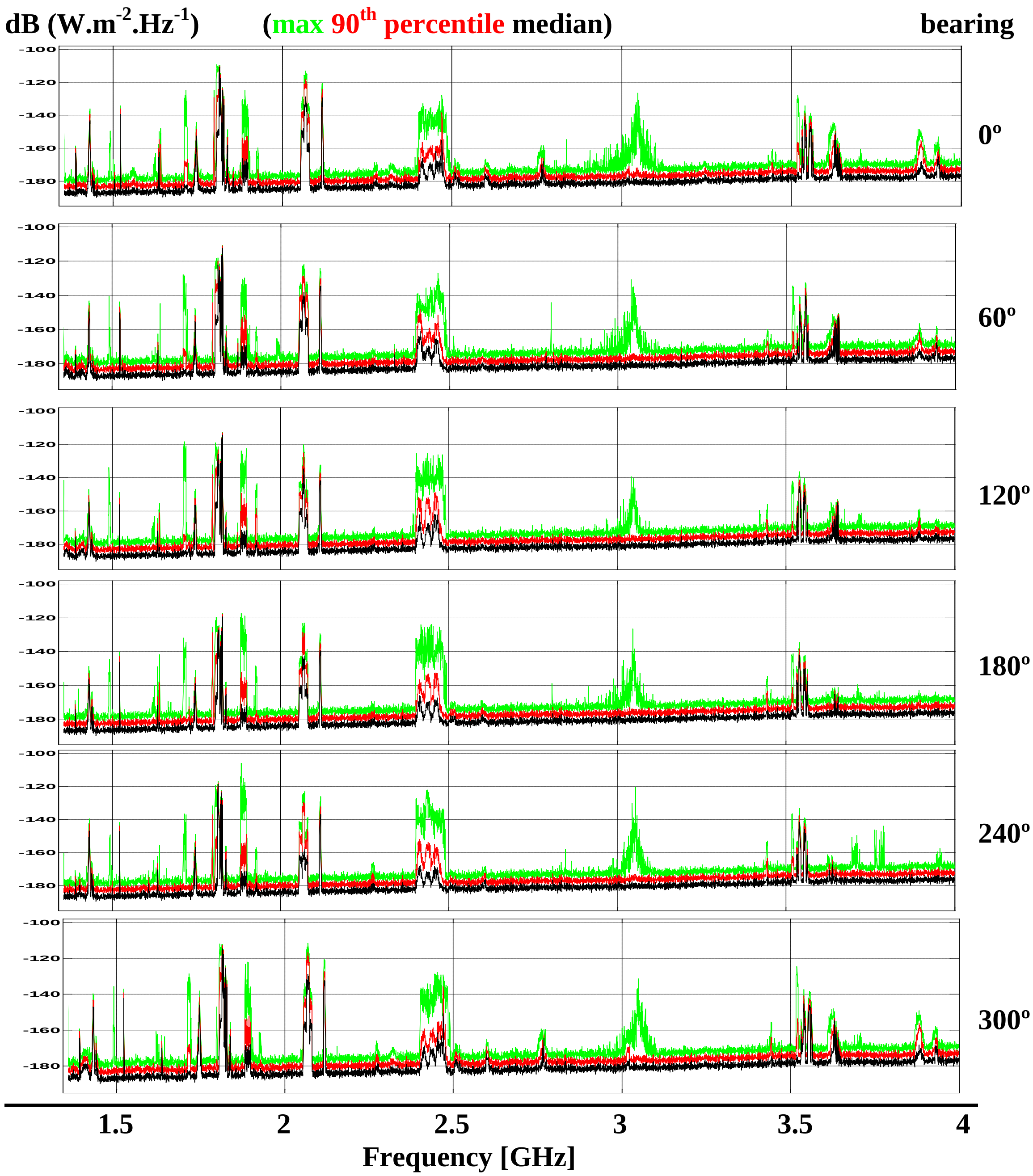
Figure B2: Hpol 30 kHz RBW 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080304t005604
t_20080305t111829
t_20080306t110054
t_20080306t141541
t_20080307t163433
t_20080307t194338

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	2500 at each bearing

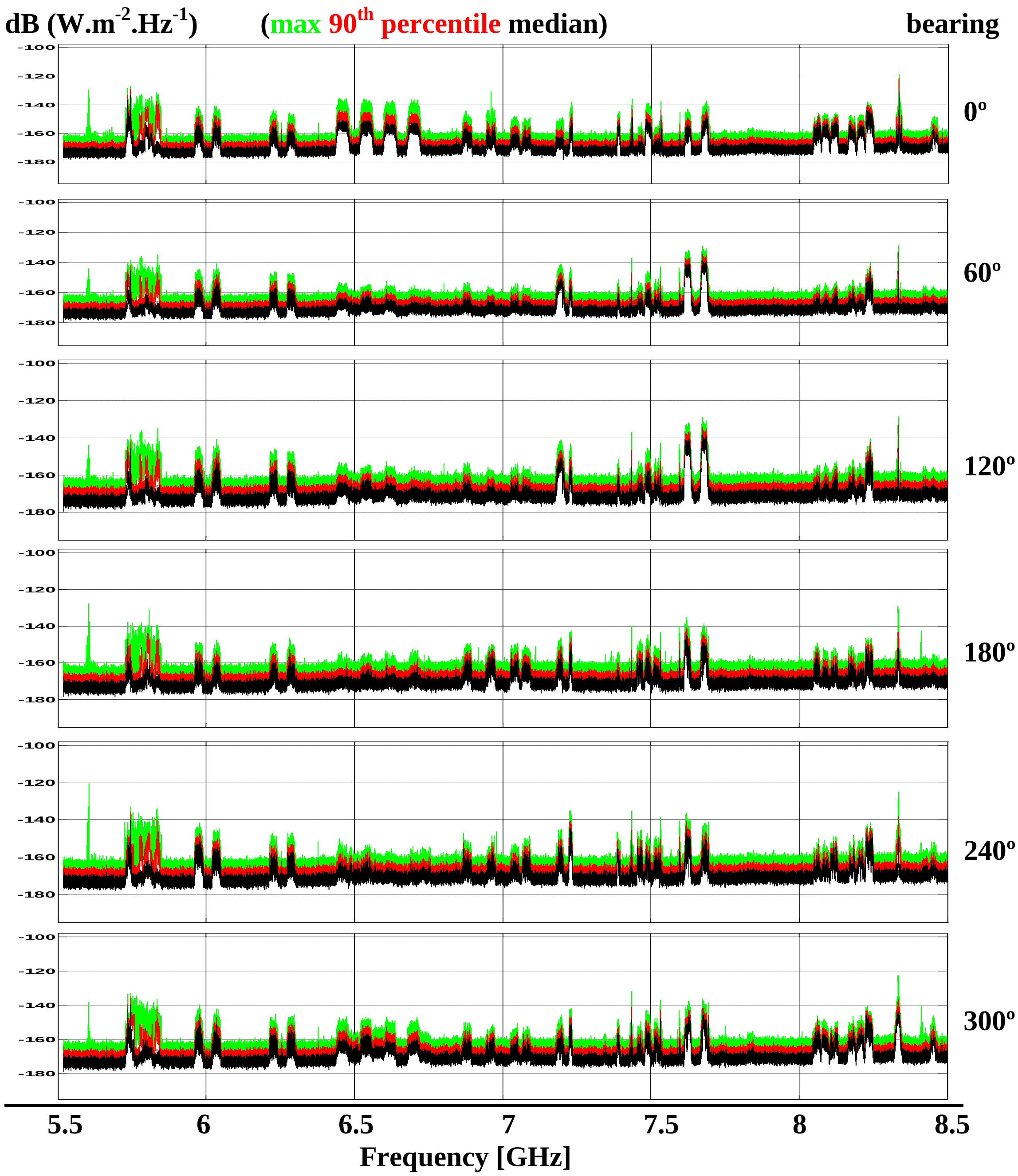
Figure B3: Vpol 300 kHz RBW 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080308t172216
t_20080308t202915
t_20080308t232659
t_20080309t022651
t_20080309t051556
t_20080308t142249

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

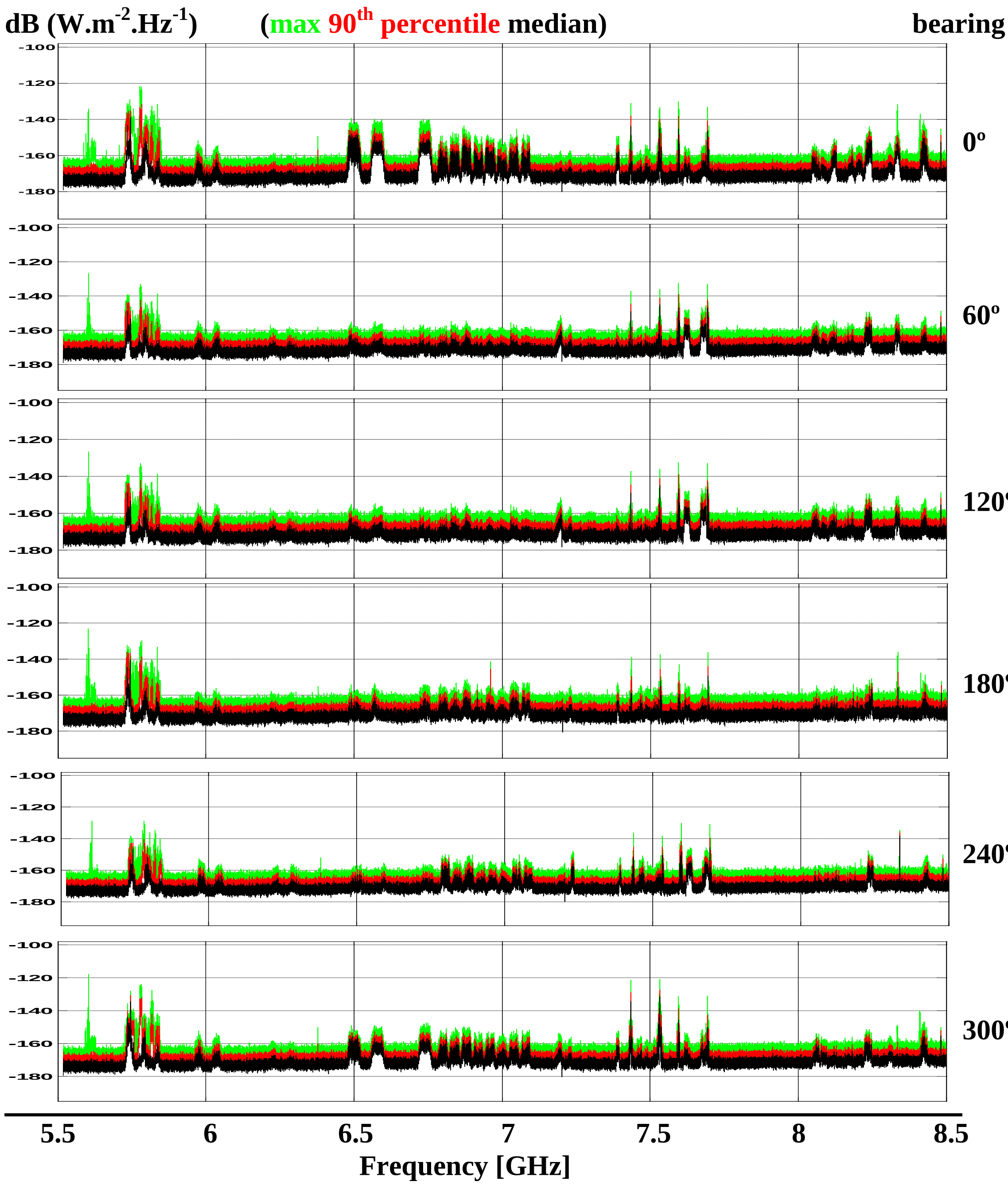
Figure B4: Hpol 300 kHz RBW 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080315t022609
t_20080315t131802
t_20080316t002335
t_20080311t135216
t_20080312t040914
t_20080312t152947

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	1000 at each bearing

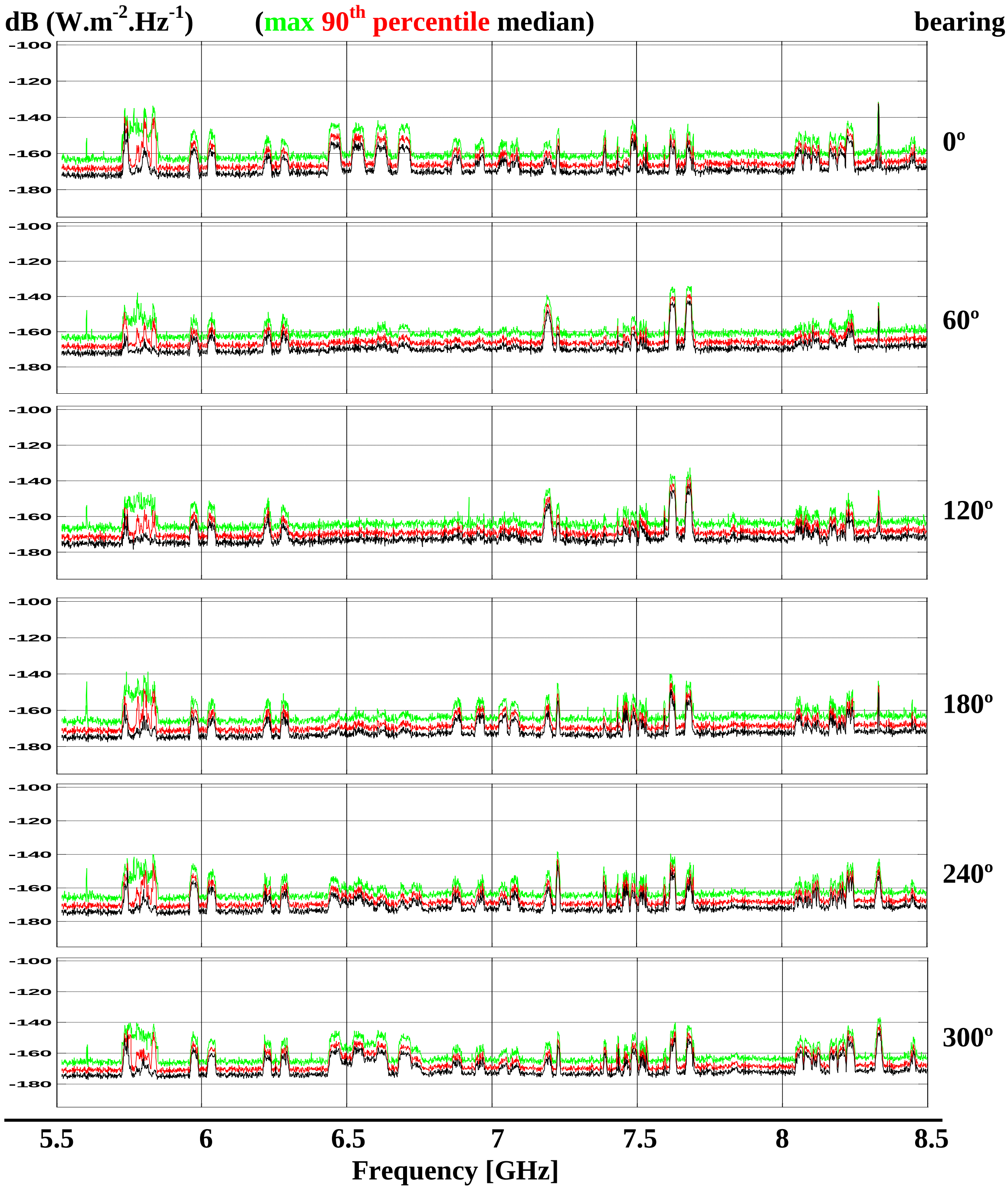
Figure B5: Vpol RBW 30 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables
t_20080313t165414
t_20080313t223320
t_20080314t083456
t_20080314t140825
t_20080314t202216
t_20080313t112400

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

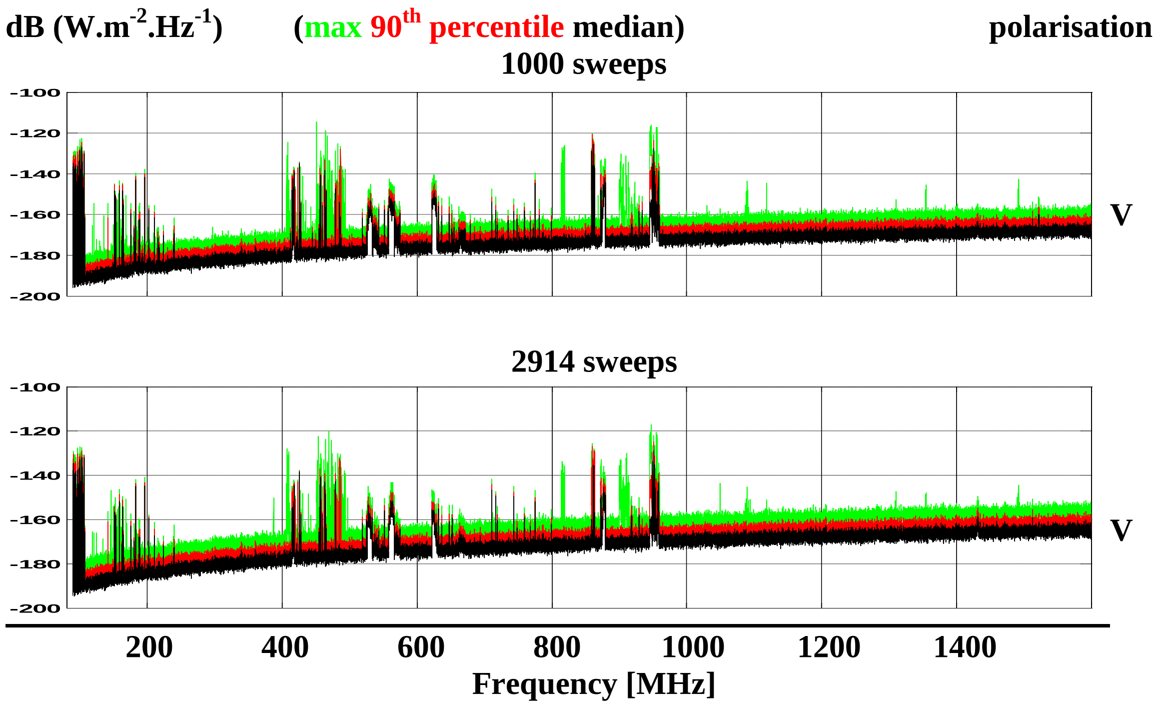
Figure B6: Hpol RBW 30 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables	Attenuation
t_20080309t203841	10 dB
t_20080309t234713	10 dB
t_20080310t152630	5 dB
t_20080311t104940	0
t_20080312t010639	0
t_20080313t023628	0

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	1000 kHz
Video Bandwidth:	300 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	5000 at each bearing

