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Analysis of Background Noise for Wireless Microwave LAN Channels

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ANALYSIS OF BACKGROUND NOISE FOR WIRELESS MICROWAVE LAN CHANNELS

BY

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

As part of the Bachelor of Engineering Degree at Edith Cowan University, students are required to undertake a final year project, which aims to complement the skills learnt throughout the course, via application. Such application is not solely technical, but also includes and draws upon research techniques and information collaboration, project management skills, and general problem solving techniques. These criteria form the basis for any real world application engineering project, and it is the underlying aim of education to best prepare students for such engagements.

Myself, as a final year engineering student (1995) at **Edith Cowan University**, entered my last year of education with great vigour and aspirations. Finally, after three years of hard work, I was looking forward to putting the skills that I had learnt, and the knowledge base that I had developed, *to the test*.

Choice of the project, was a factor that I considered very important, and thus received great deliberation on my behalf. For my project, I chose to work with **Dr Tadeusz Wysocki**, in collaboration with the CRC BTN ECU Research group (Broadband Telecommunications and Networking), to undertake an **Analysis of Background Noise for Wireless Microwave LAN Channels**. My decision was based upon two underlying factors; (1) my interest in wireless communications that had blossomed as a result of my education, and (2) the work which I undertook while completing my twelve weeks vacation employment with Telstra, over the 1994/1995 summer vacation period. The majority of my time with Telstra, was spent analysing, understanding the principle of operation, and testing the practical worth of wireless modems, with respect to the possible applications that this emerging technology could provide. In light of this, upon realising the opportunity to continue this work in a

related field, as well as being able to work with Dr Tadeusz Wysocki, the decision to undertake this project was premeditated, and subsequently rewarding.

This report outlines the details of my work, for the academic year of 1995. Perusal of the details within, should provide the reader with an insight into general wireless indoor communications within the microwave spectrum, with respect to the problems faced, specific to noise corruption of the transmitted signal. Indoor communication systems are difficult to model, due to the largely random nature of the relevant environment, and the compounding factors that degrade system performance. These factors are many and varied, in accordance with the operational topologies of possible application areas. However, there exists a common and increasing need to effectively model the communication links in question. Part of this strategy involves having an understanding of what levels of background noise exist within the operational area involved, and to what degree it is variable in accordance with application and link topologies. It is this requirement that provided the catalyst for my investigations.

This study investigates the various noise sources evident on the two frequency bands allocated for wireless LAN applications, and considers the relative importance of the findings. As further persual will reveal, the major disturbance likely to affect such technologies, are microwave ovens, both on a domestic and commercial scale. A full statistical analysis is presented for the spectrum distribution and corresponding power levels for microwave ovens, with the results being utilised to present an examination of the possible influence that they may have upon the system, and the significance of such claims.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree of diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

ACKNOWLEDGMENTS

For the subsequent report material, I wish to extend my thanks and gratitude to all those concerned, who provided me with direction, inspiration, and contributed to the progression of my work. I wish to thank my research colleagues in the CRC, and convey a special thanks to my supervisor, Dr Tadeusz Wysocki, and Mr Ted Walker (Ph.D student with Dr Wysocki), who's work was in close relation to mine. Their input and combined effort was greatly appreciated, and for this I am graciously indebted.

CONTENTS

1. OVERVIEW

Over the past four to five years, interest in wireless indoor communications has been nothing short of spectacular to say the least. This can largely be attributed to enormous growth in the development and implementation of computer based terminal solutions in almost every economic situation imaginable. Such technology has seen a tremendous demand to have these computing facilities operating under more flexible environments, meaning increased mobility. The most relevant means to provide such mobile services, is quite obviously through wireless communications.

In light of the fact that relatively broad bandwidth's are required for such communication, one of the most popular choices of carrier frequency for this emerging technology, has been within the microwave spectrum.

This study focuses on wireless networks that employ microwave transmission for communication, and to examine details pertaining to the background noise germane to this frequency band. The aim was to develop a comprehensive understanding of what sources contribute to the level of background noise, and to what extent, from both a theoretical and practical perspective.

Consideration given to the microwave spectrum in Australia, access is strictly controlled by the Spectrum Management Authority (SMA). Traditionally, users of microwave transmission technologies must pay a 'per end' licence fee, which is variable according to the type of equipment utilised.