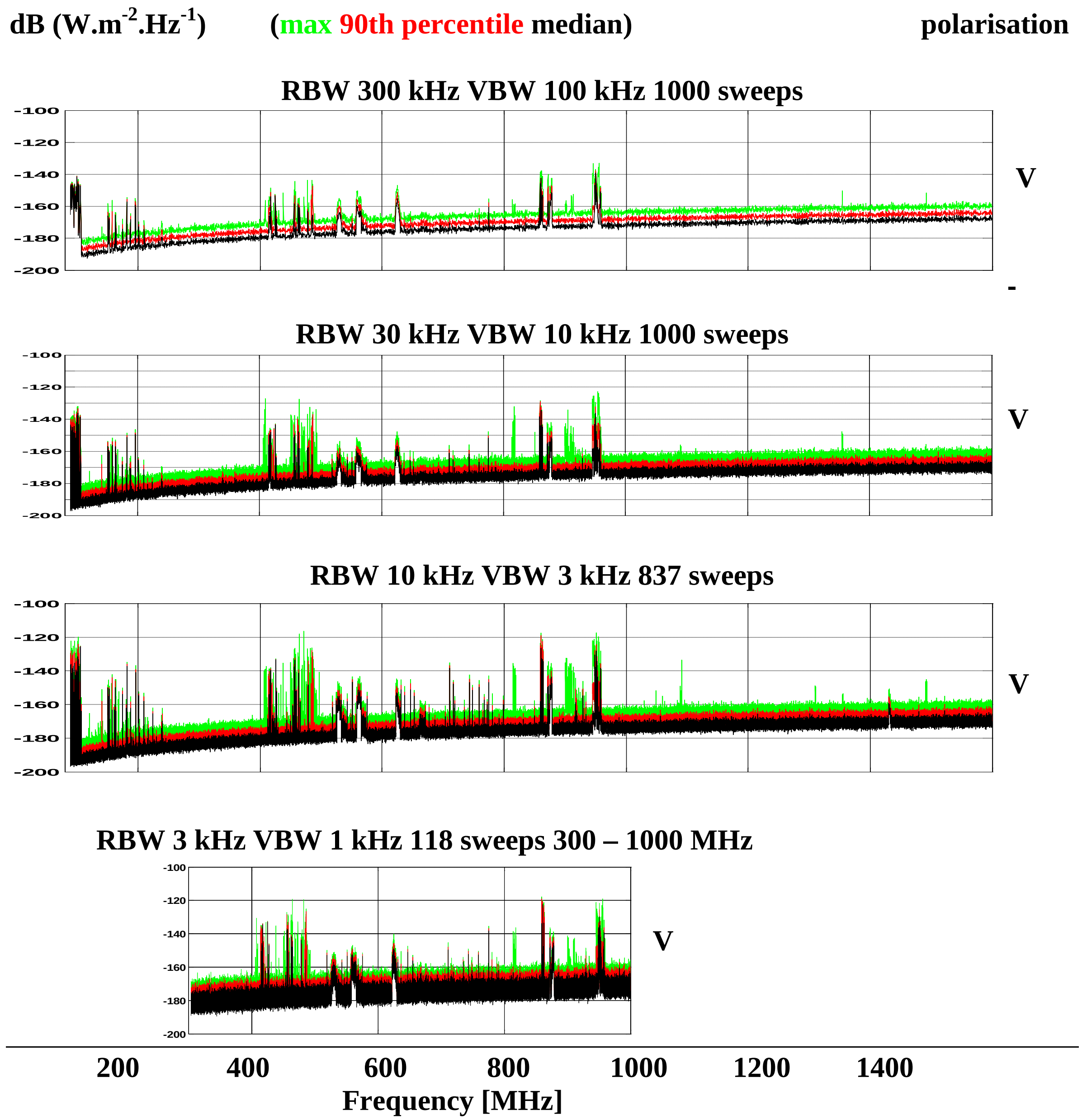
Figure B7: Vpol RBW 1000 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables
t_20080317t063338
t_20080319t023912

Antenna:	HK014
dB scales:	-200 to -100
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

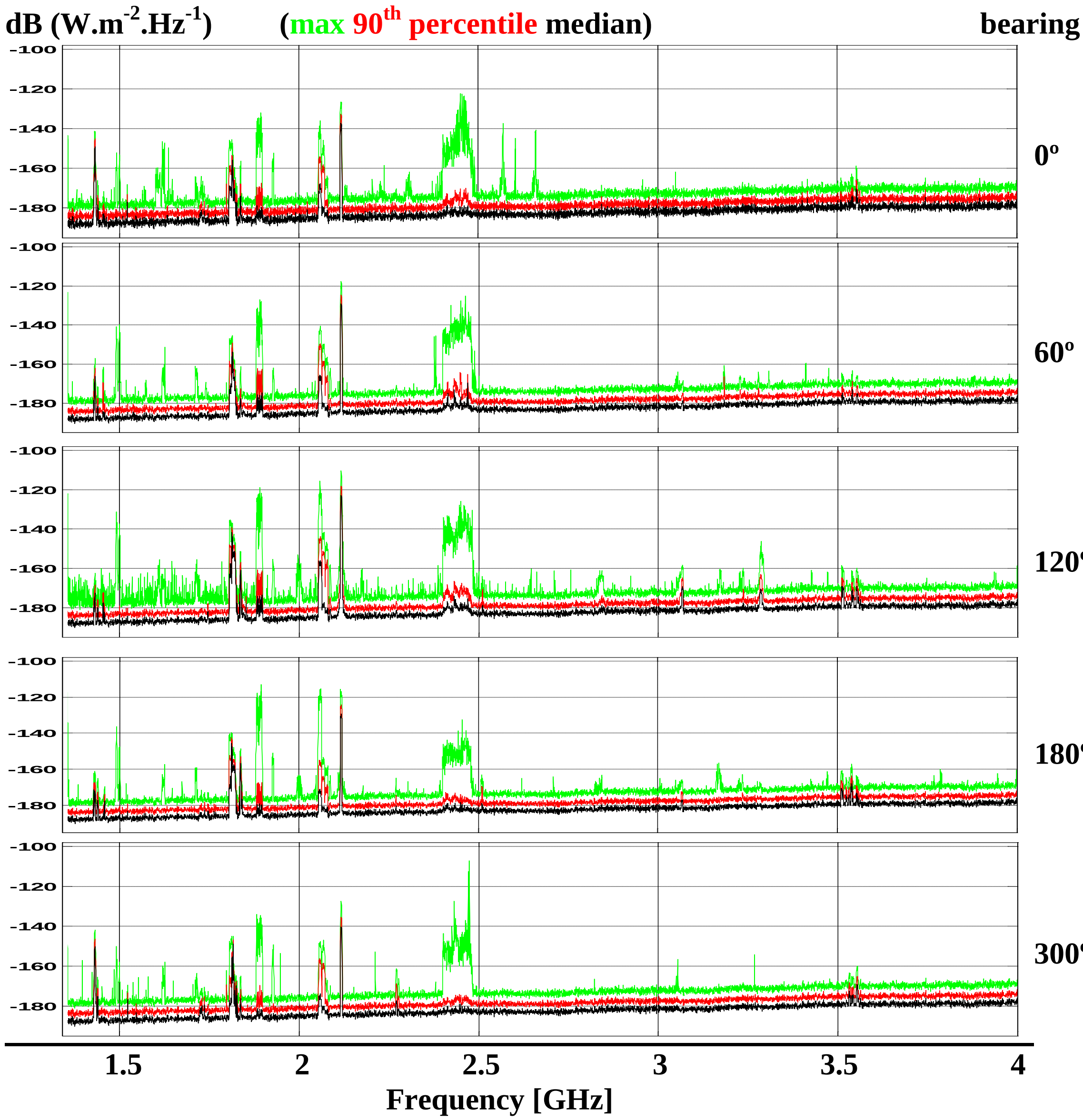
Figure B8: RBW 30 kHz 80 – 1600 MHz at AUT Auckland City



Tables
t_20080318t011904
t_20080318t113456
t_20080319t185706
t_20080318t020454

Antenna:	HK014
dB scales:	-200 to -100
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

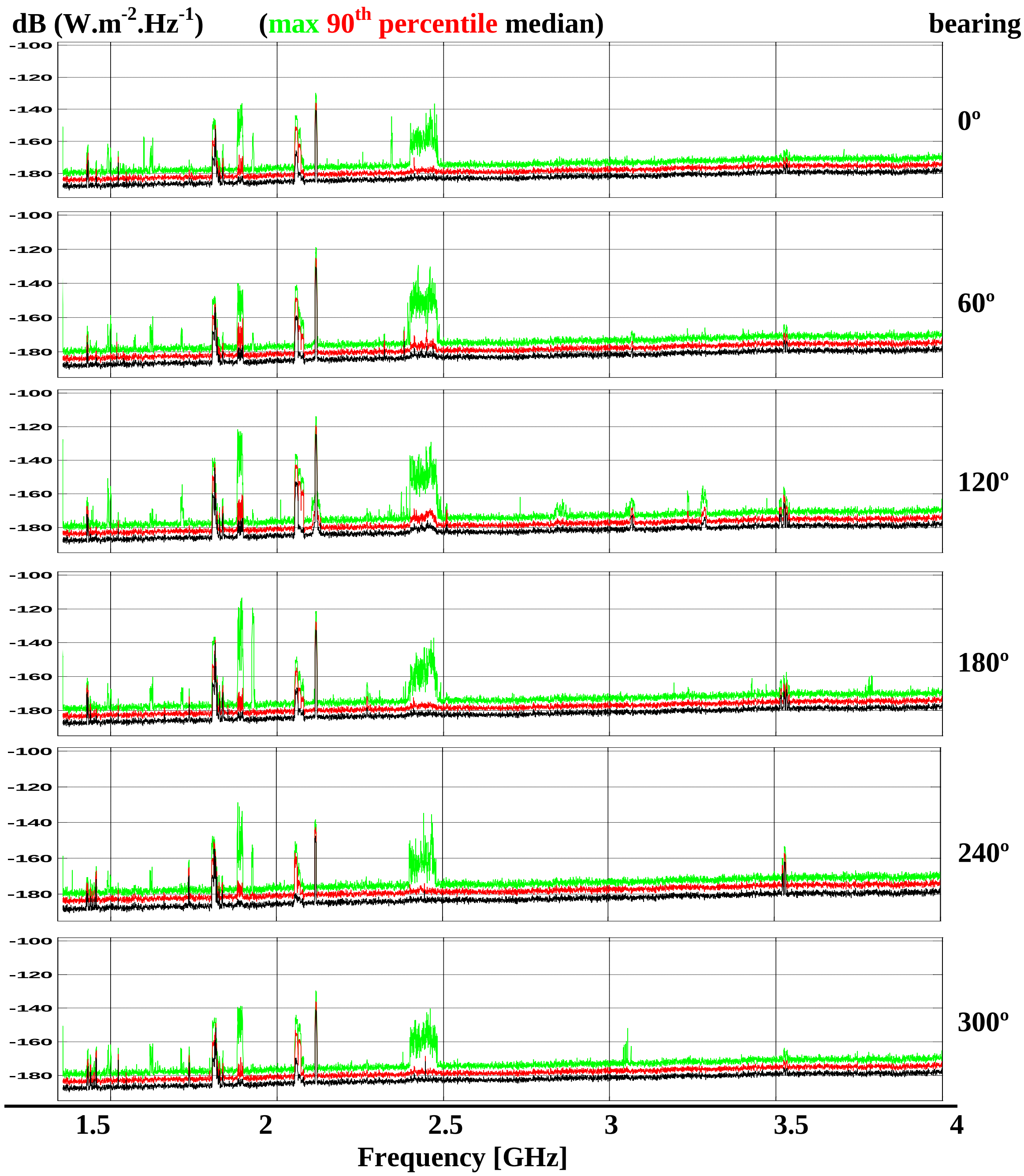
Figure B9: Varied RBW 80 – 1600 MHz at AUT Auckland City



Tables
t_20080208t072311
t_20080208t194741
t_20080209t080720
t_20080209t201923
t_20080210t205400

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated (240º corrupt)
Sweeps:	~5000 at each bearing

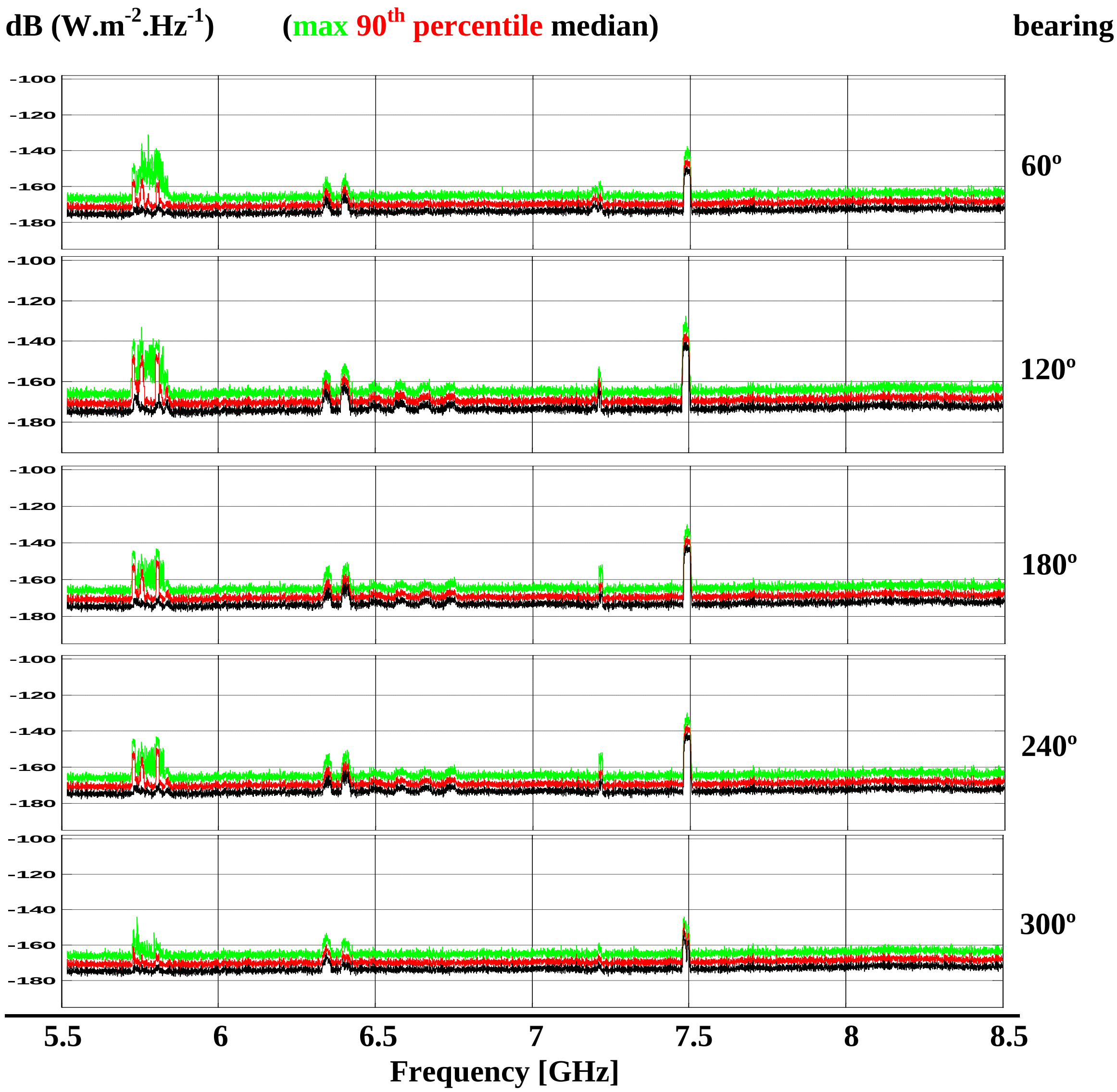
Figure B10: Vpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington residence



Tables
t_20080211t113433
t_20080211t140551
t_20080211t163138
t_20080211t190506
t_20080211t220709
t_20080211t091042

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	479 at 240 ° and 1000 at other bearings

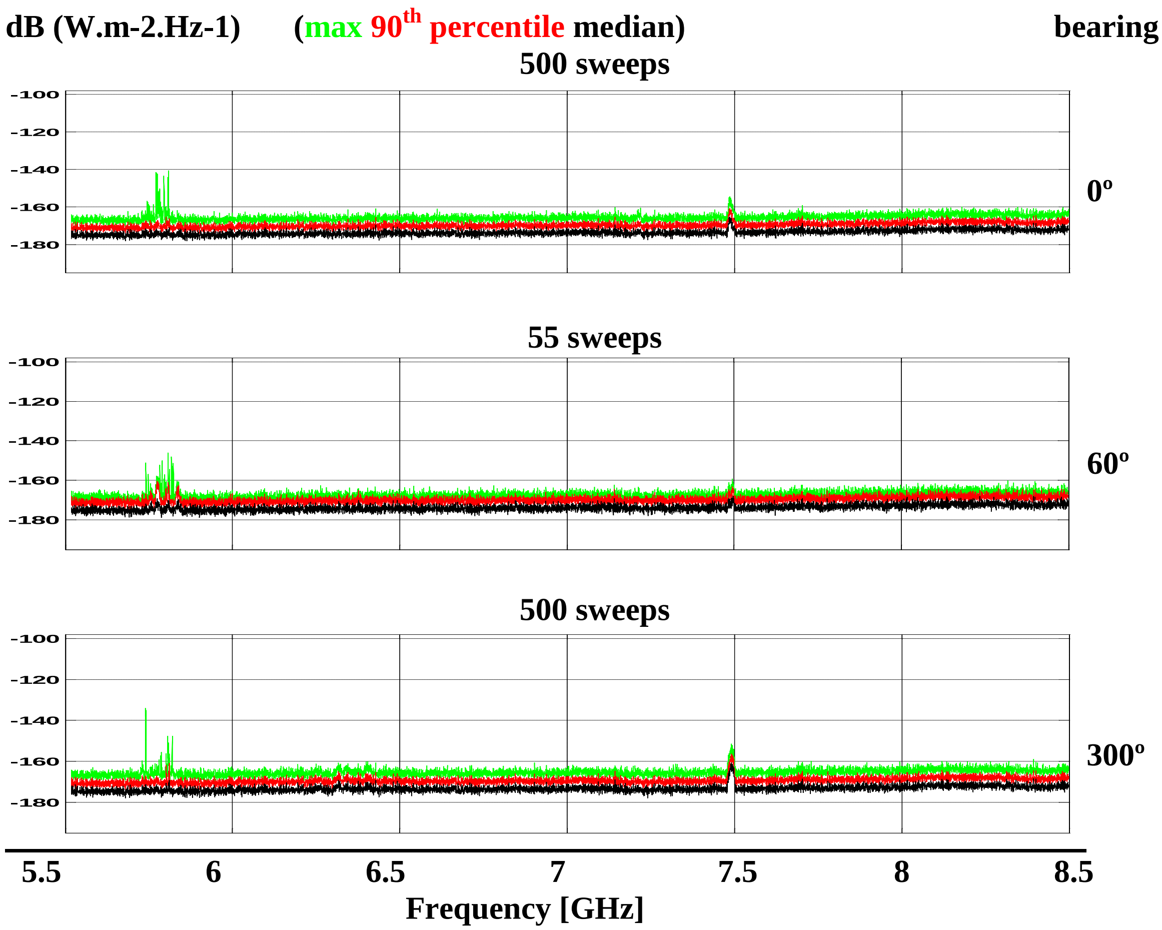
Figure B11: Hpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington Residence



Tables
t_20080216t123038
t_20080216t202327
t_20080217t041500
t_20080217t140530
t_20080217t220154

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated (0º corrupt)
Sweeps:	~2000 at each bearing

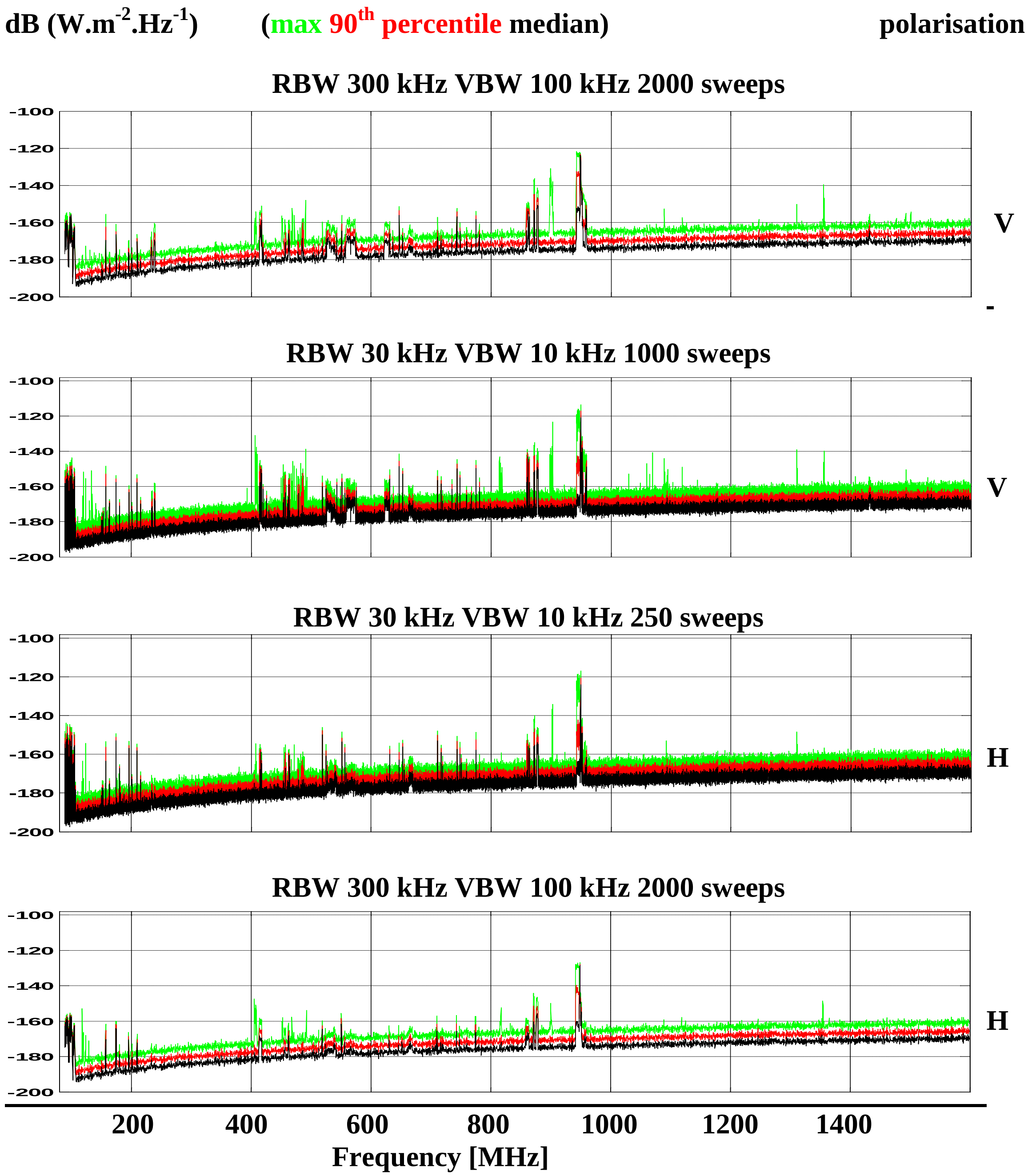
Figure B12: Vpol RBW 300 kHz 5.5 – 8.5 GHz at Mt. Wellington Residence



Tables
t_20080218t105805
t_20080218t130206
t_20080218t084115

Antenna:	HL050
dB scales:	-195 to -98
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	As indicated

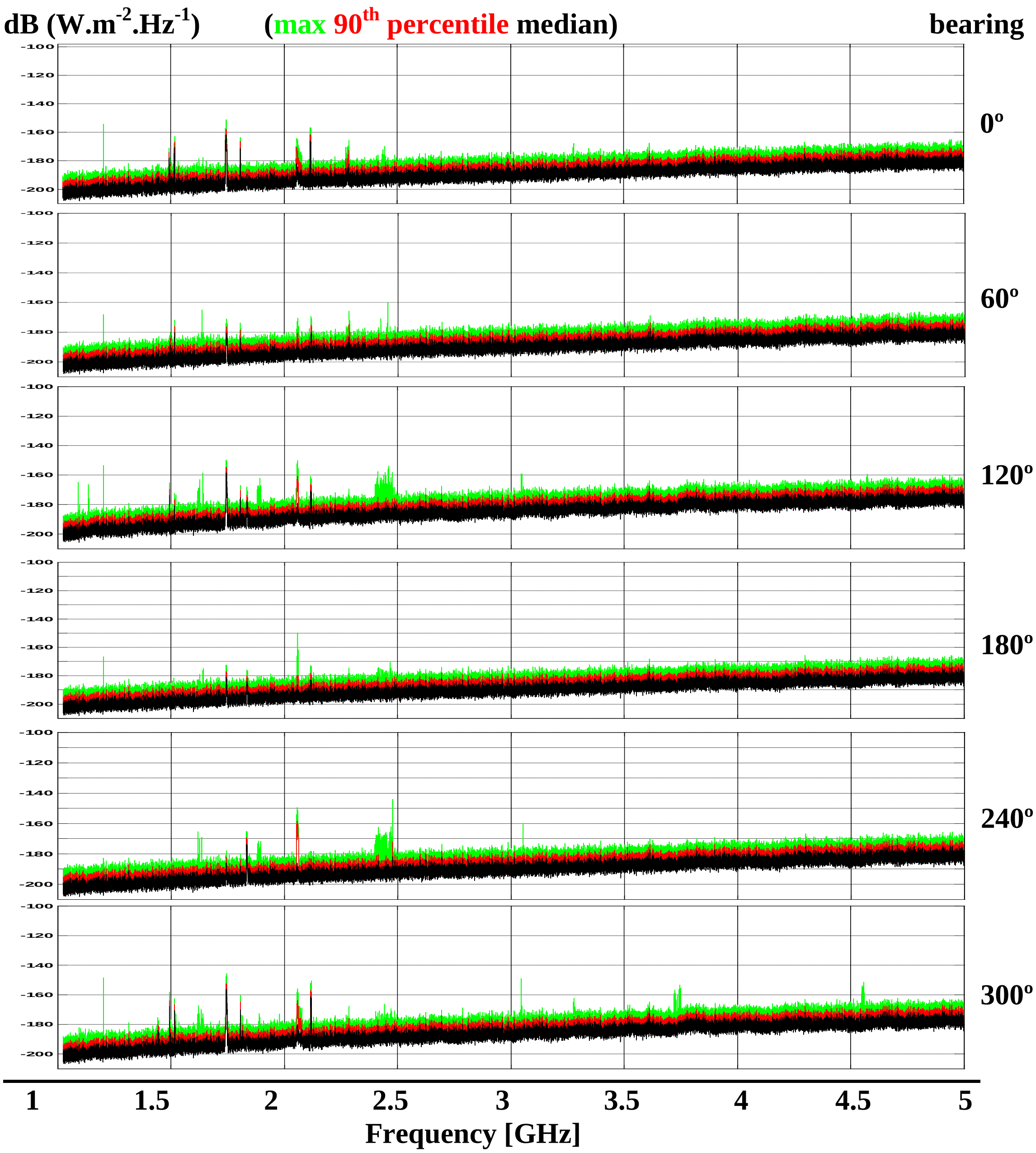
Figure B13: Hpol 300 kHz RBW 5.5 – 8.5 GHz at Mt. Wellington Residence



Tables
t_20080226t212253
t_20080227t002050
t_20080226t172605
t_20080226t143451

Antenna:	HK014
dB scales:	-200 to -100
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

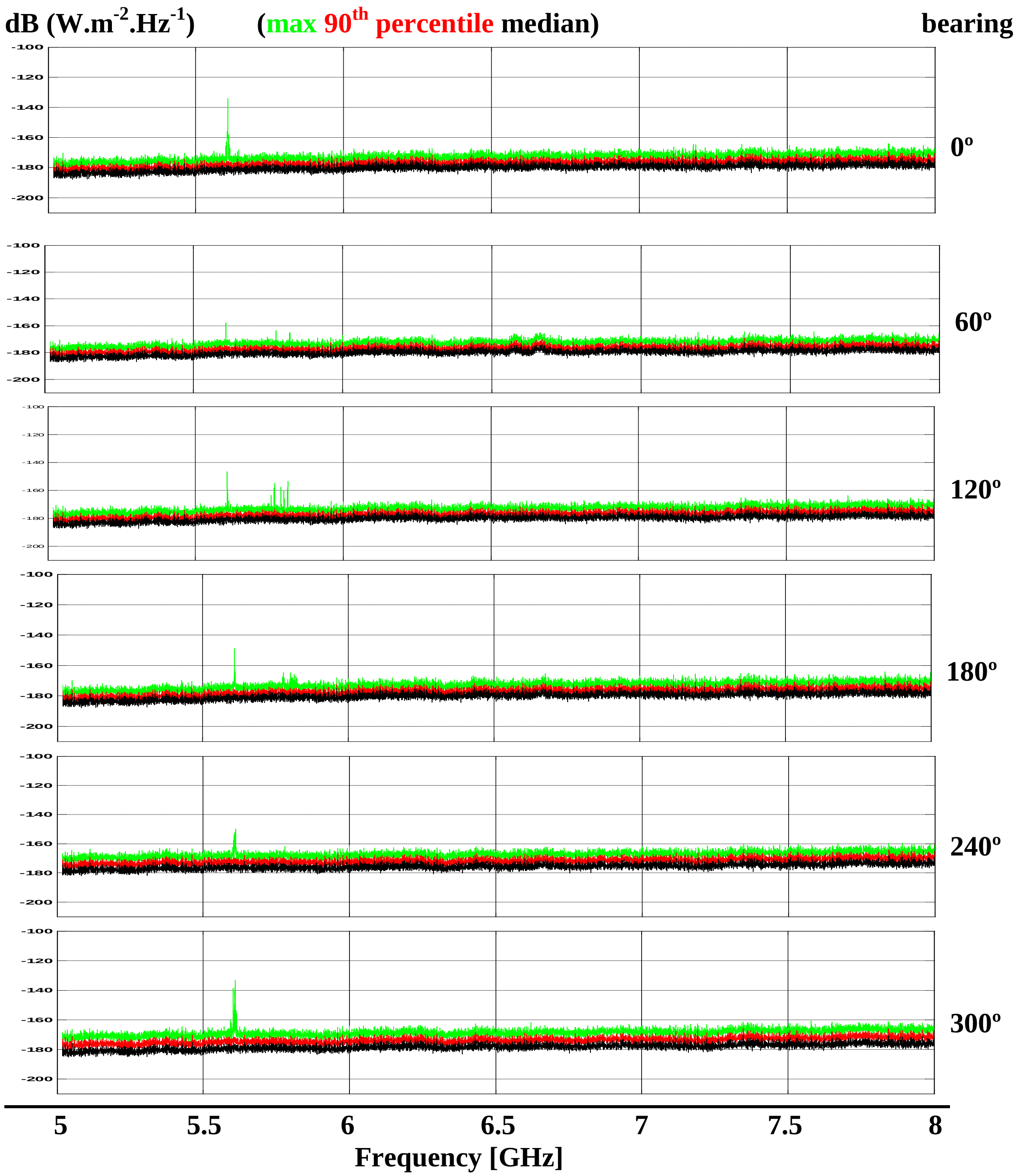
Figure B14: Various RBW 80 – 1600 MHz at Mt. Wellington residence



Tables
t_20071027t204012
t_20071030t191204
t_20071029t232407
t_20071028t233320
t_20071029t024424
t_20071031t233456

Antenna:	HL050
dB scales:	-210 to -100
Resolution band width	100 kHz
Video band width	30 kHz
Polarisation:	Vertical
Sweeps:	1000 at each bearing

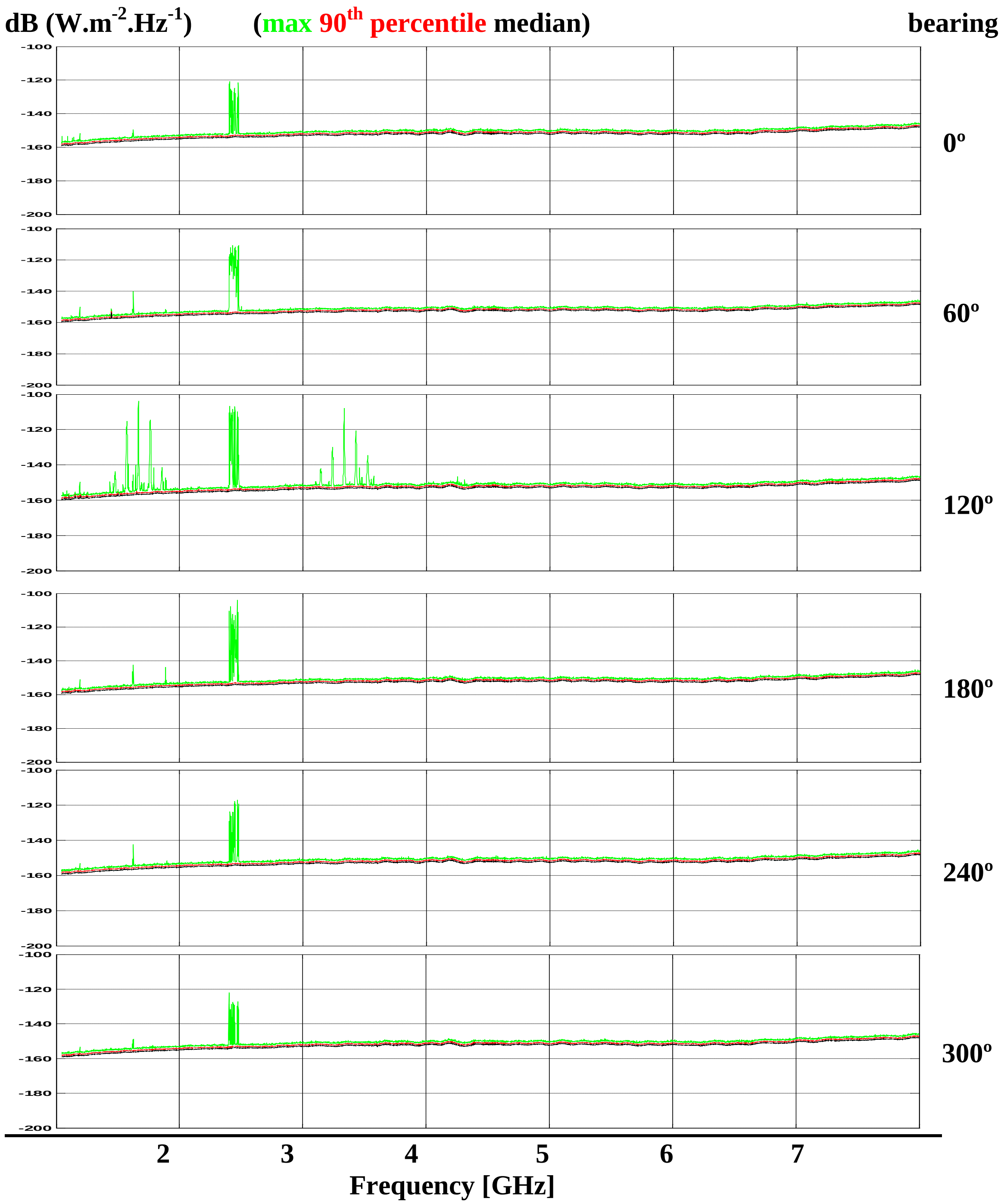
Figure B15: Vpol RBW 100 kHz 1 – 5 GHz at Awarua Station



Tables
t_20071028t104331
t_20071031t072027
t_20071030t091040
t_20071029t092057
t_20071102t123835
t_20071101t094252

Antenna:	HL050
dB scales:	-210 to -100
Resolution band width	300 kHz
Video band width	100 kHz
Polarisation:	Vertical
Bearing:	as indicated
Sweeps:	1000 at each bearing

Figure B16: Vpol RBW 300 kHz 5 – 8 GHz at Awarua Station



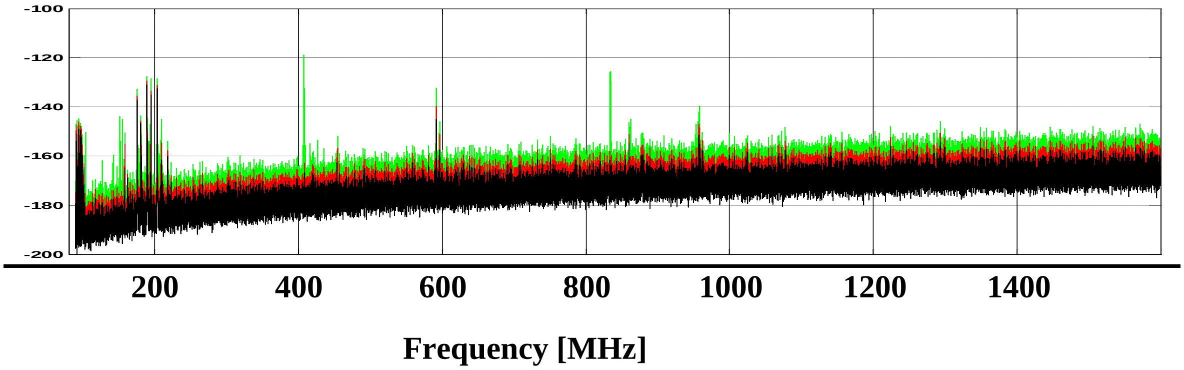
Tables
t_20070923t023029
t_20070923t123550
t_20070923t145555
t_20070925t162123
t_20070922t164353
t_20070922t222635