The SMA has allocated four frequency bands in the Industrial, Scientific and Medical bands in which wireless technologies can operate. These bands are : 915-928 MHz (typically Spread Spectrum Radio), 2.4-2.485 GHz, 5.5-5.585

GHz and 19.15-19.21 GHz. This study is primarily concerned with the 2.4-2.485 GHz band, although a brief investigation of the 5.5-5.585 GHz band is also presented. Users of wireless technologies operating in these bands are not required to obtain operating licences provided that higher gain antennae are not used which subsequently raise power levels above maximum prescriptions. If this was the case, then appropriate licensing actions must be undertaken with the SMA. This wavering of licensing requirements, in conjunction with the fact that the relatively high frequency of microwave transmission facilitates increased bandwidth's, renders microwave LAN's a popular choice for current and future applications.

Microwave devices are beset by one major limitation. Microwave propagation necessitates line of sight transmission, as the higher frequencies degrade very fast as they hit obstructions. This is because the wavelengths are not long enough to pass through a number of obstructions (such as interior walls), and still carry useful data. This is one of the major concerns for applications that require *roaming* capabilities (mobility).

In order to determine projected performance capabilities for microwave LAN's (or any communication links for that matter), **link budget analyses** are necessary. "Link budgets are especially useful for predicting system performance with respect to system design trade-offs" (Jackson, 1988). This is common practice for long distance microwave systems, but such parameters are difficult to determine for the relatively short distances that wireless LAN's operate over, and more importantly the relatively random nature of the typical operating environments.

"For a typical budget analysis, an accurate knowledge of all attenuation and noise sources is essential because they determine how much margin should be

designed into the link to prevent an outage" (Jackson, 1988). In analysing these attenuation and noise sources, there are many parameters that must be considered. Attenuation considerations (Jackson, 1988) includes factors such as random losses, atmospheric scintillation, multipath fading effects, and atmospheric de-focusing caused by clouds, rain and gaseous absorption. Noise consideration requires an analysis of the earths inherent atmospheric and surface emissions, the effect of sunlight and other extraterrestrial sources (all natural sources), as well as the scourge of communications, man-made (artificial) sources.

For the purpose of this analysis, my focus was directed solely towards noise considerations, as this limits the project to the required scope. Some consideration has been given to attenuation constraints, as in most cases they must be considered in conjunction with noise sources, as the two often occur in tandem. However, this facet has only be studied and duly noted as appropriate, in order to remain divergent towards the main goal : **a study of background noise as applicable to wireless LAN's**.

In conclusion, it is hoped that as a result of my research, it will be possible to determine of all the relevant noise sources, which types and of what form contribute to the level of background noise evident within the prescribed frequency bands for microwave wireless LAN's. Finally, after due consideration of appropriate operating environments applicable to the application of wireless LAN's, a full statistical analysis of the measurements collected has been undertaken, in an effort to produce an accurate and field relevant statistical model(s) of the background noise. Such a model(s) can then be employed when designing future wireless links, and when considering general channel characteristics.

2. PROJECT DEFINITION

2.1 AIM

The aim of this project was to *study the details pertaining to, and measure the level of background noise evident on frequency bands allocated for microwave wireless LAN's. These measurement results could subsequently be used to perform the appropriate statistical analyses, thus providing the avenue for the development and integration of the corresponding statistical models. Such tactics yield a comprehensive understanding of what sources contribute to the inherent level of background noise, and to what extent.*

2.2 SCOPE

In order to obtain results representative of the possible application environments, there exists a requirement to diversify the measurements. This involved taking both omnidirectional and selective measurements in different operational environments, as well as considering variations in building topologies for similar environments. Such precautions not only allowed determination the average noise strength, but also allowed isolation of the various noise sources, and to what extent they influenced possible systems in the various applications and their allocated bandwidth.

The two frequency bands of interest in this project, out of four allocations, are :

- 2.4-2.485 GHz.
- 5.5-5.585 GHz.

Note : Subsequent material will show that the majority of effort was directed towards the 2.4-2.485 GHz band.

One important factor that must be considered, originates from the definition of background noise itself. Noise arises from :

1. Unwanted signal energy being injected into the communication link, or;
2. Thermal noise generated from within the link itself.