Antenna:	HL050
dB scales:	-200 to -100
RBW : VBW	1 MHz : 10 kHz
Polarisation:	Vertical
Bearing:	as indicated
Sweeps:	~500 at each bearing

Figure B17: Vpol RBW 1 MHz 1 - 8 GHz at Kauri Flat Northland

dB (W.m^{-2}.Hz^{-1}) **(max 90th percentile median)**

North corner of house



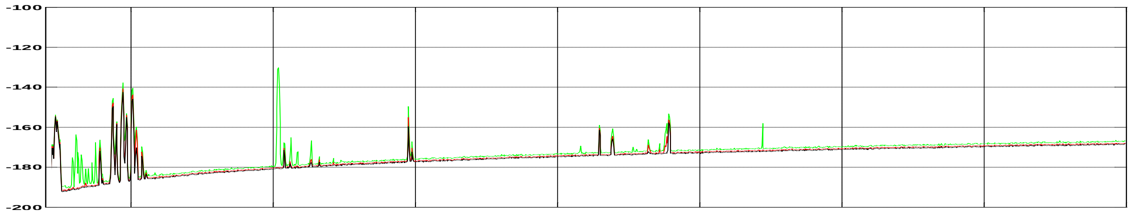
Tables
t_20070924t210248

Antenna:	HK014
dB scales:	-200 to -100
RBW :	30 kHz
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	1002

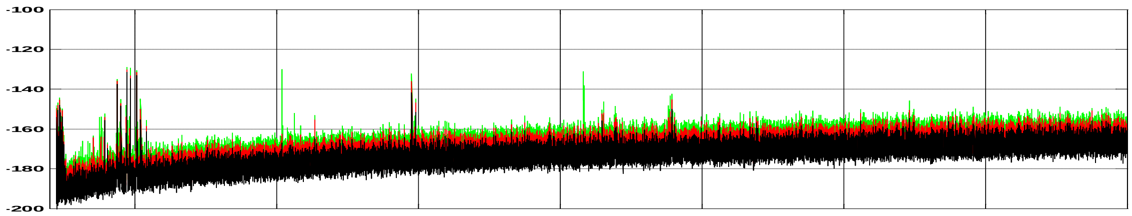
Figure B18: Vpol 80 – 1600 MHz Kauri Flat Northland

dB ($W.m^{-2}.Hz^{-1}$) **(max 90th percentile median)**

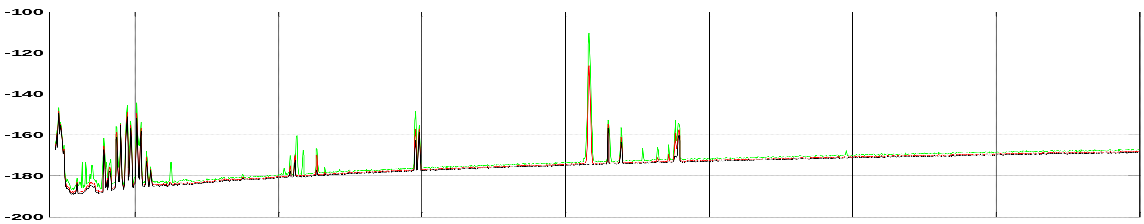
North corner of house, RBW 1000 kHz, 7504 sweeps



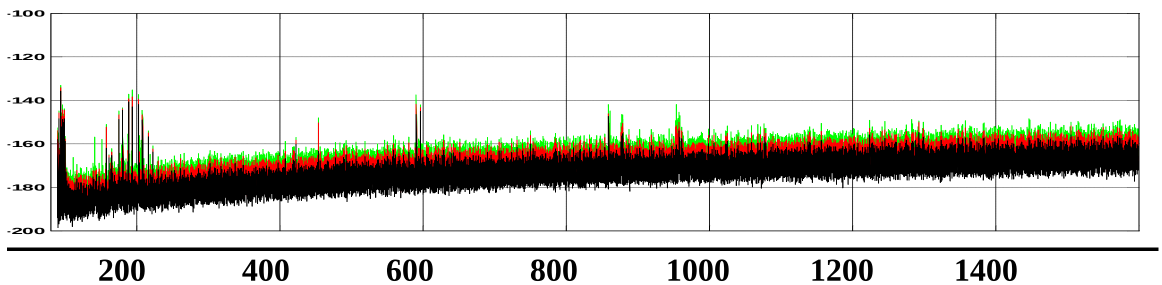
North corner of house, RBW 30 kHz, 97 sweeps



South corner of house, RBW 1000 kHz, 2051 sweeps



South corner of house, RBW 30 kHz, 85 sweeps



Frequency [MHz]

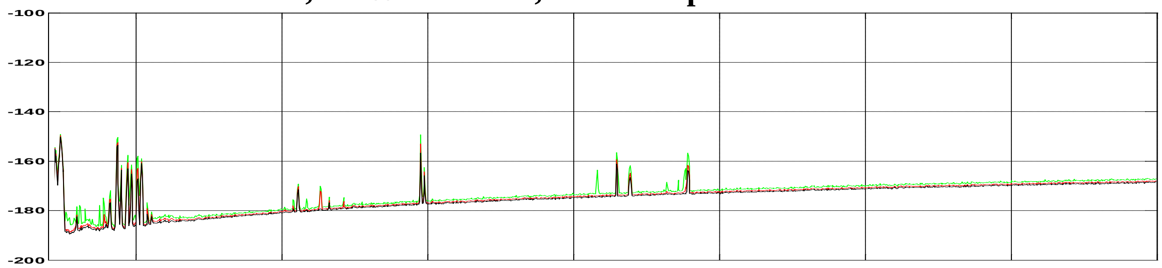
Tables
t_20070923t051748
t_ 20070924t135111
t_20070925t184807
t_ 20070925t200952

Antenna:	HK014
dB scales:	-220 to -100
RBW :	as indicated
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	as indicated

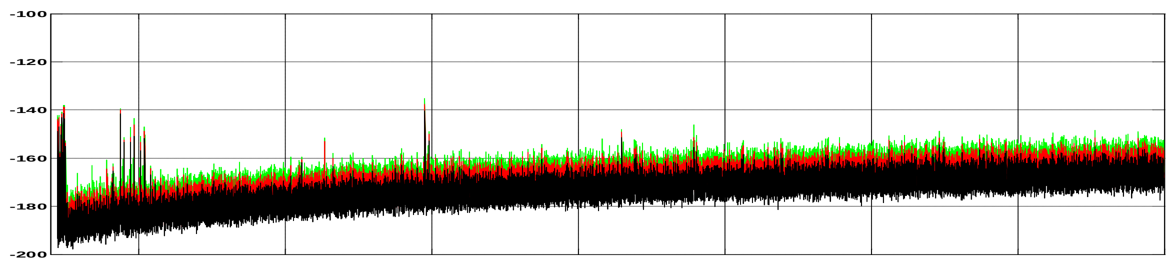
Figure B19: Various RBW 80 - 1600 MHz at Kauri Flat Northland

dB (W.m^{-2}.Hz^{-1}) **(max 90th percentile median)**

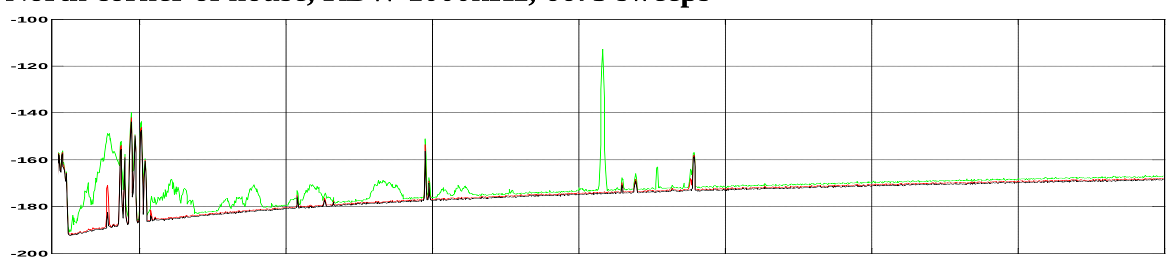
South corner of house, RBW 1000 kHz, 1880 sweeps



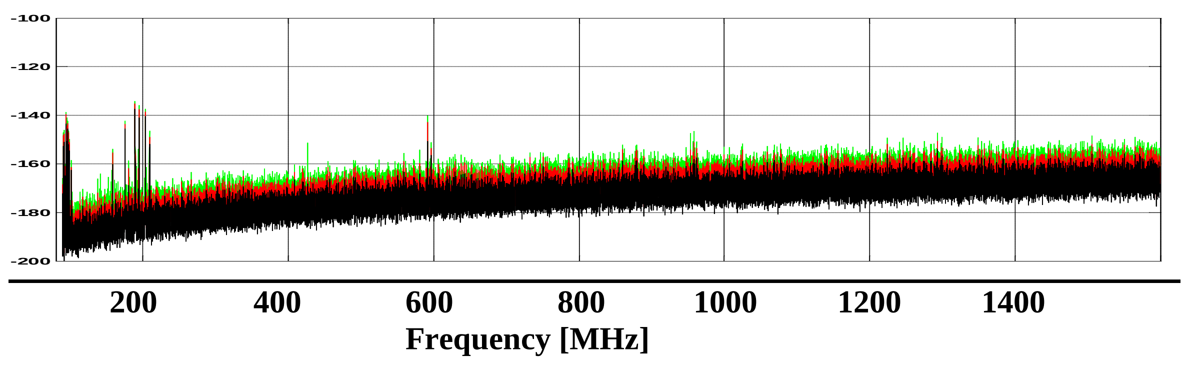
South corner of house, RBW 30 kHz, 88 sweeps



North corner of house, RBW 1000kHz, 6675 sweeps



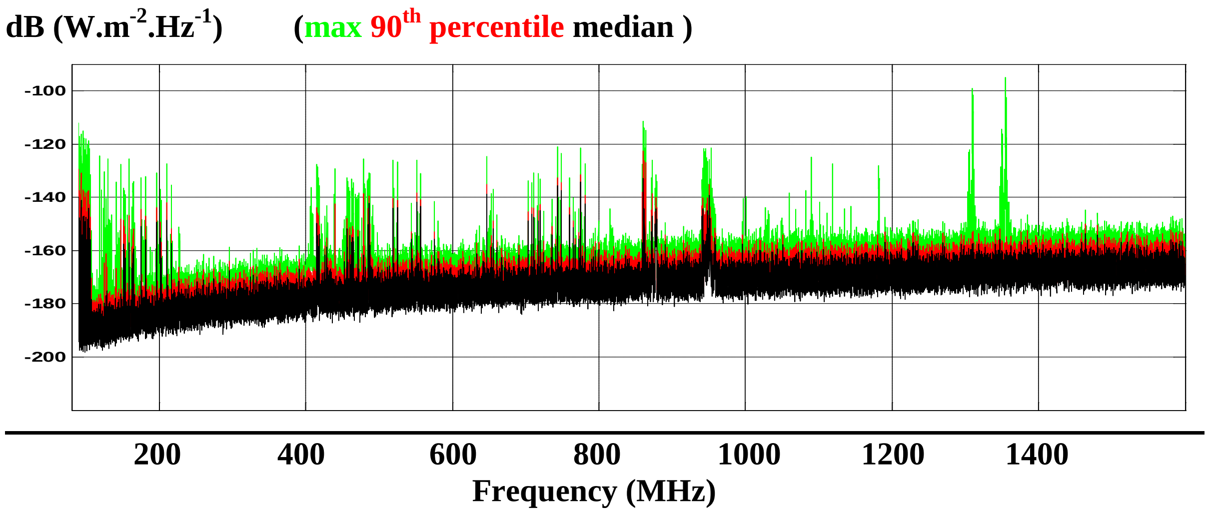
North corner of house, RBW 30 kHz, 86 sweeps



Tables
t_ 20070925t233402
t_ 20070926t004251
t_20070923t214627
t_20070924t163919

Antenna:	HK014
dB scales:	-200 to -100
RBW :	as indicated
Polarisation:	Horizontal
Bearing:	omni-directional
Sweeps:	as indicated

Figure B20: Various RBW 80 - 1600 MHz Hpol at Kauri Flat Northland



Tables
t_20070506t182514

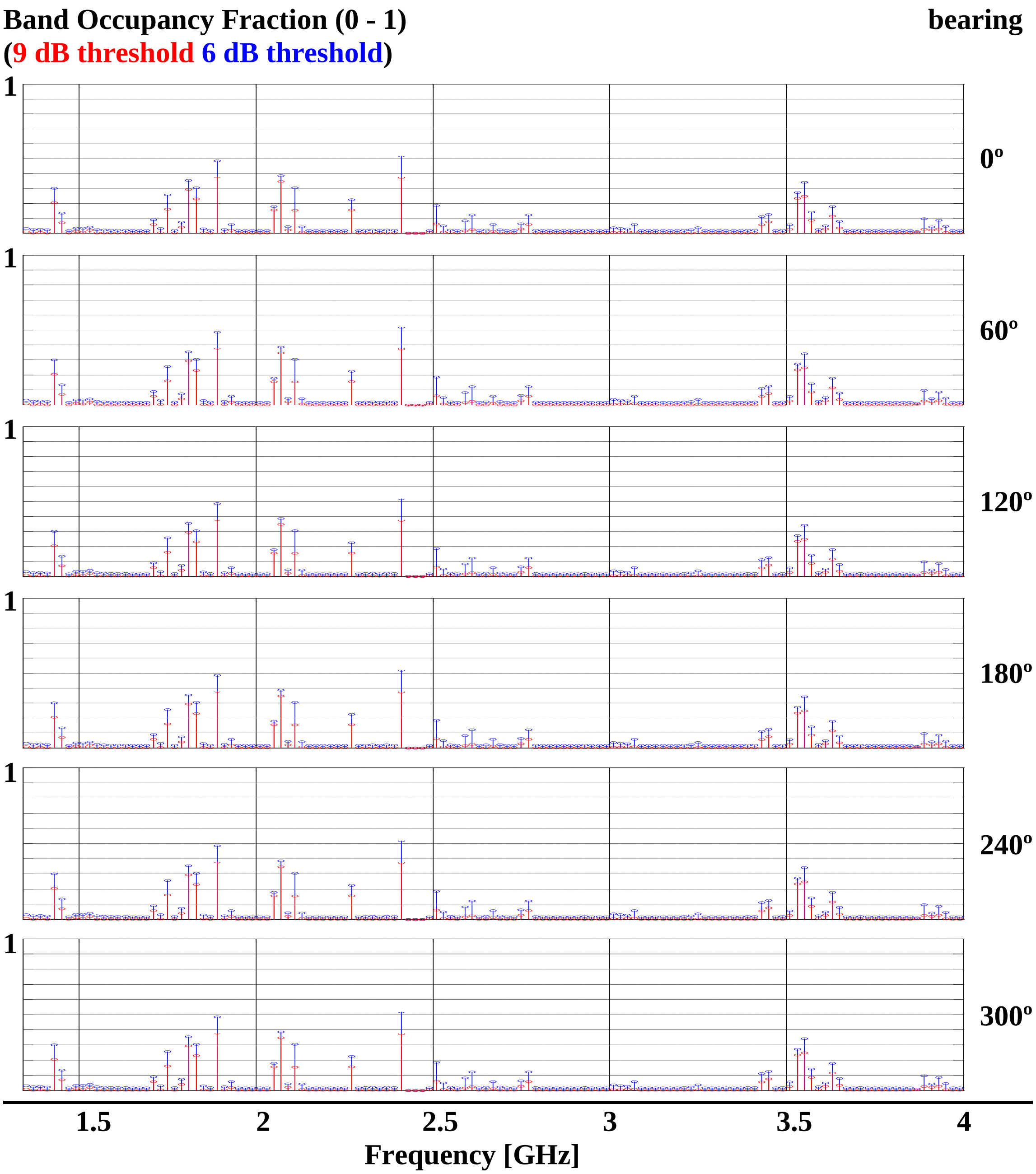
Antenna:	HK014
dB scales:	-220 to -90
RBW : VBW:	30 kHz : 10 kHz
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	2172
Recording:	1825 060507 to 2000 070507

Figure B21: Vpol 80 – 1600 MHz RBW 30 kHz near Karaka

Appendix C: Band Occupancy Fraction (0-1)

Figures C1 – C21 provide summary charts of band occupancy fraction from 0 – 1. These give a guide as to the presence of signals within measurement periods for threshold limits of 6 and 9 dB above a fifth order polynomial fit to the mean signal level in empty channels. They were used with the charts of appendix B in SKA site considerations. It is possible to determine temporal aspects of the signals from the 20 MHz band charts in “RFI Directories 2008 2009”. It is recommended that the Matlab code is modified to summarise them.

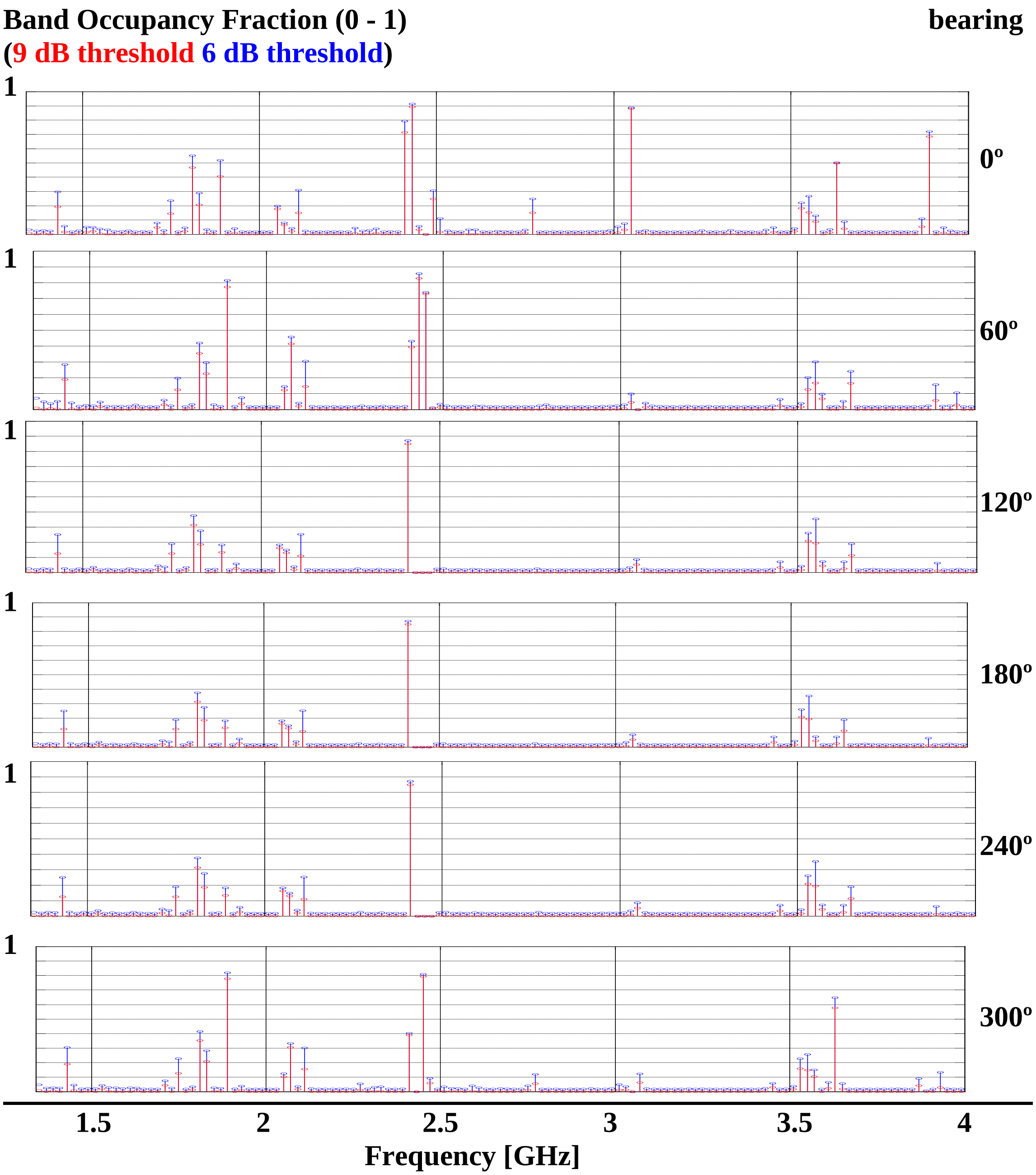
The figure number sequence matches figure numbers in appendix A and appendix B as they use the same data tables. In a few cases the appendix A data tables became corrupted and could not be plotted with the 20 MHz analysis code, which are summarised in appendix B and C.



Tables
t_20080304t134343
t_20080305t140111
t_20080306t003358
t_20080306t183456
t_20080307t062858
t_20080307t225516

Antenna:	HL050
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	1000 at each bearing

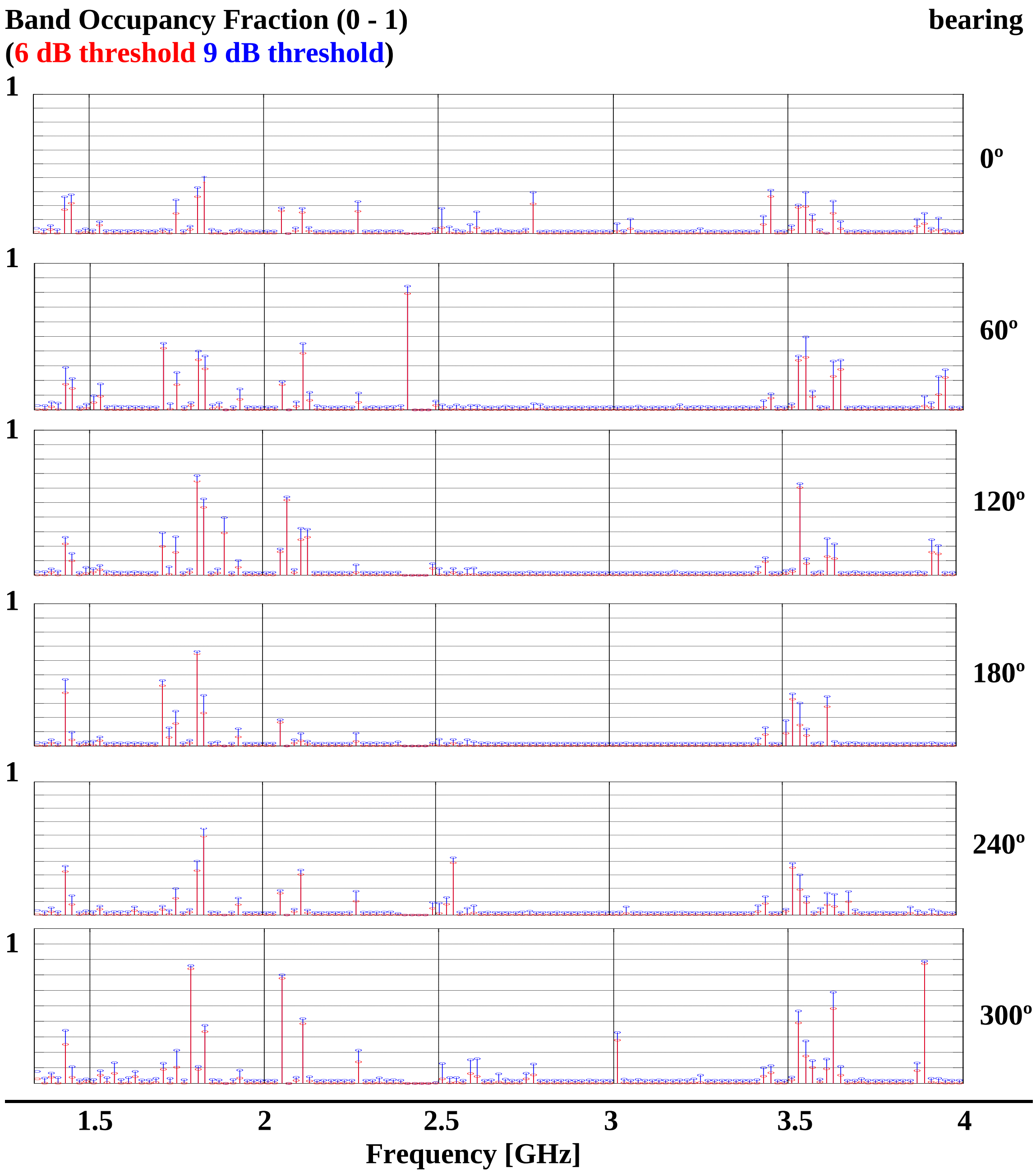
Figure C1: Vpol RBW 30 kHz 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080308t175831
t_20080308t210603
t_20080308t235945
t_20080309t030406
t_20080309t055643
t_20080308t150216

Antenna:	HL050
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	200 at each bearing

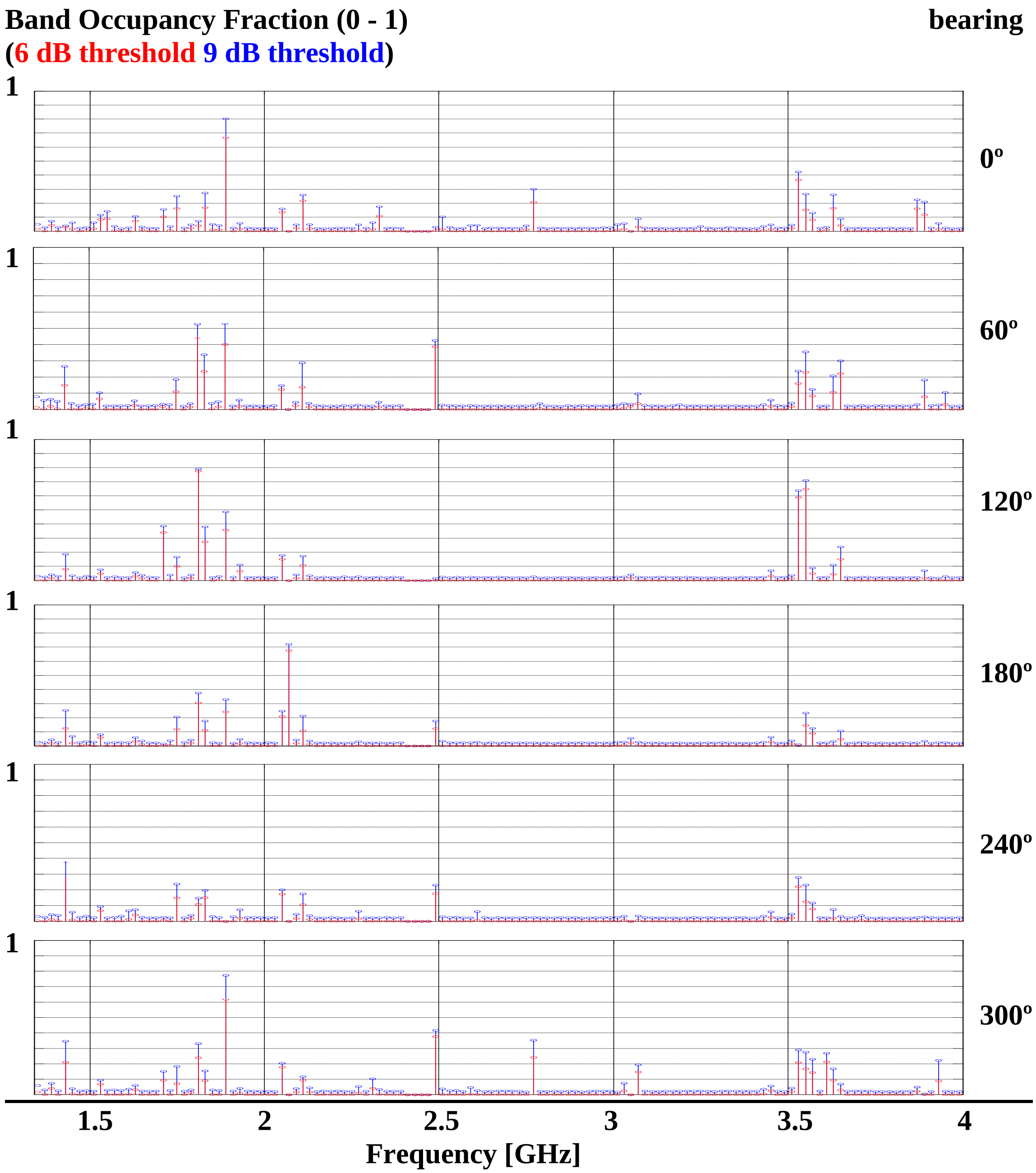
Figure C2: Hpol RBW 30 kHz 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080304t005604
t_20080305t111829
t_20080306t110054
t_20080306t141541
t_20080307t163433
t_20080307t194338

Antenna:	HL050
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	2500 at each bearing

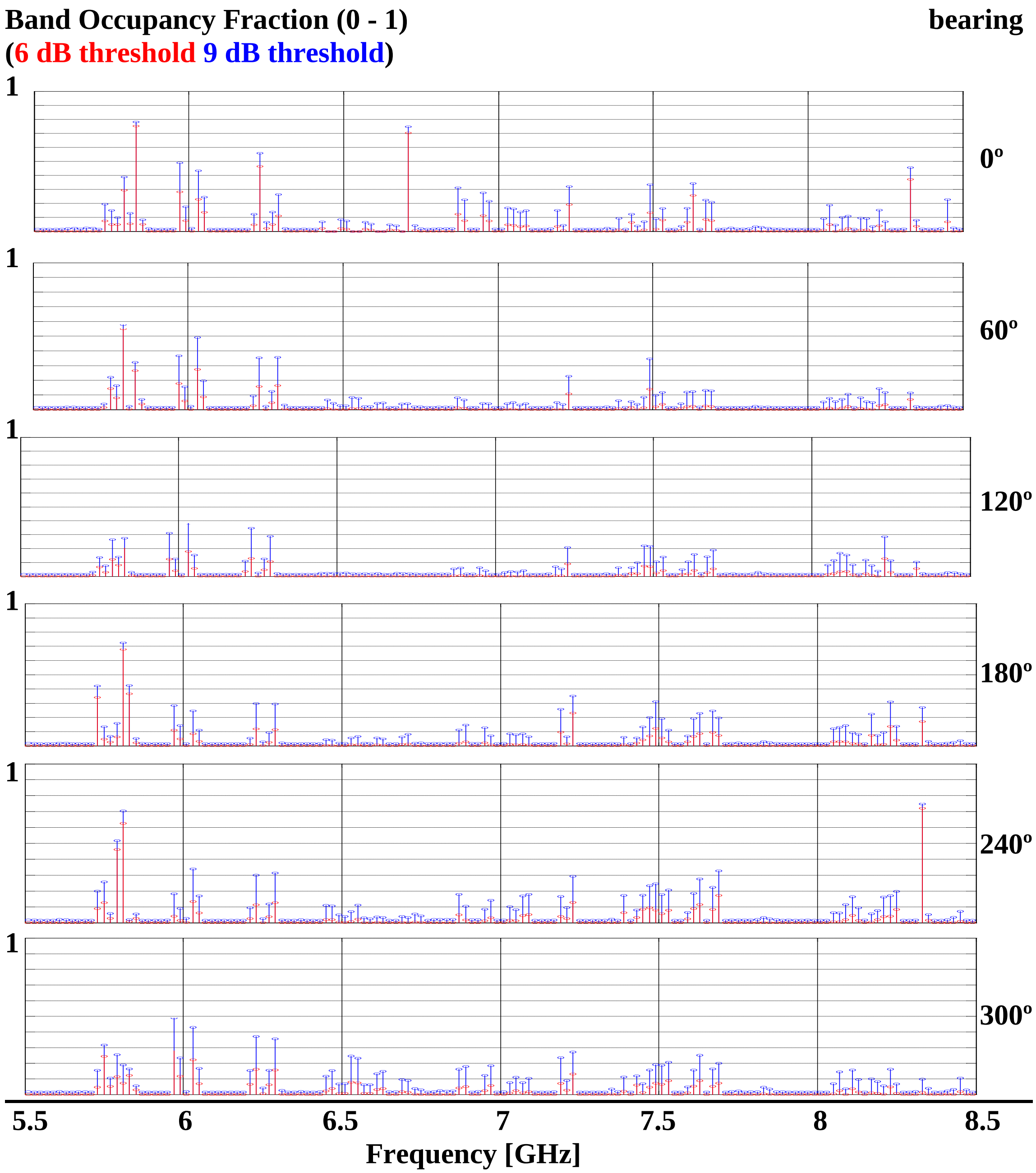
Figure C3: Vpol RBW 300 kHz 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080308t172216
t_20080308t202915
t_20080308t232659
t_20080309t022651
t_20080309t051556
t_20080308t142249

Antenna:	HL050
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

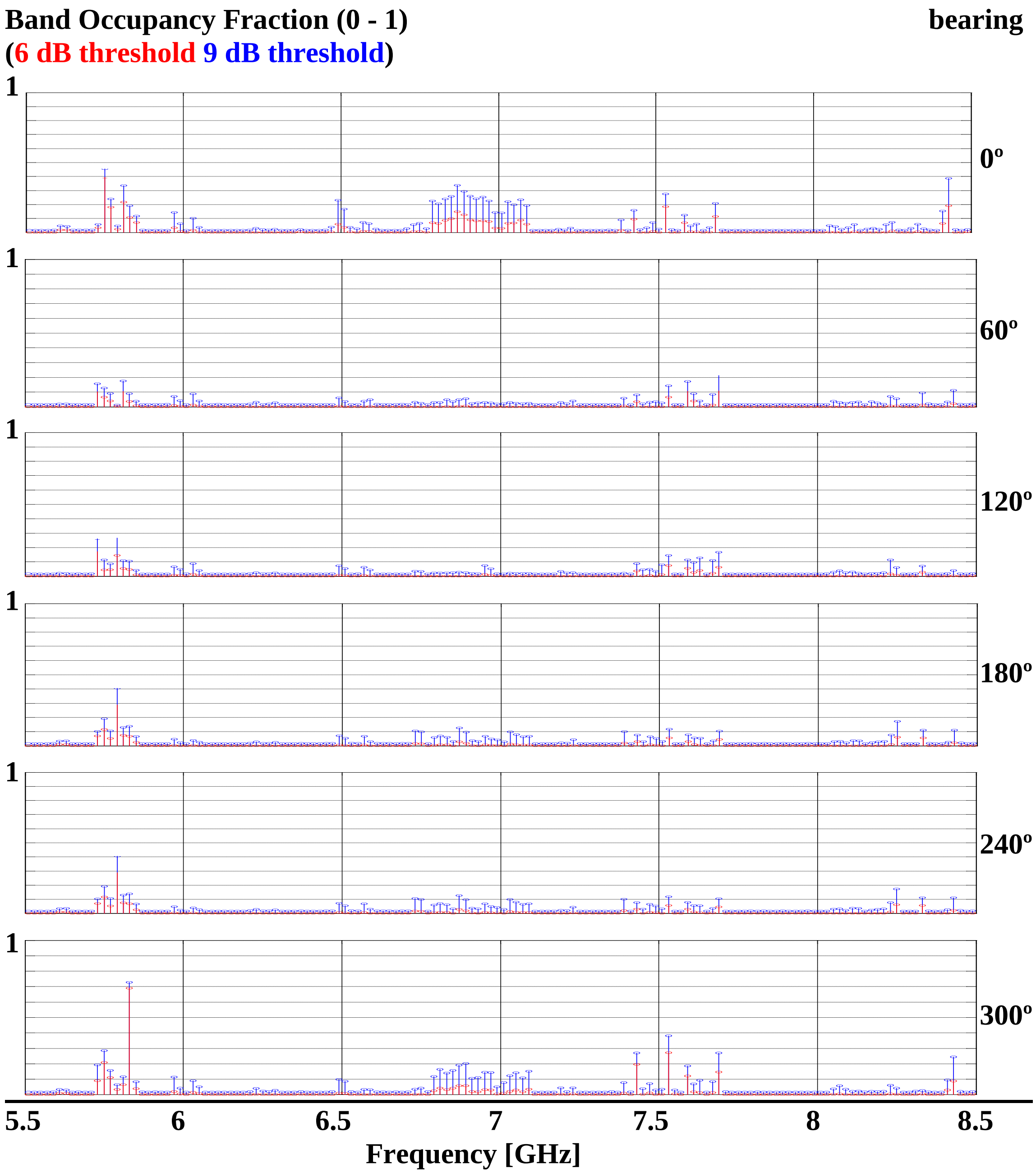
Figure C4: Hpol RBW 300 kHz 1.34 – 4 GHz at AUT Auckland City



Tables
t_20080315t022609
t_20080315t131802
t_20080316t002335
t_20080311t135216
t_20080312t040914
t_20080312t152947

Antenna:	HL050
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	1000 at each bearing

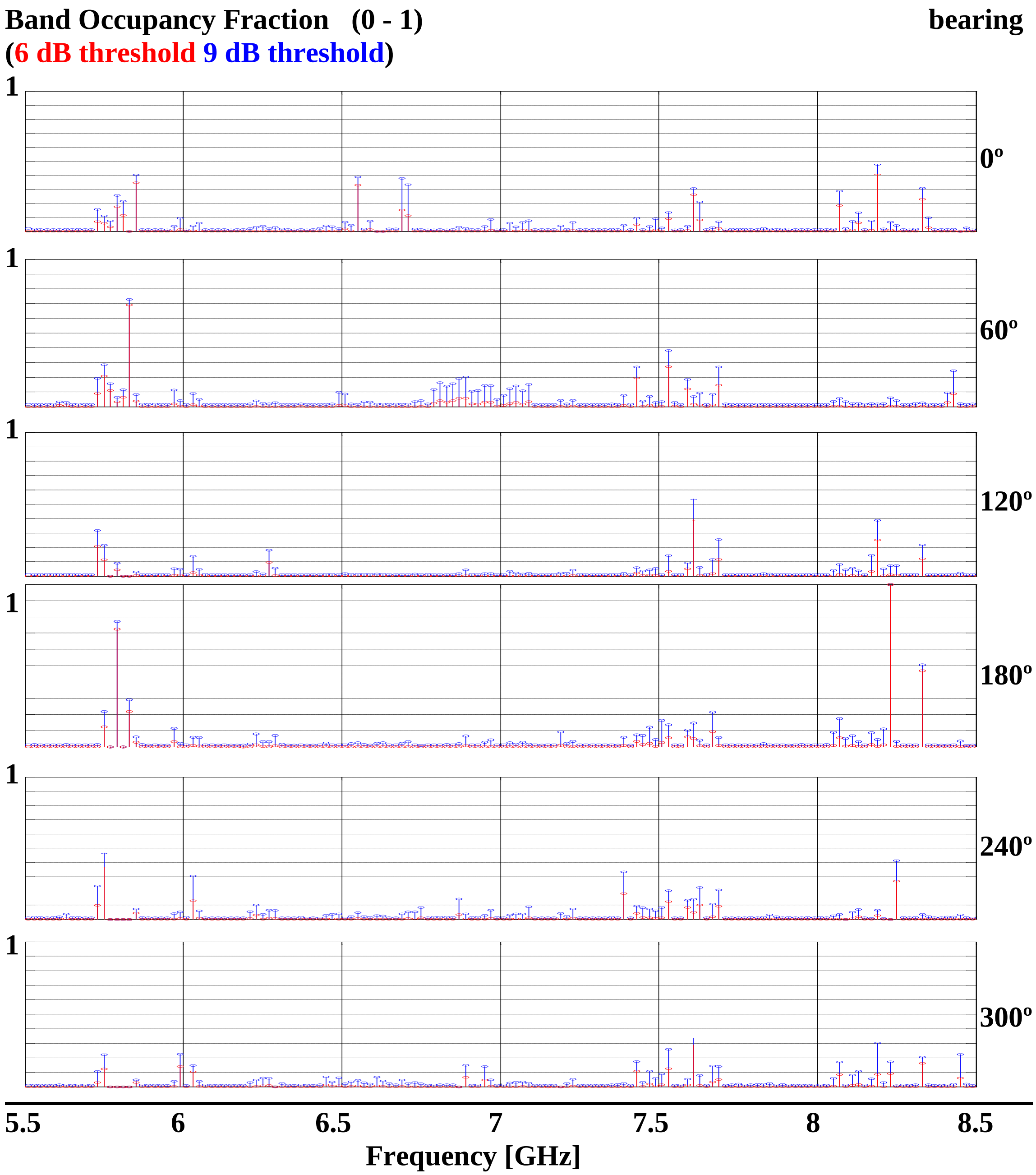
Figure C5: Vpol RBW 30 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables
t_20080313t165414
t_20080313t223320
t_20080314t083456
t_20080314t140825
t_20080314t202216
t_20080313t112400

Antenna:	HL050
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	500 at each bearing

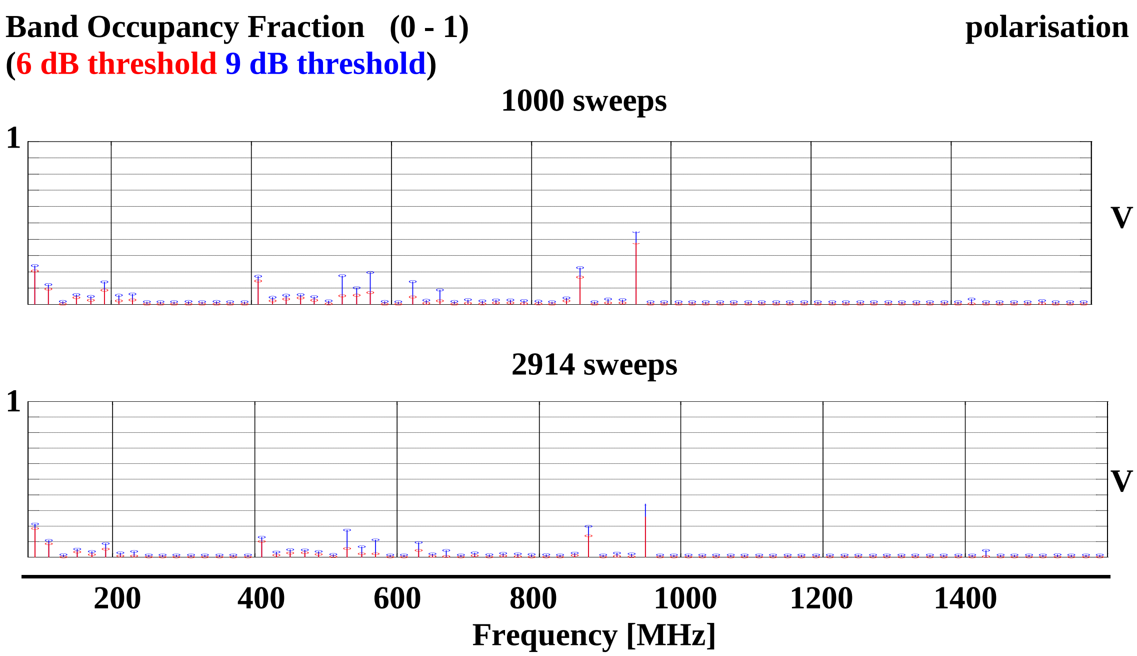
Figure C6: Hpol RBW 30 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables	Attenuation
t_20080309t203841	10 dB
t_20080309t234713	10 dB
t_20080310t152630	5 dB
t_20080311t104940	0
t_20080312t010639	0
t_20080313t023628	0

Antenna:	HL050
Resolution Bandwidth:	1000 kHz
Video Bandwidth:	300 kHz
Polarisation:	Vertical
Bearing:	As indicated
Sweeps:	5000 at each bearing

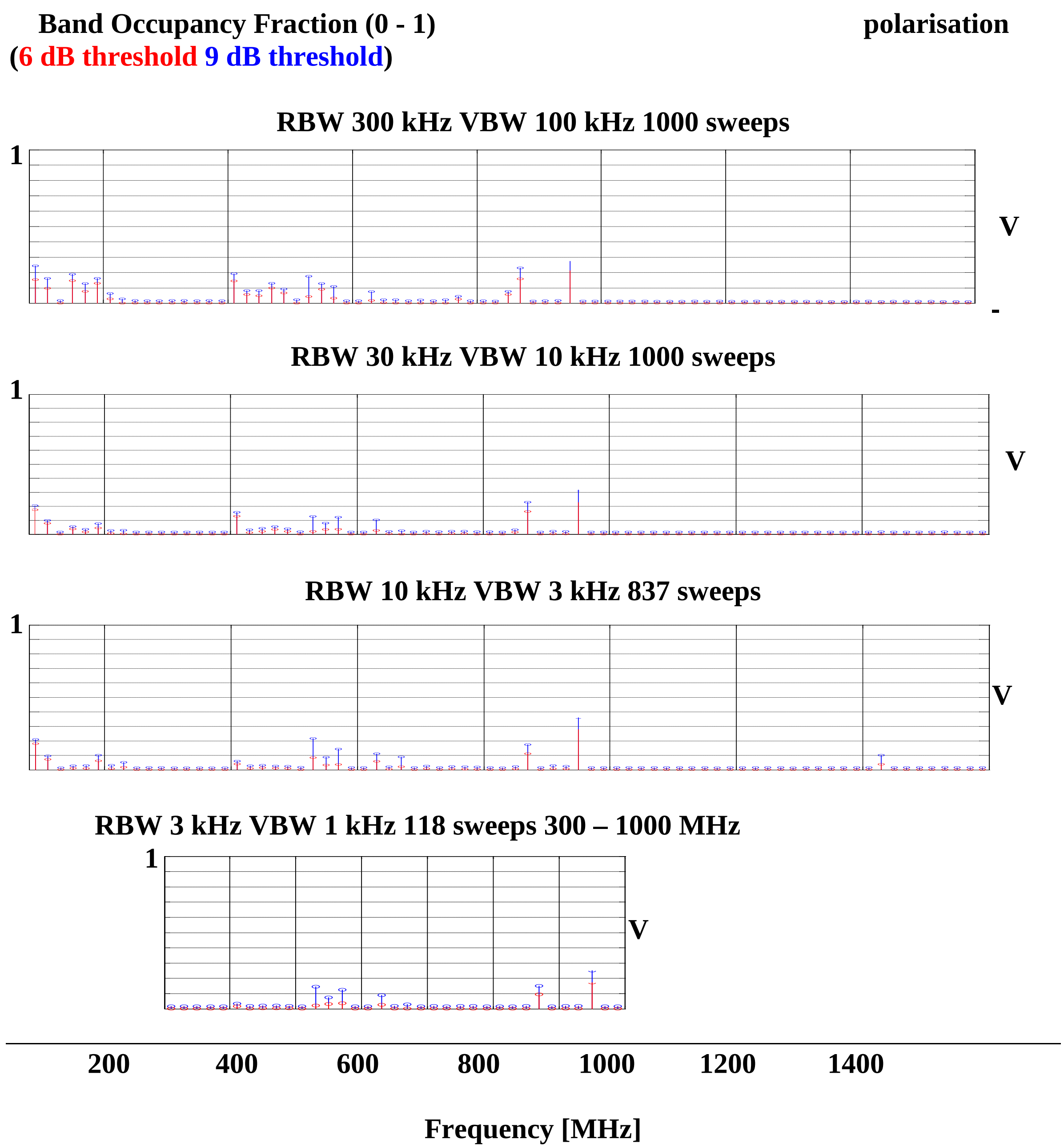
Figure C7: Vpol RBW 1000 kHz 5.5 – 8.5 GHz at AUT Auckland City



Tables
t_20080317t063338
t_20080319t023912

Antenna:	HK014
Resolution Bandwidth:	30 kHz
Video Bandwidth:	10 kHz
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

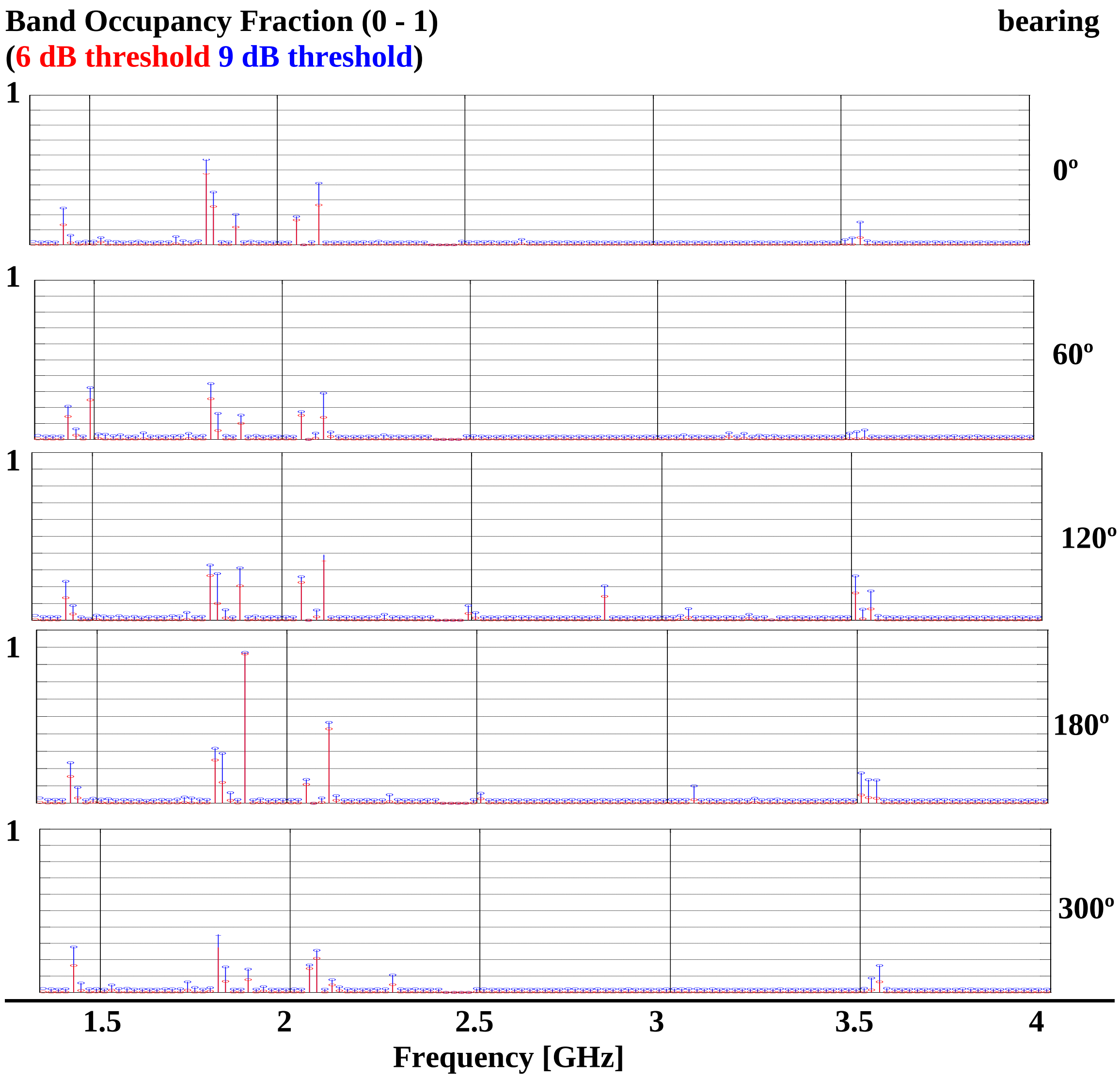
Figure C8: RBW 30 kHz 80 – 1600 MHz at AUT Auckland City



Tables
t_20080318t011904
t_20080318t113456
t_20080319t185706
t_20080318t020454

Antenna:	HK014
Range:	80 – 1600 MHz
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	V or H indicated
Bearing:	Omni-directional
Sweeps:	as indicated

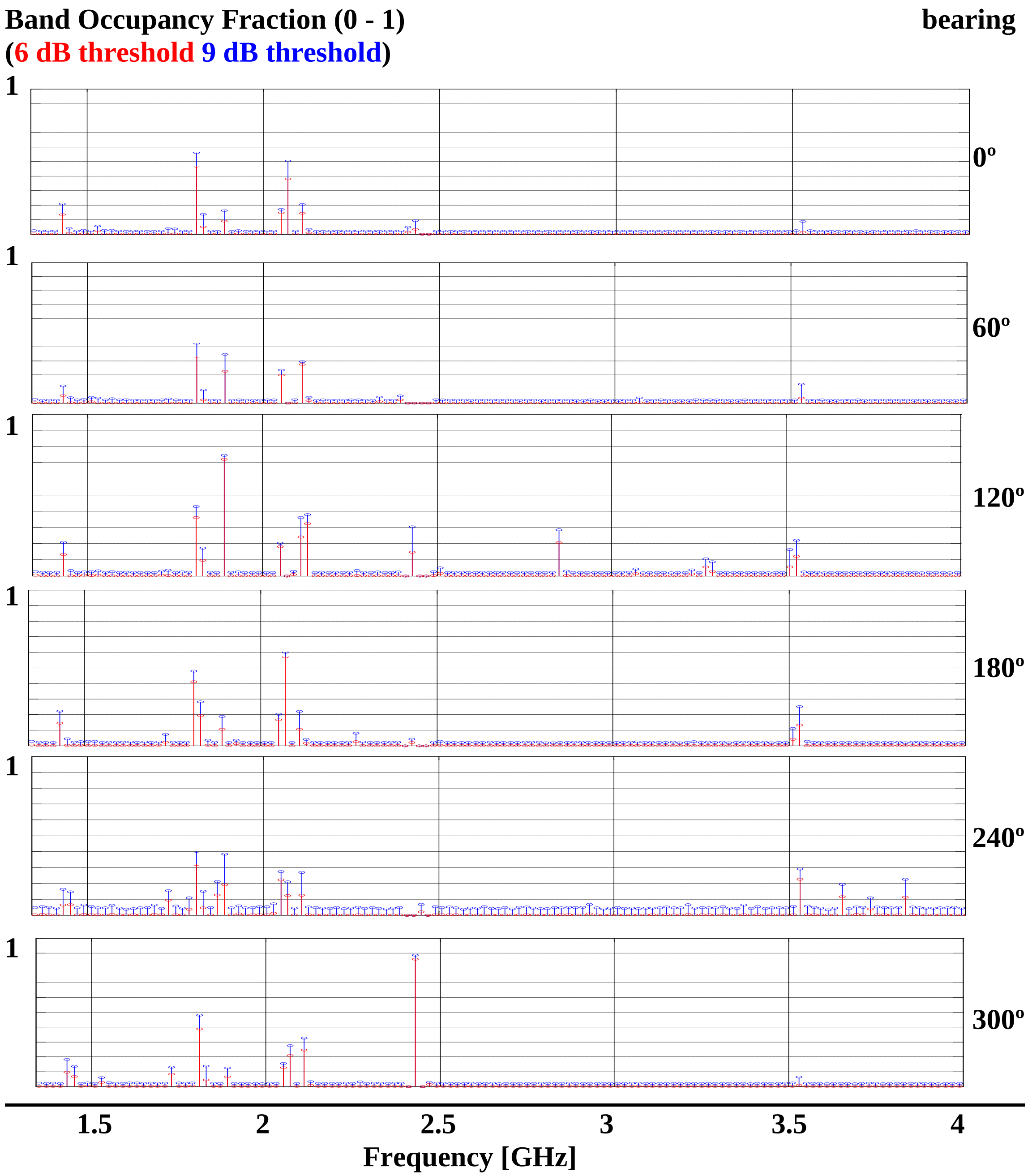
Figure C9: Various RBW 80 – 1600 MHz at AUT Auckland City



Tables
t_20080208t072311
t_20080208t194741
t_20080209t080720
t_20080209t201923
t_20080210t205400

Antenna:	HL050
Range:	1.34 – 4 GHz
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated (240º corrupt)
Sweeps:	~5000 at each bearing

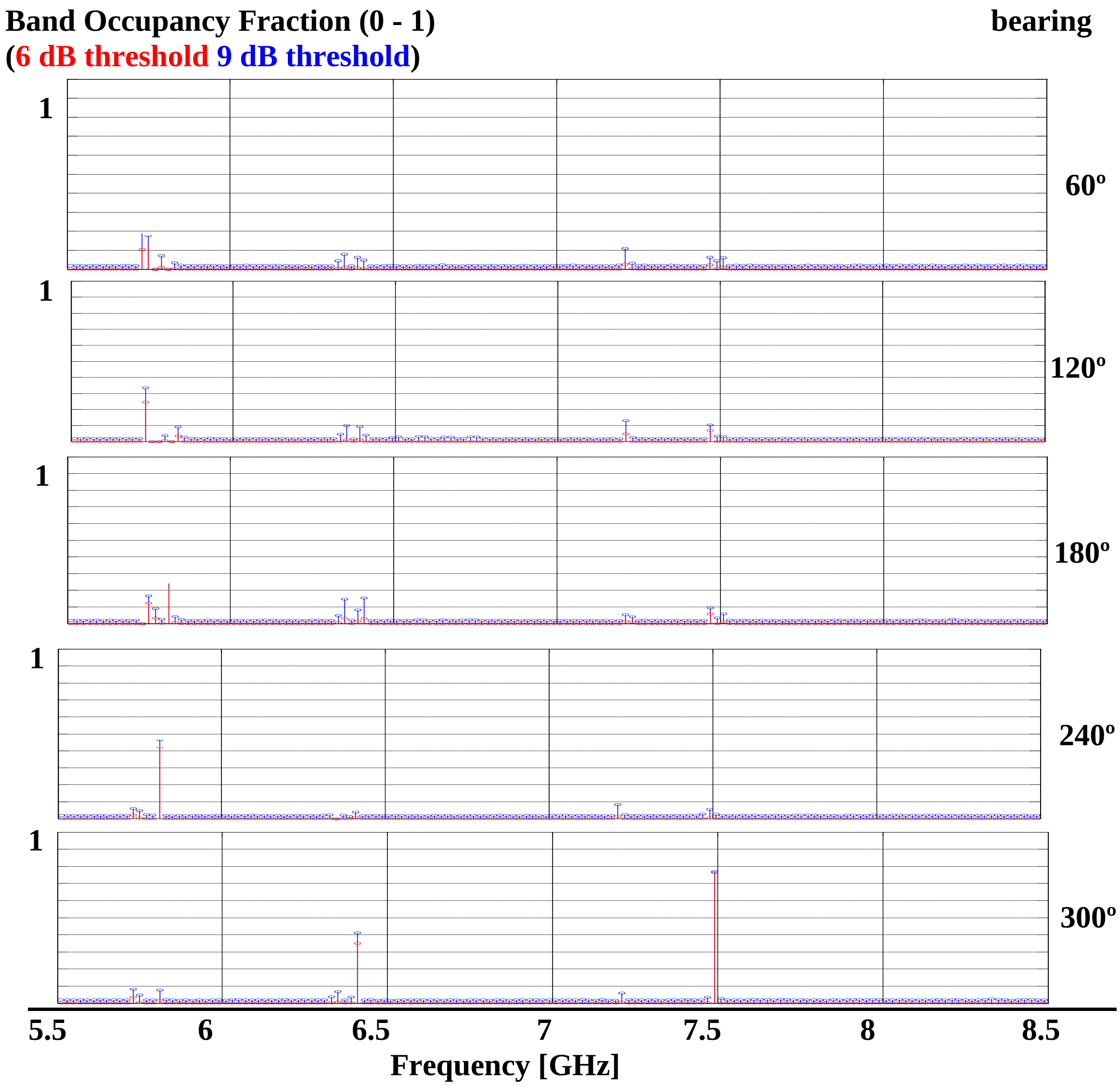
Figure C10: Vpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington residence



Tables
t_20080211t113433
t_20080211t140551
t_20080211t163138
t_20080211t190506
t_20080211t220709
t_20080211t091042

Antenna:	HL050
Range:	1.34 – 4 GHz
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	479 at 240 º and 1000 at other bearings

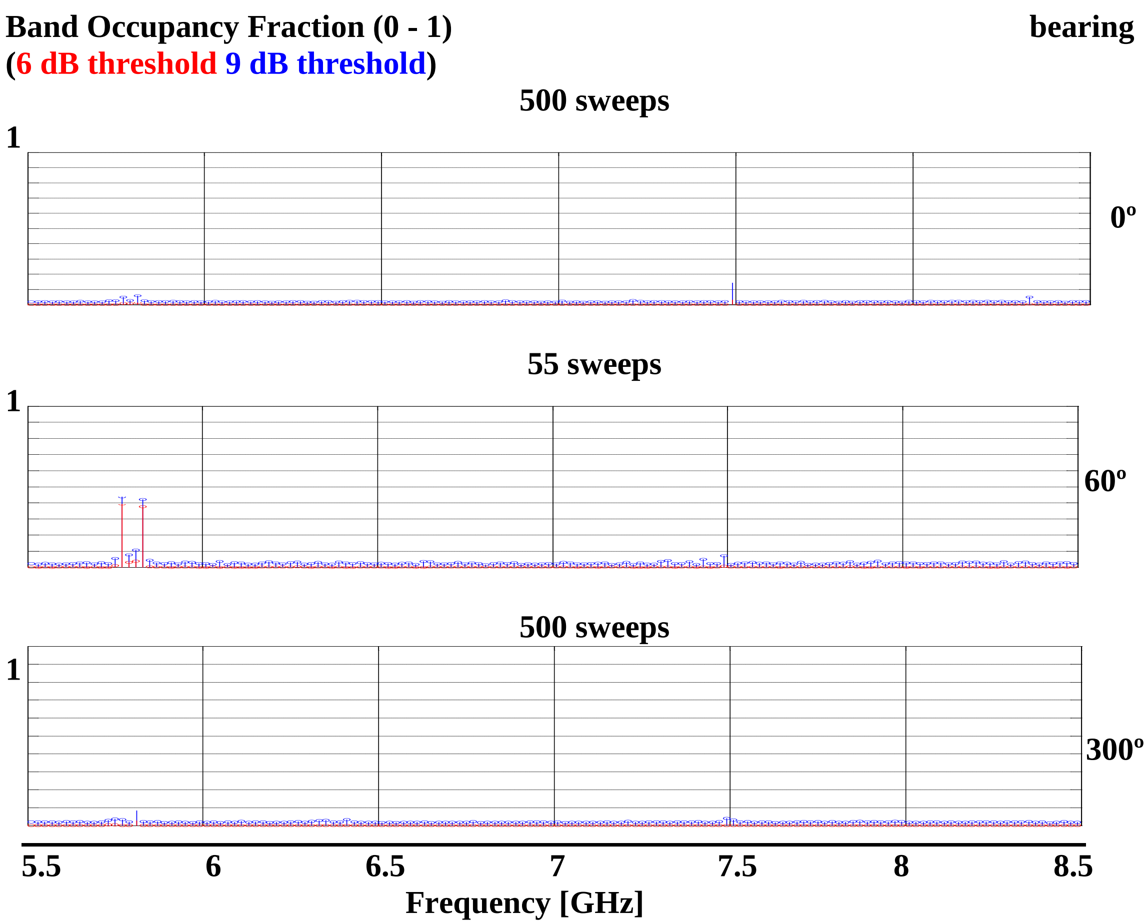
Figure C11: Hpol RBW 300 kHz 1.34 – 4 GHz at Mt. Wellington residence



Tables
t_20080216t123038
t_20080216t202327
t_20080217t041500
t_20080217t140530
t_20080217t220154

Antenna:	HL050
Range:	5.5 – 8.5 GHz
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Vertical
Bearing:	As indicated (0º corrupt)
Sweeps:	~2000 at each bearing

Figure C12: Vpol RBW 300 kHz 5.5 – 8.5 GHz at Mt. Wellington residence

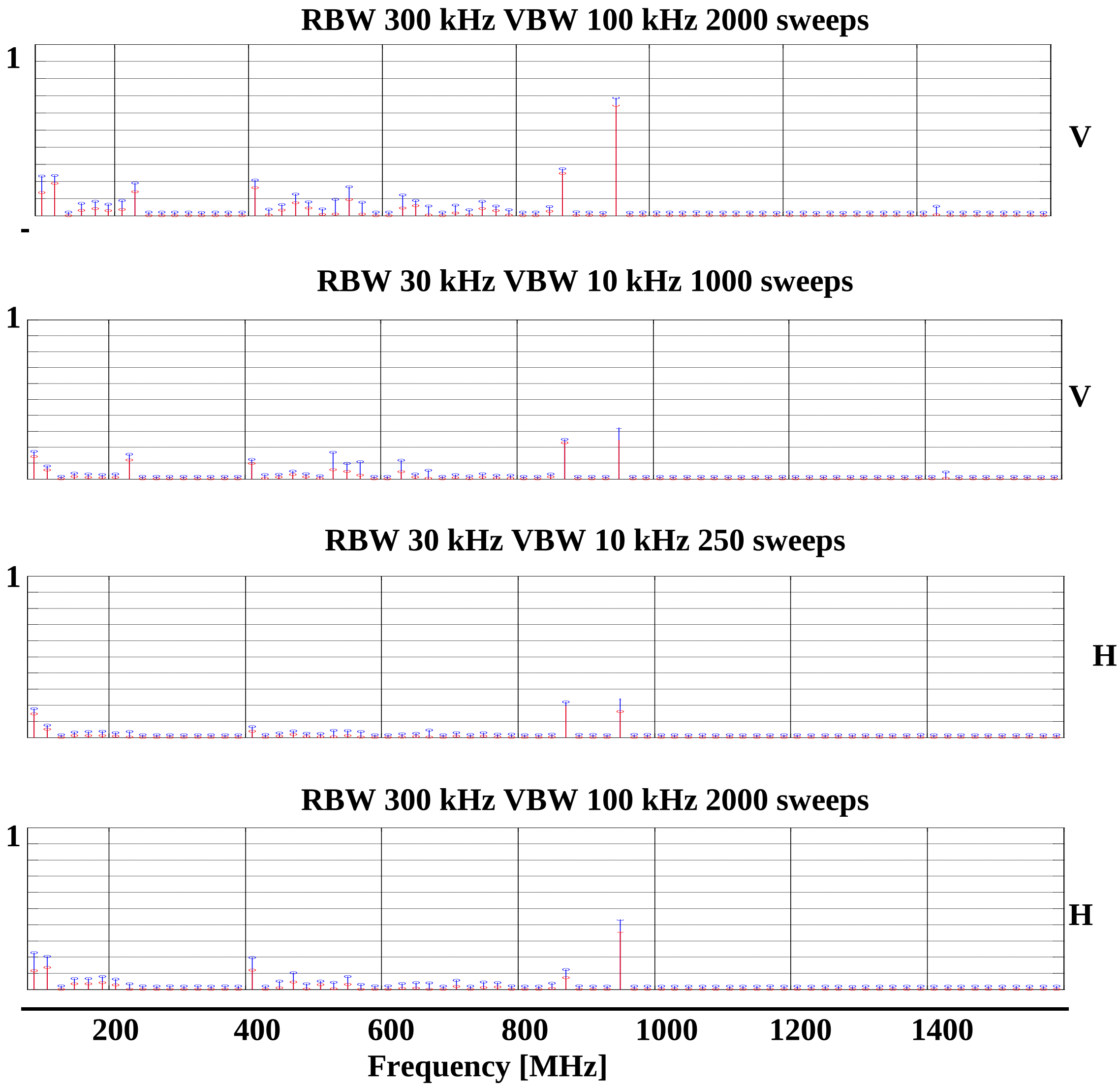


Tables
t_20080218t105805
t_20080218t130206
t_20080218t084115

Antenna:	HL050
Range:	5.5 – 8.5 GHz
Resolution Bandwidth:	300 kHz
Video Bandwidth:	100 kHz
Polarisation:	Horizontal
Bearing:	As indicated
Sweeps:	As indicated

Figure C13: Hpol RBW 300 kHz 5.5 – 8.5 GHz at Mt. Wellington Residence

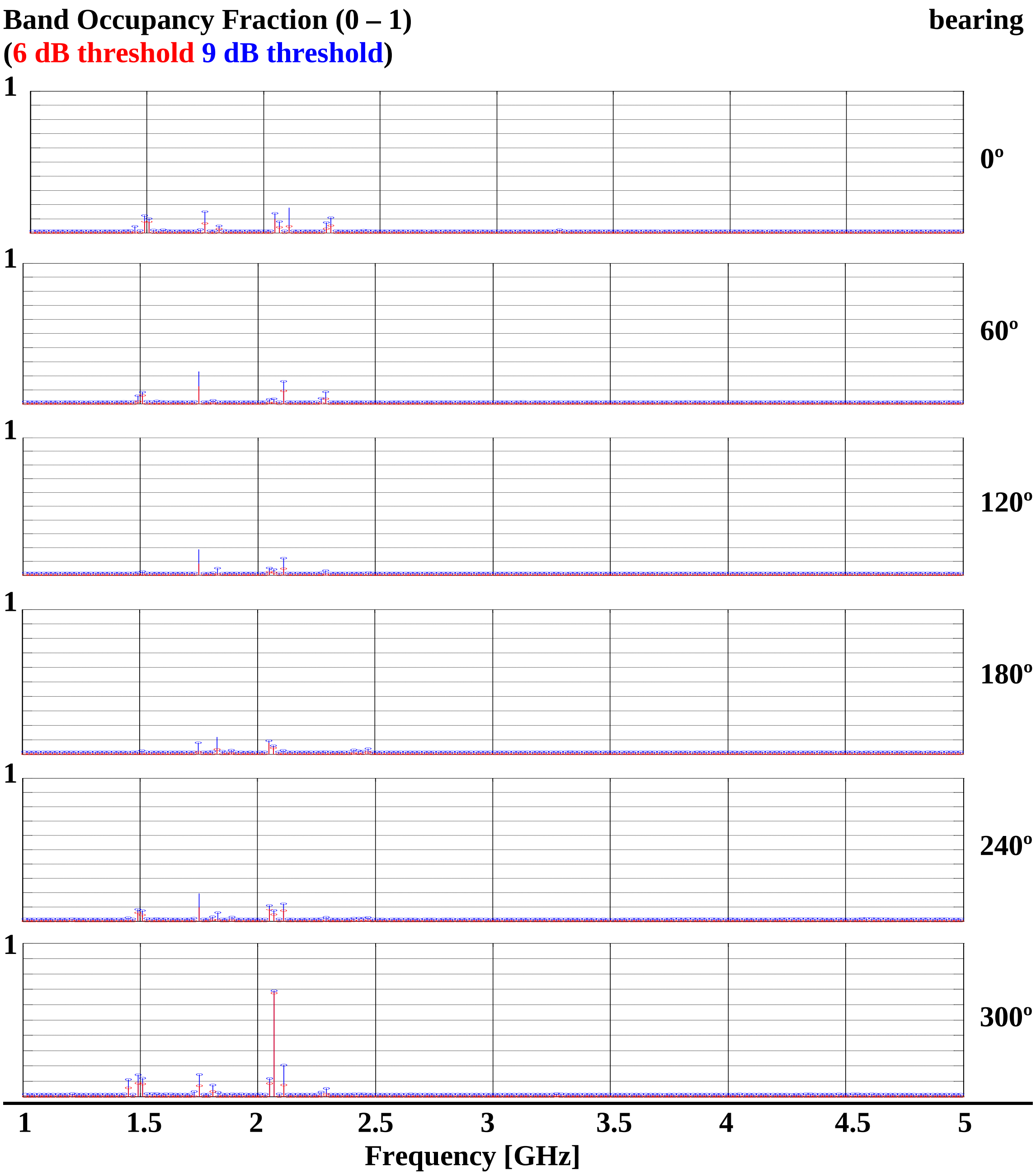
Band Occupancy Fraction (0 - 1) **bearing**
(6 dB threshold 9 dB threshold)



Tables
t_20080226t212253
t_20080227t002050
t_20080226t172605
t_20080226t143451

Antenna:	HK014
Range:	80 – 1600 MHz
Resolution Bandwidth:	as indicated
Video Bandwidth:	as indicated
Polarisation:	as indicated
Bearing:	Omni-directional
Sweeps:	as indicated

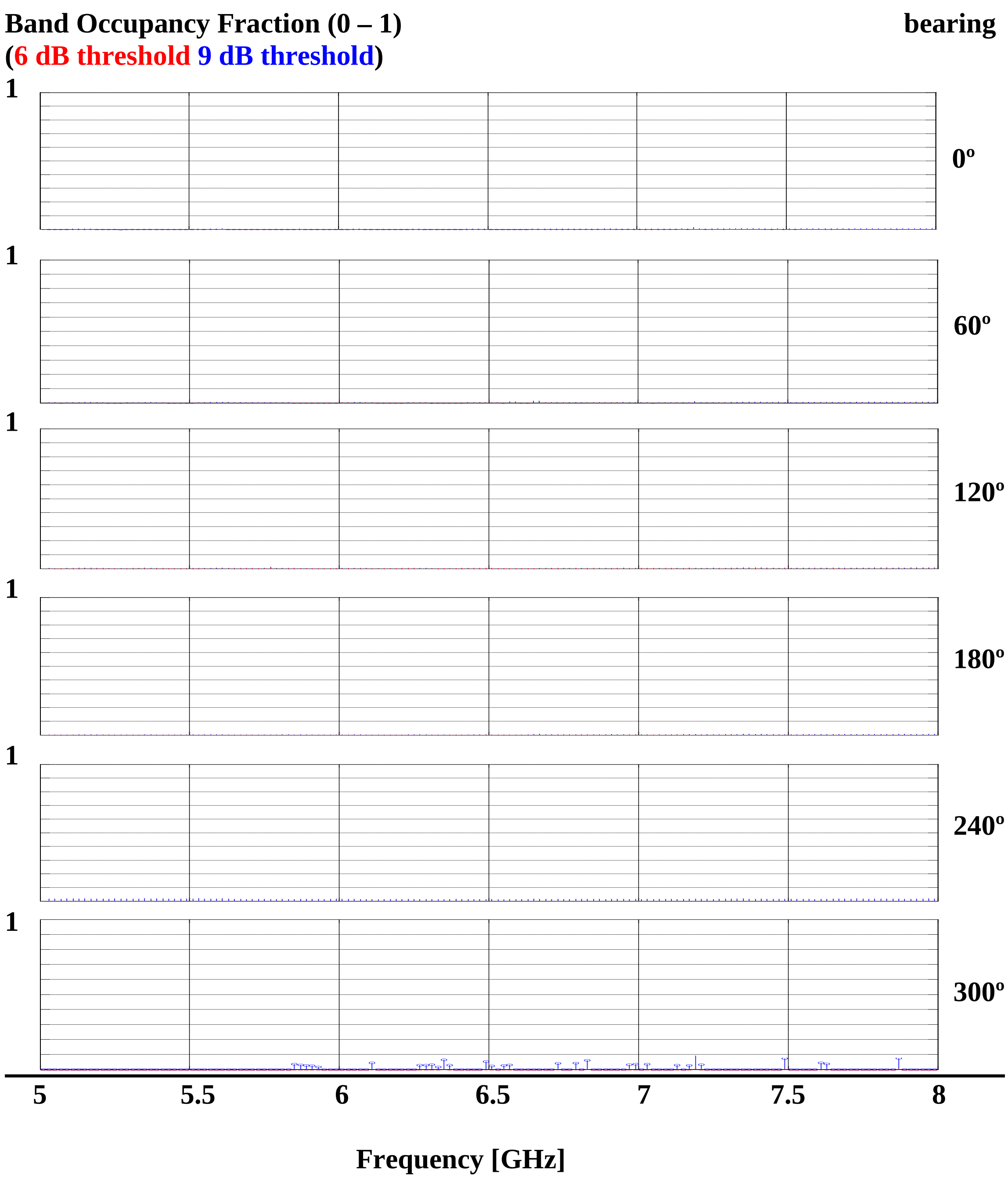
Figure C14: Various RBW 80 – 1600 MHz at Mt. Wellington residence



Tables
t_20071027t204012
t_20071030t191204
t_20071029t232407
t_20071028t233320
t_20071029t024424
t_20071031t233456

Antenna:	HL050
Resolution band width	100 kHz
Video band width	30 kHz
Polarisation:	Vertical
Sweeps:	1000 at each bearing

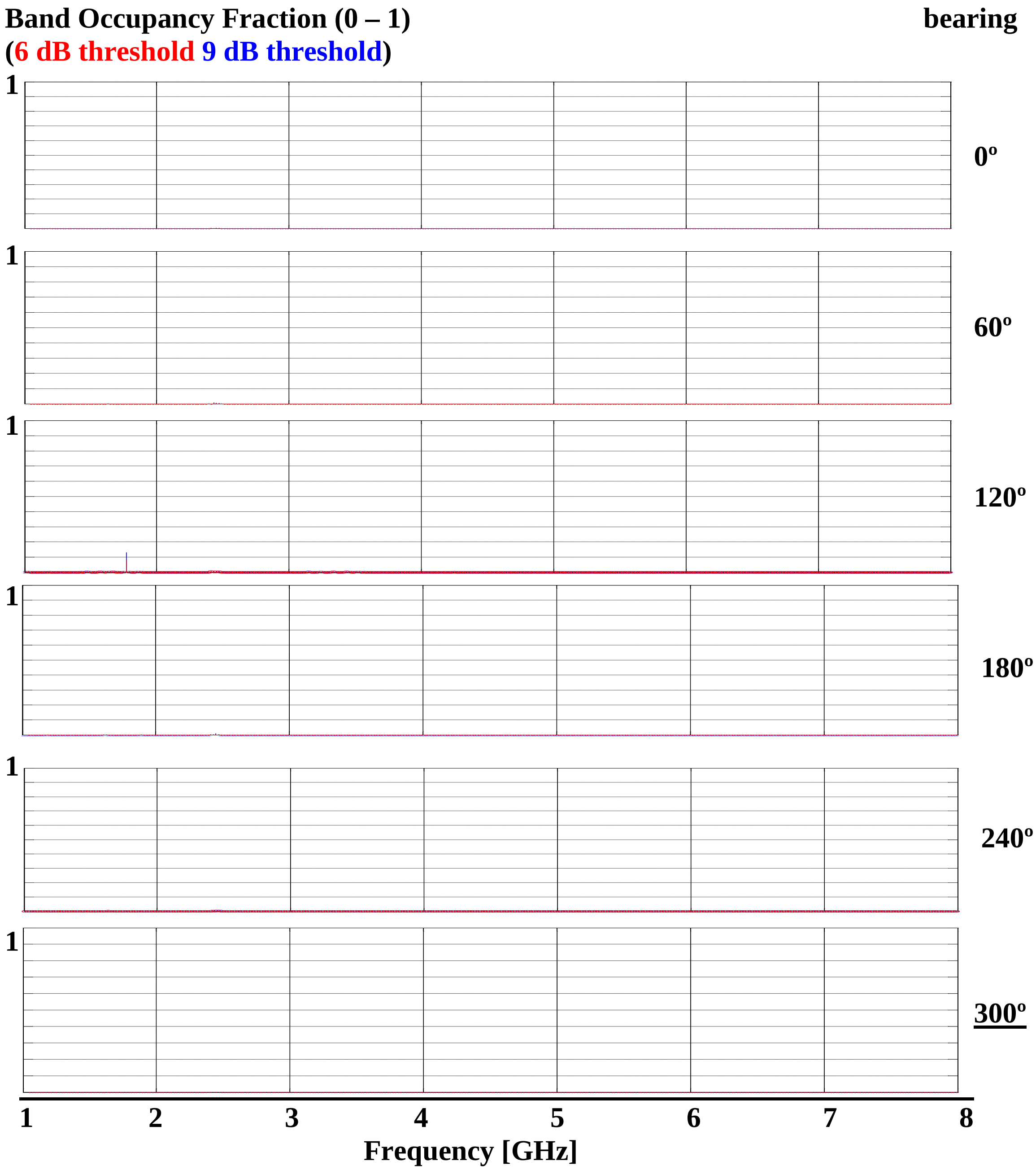
Figure C15: Vpol RBW 100 kHz 1 – 5 GHz at Awarua Station



Tables
t_20071028t104331
t_20071031t072027
t_20071030t091040
t_20071029t092057
t_20071102t123835
t_20071101t094252

Antenna:	HL050
Frequency Range:	5 – 8 GHz
Resolution band width	300 kHz
Video band width	100 kHz
Polarisation:	Vertical
Bearing:	as indicated
Sweeps:	1000 at each bearing

Figure C16: Vpol RBW 300 kHz 5 - 8 GHz at Awarua Station



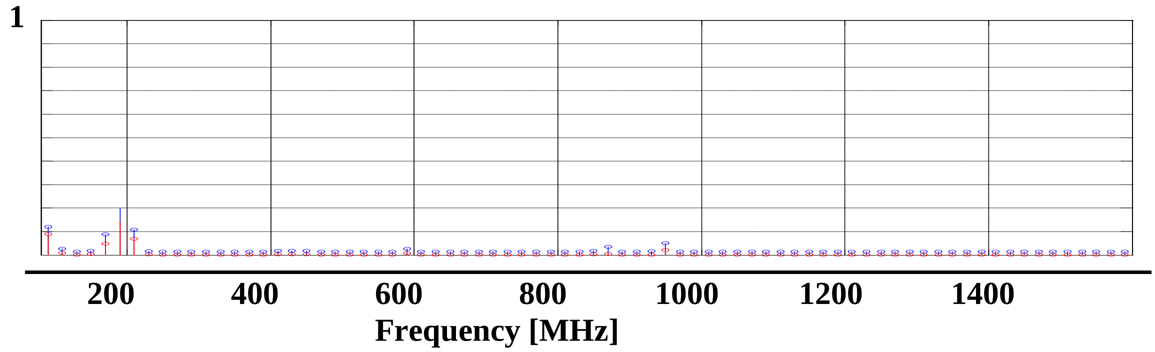
Tables
t_20070923t023029
t_20070923t123550
t_20070923t145555
t_20070925t162123
t_20070922t164353
t_20070922t222635

Antenna:	HL050
RBW : VBW	1 MHz : 10 kHz
Polarisation:	Vertical
Bearing:	as indicated
Sweeps:	~500 at each bearing

Figure C17: Vpol RBW 1 MHz 1 - 8 GHz at Kauri Flat Northland

Band Occupancy Fraction (0 – 1) **(6 dB threshold 9 dB threshold)**

North corner of house



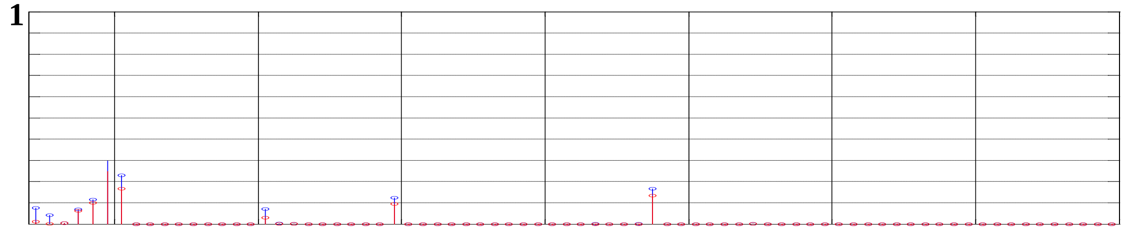
Tables
t_20070924t210248

Antenna:	HK014
RBW :	30 kHz
Polarisation:	vertical
Bearing:	omni-directional
Sweeps:	1002

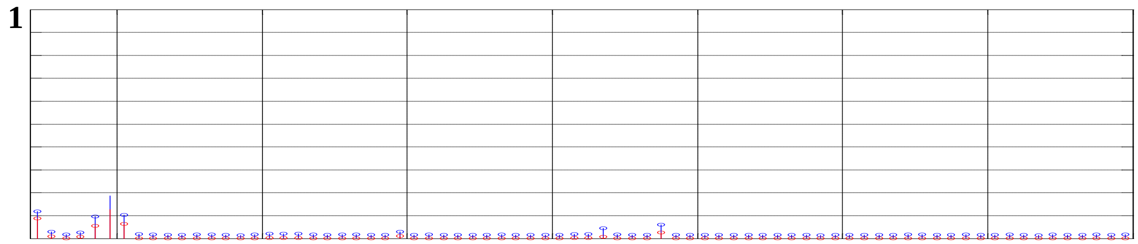
Figure C18: RBW 30 kHz 80 - 1600 MHz at Kauri Flat Northland

Band Occupancy Fraction (0 – 1) **(6 dB threshold 9 dB threshold)**

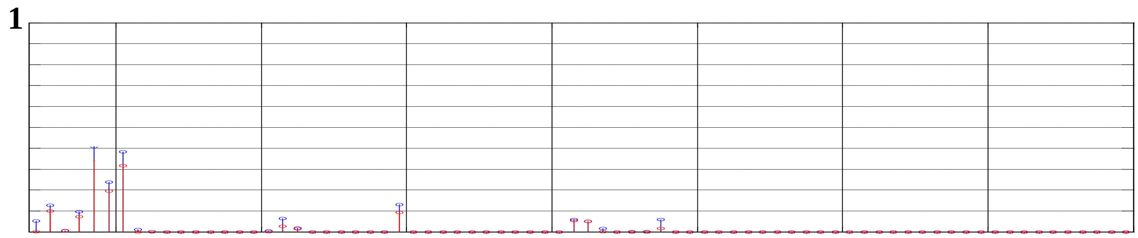
North corner of house, RBW 1000 kHz, Vpol, 7504 sweeps



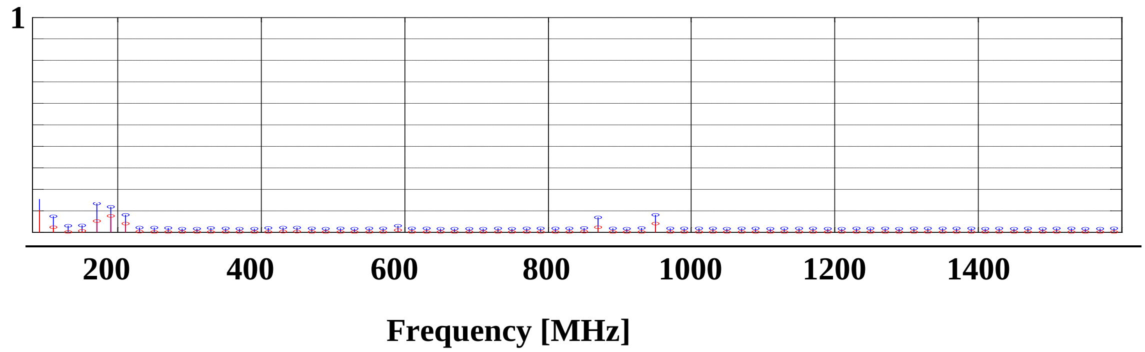
North corner of house, RBW 30 kHz, Vpol, 97 sweeps



South corner of house, RBW 1000 kHz, 2051 sweeps



South corner of house, RBW 30 kHz, 85 sweeps



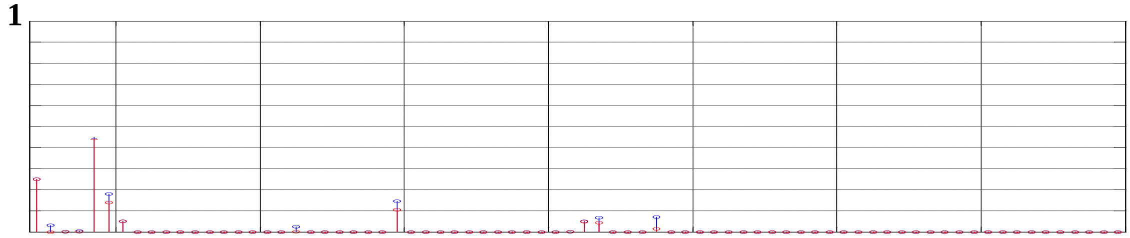
Tables
t_20070923t051748
t_ 20070924t135111
t_20070925t184807
t_ 20070925t200952

Antenna:	HK014
RBW :	as indicated
Polarisation:	vertical
Bearing:	omni-directional
Sweeps:	as indicated

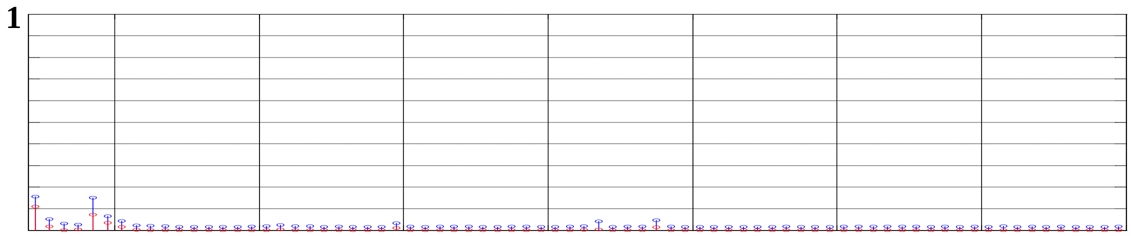
Figure C19: Various RBW 80 - 1600 MHz at Kauri Flat Northland

Band Occupancy Fraction (0 – 1) **(6 dB threshold 9 dB threshold)**

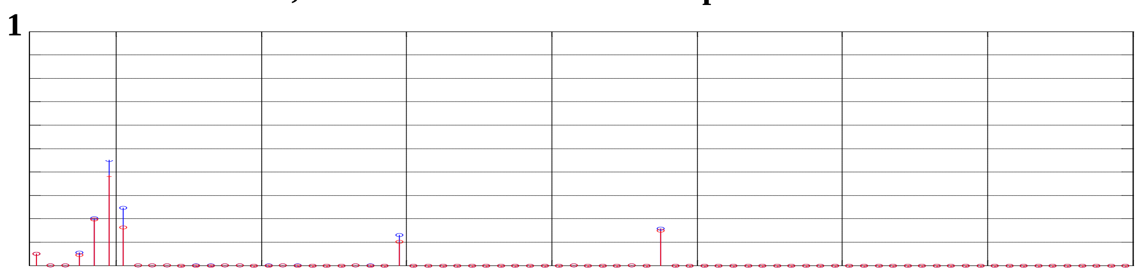
South corner of house, RBW 1000 kHz, 1880 sweeps



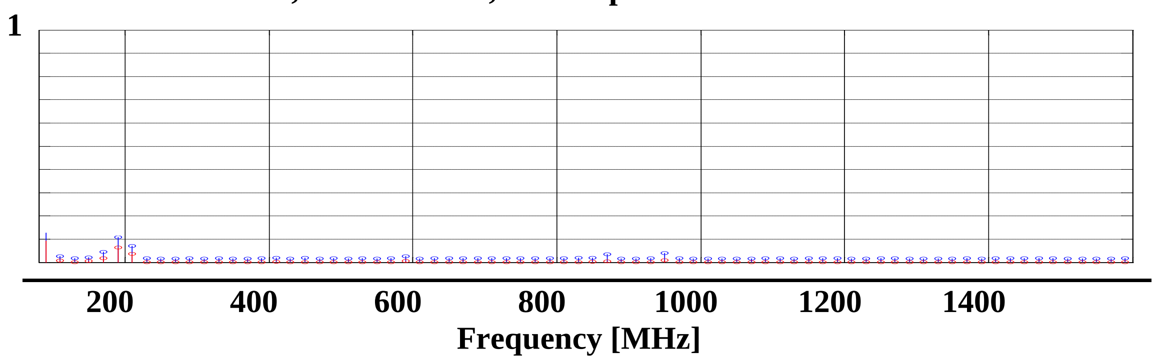
South corner of house, RBW 30 kHz, 88 sweeps



North corner of house, RBW 1000kHz 6675 sweeps



North corner of house, RBW 30 kHz, 86 sweeps

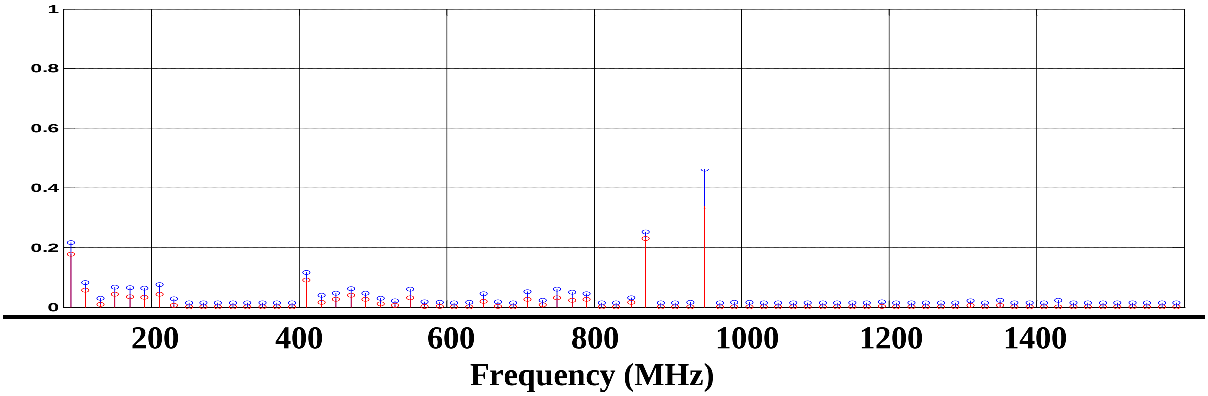


Tables
t_ 20070925t233402
t_ 20070926t004251
t_20070923t214627
t_20070924t163919

Antenna:	HK014
RBW :	as indicated
Polarisation:	Horizontal
Bearing:	omni-directional
Sweeps:	as indicated

Figure C20: Various RBW 80 - 1600 MHz Hpol at Kauri Flat Northland

Band Occupancy Fraction (0 - 1) **(9 dB threshold 6 dB threshold)**



Tables
t_20070506t182514

Antenna:	HK014
dB scales:	-220 to -90
RBW : VBW:	30 kHz : 10 kHz
Polarisation:	Vertical
Bearing:	omni-directional
Sweeps:	2172
Recording:	1825 060507 to 2000 070507

Figure C21: Vpol 80 – 1600 MHz RBW 30 kHz near Karaka