Specifically related to (2), background noise is a purely random signal that exists within the communication channel itself, and is not generally a consequence of transmission, whereby interaction with the environment results in signal degradation (absorptive loss). Although absorptive losses are contributory to general system degradation, for the purpose of this study, the focus is aimed at examining the noise that exists within the communication channel, which is independent of the transmitted signal. Some consideration has been given to absorptive loss noise, as it helps to complete the picture, but this was only addressed as appropriate.

2.3 STRATEGY

The strategic development of the project, involved a series of sequential steps. These steps have been utilised to ensure that the project progressed in a logical and efficient manner. The proposed strategy, listed in chronological order for the academic year of 1995 was as follows :

1. Literature review.
2. Determination of aerials required to take measurements.
3. Production of measurement plan.

4. Obtainment of approval from all parties pertaining to the conduction of measurement experiments at the sites listed in the measurement plan.
5. Thorough testing and calibration of all measurement equipment, before beginning field measurements.
6. Establishment of dates for the acquisition of measurement data at the various application sites.
7. Arrangement of appropriate transport for measurement equipment to measurement sites. This would require University approval for use of its vehicle.
8. Collection of sufficient measurement data, to perform brief analysis to ensure that results are both reasonable and consistent, with respect to theory and the physical environment. Any anomalies should be isolated, the cause determined, and appropriate corrective action taken.
9. Confirmation that all processes are recorded for subsequent reference.
10. Based upon brief analysis of measurement data, decision should be made to determine if more measurements are required to facilitate the creation of the proposed statistical models.
11. Development of statistical models.
12. Finalisation of report.

Suffice to say, the proposed development strategy for the project was particularly accurate, with all steps being followed and completed in the specified sequence. Without elaborating substantially, step 10 proved most useful, as the major finding in the preliminary measurements dictated that more data (increased sample size and data classification) was necessary to fully describe the characteristics of noise produced by microwave ovens.

3. PROPAGATION

Before delving into the details of the project and background noise specifics, it is important to clarify the general characteristics of microwave propagation, and to consider the phenomena that contribute to its degradation. Such an understanding will serve to enhance the clarity of the discussion of background noise, as well as the general report content. I stress that this is a brief analysis, with only the fundamental ideas conveyed, as it is beyond the scope of this report to consider in detail, the characteristics of microwave propagation.

3.1 SYNOPSIS

Study of line of sight paths (an inherent and restrictive characteristic of microwaves, due to short wavelengths being unable to effectively penetrate solid objects) first began with the introduction of FM systems in the early 1950's. Usually, FM systems are adversely affected by loss of power at the carrier frequency, but relatively unaffected by loss of signal in only one of the sidebands. In contrast, a spectrally efficient radio frequency signal does not have redundant information in its sidebands. Consequently, the selective loss of some of its frequency components can affect the detectability of the received signal.

Under many propagation conditions, the loss or gain of signal strength due to the atmosphere, is uniform across the radio channel bandwidth. In these cases, the approaches developed for the FM systems are equally applicable to digital radio signals, or any other systems involving microwave transmission. However, when the signal loss imposed by the atmosphere varies across the frequency band, the channel is said to be experiencing *selective fading*.

We begin this discussion with an overview of electromagnetic waves, and then an elementary description of propagation in an ideal atmosphere. This will provide the catalyst, and form the basis for further analyses of the significant phenomena that can impair propagation performance.

3.2 ELECTROMAGNETIC WAVES

When electric power is applied to an electronic circuit, a system of voltages and currents is set up, with certain relations governed by the properties of the circuit itself. In a similar manner, any power escaping into *free space*, is governed by the characteristics of free space. If such power is intentionally allowed to escape, it is said to have been *radiated.* It is then free to propagate in space in the shape of what is known as an electromagnetic wave (referred to as microwaves at microwave frequencies). Electromagnetic waves are energy propagated through free space at the velocity of light, which is approximately 300 metres per microsecond.

An important relation of electromagnetic waves, is the *power density.* The power density is defined as radiated power per unit area. This well published relationship is quoted by Kennedy and Davis (1993, p.225) as :

$$P = \frac{P_t}{4\pi r^2} \tag{1}$$

where :

r = distance from an isotropic source.

P_t = transmitted power.

From this relationship, it follows that power density is reduced to one quarter of its value when distance from the source is doubled. This is known as the *inverse square law of radiation.* A typical description of this law is given by Ippolito (1986, p.13), whereby "the power density of a radiowave propagating from a source is inversely proportional to the square of the distance from the source."

Finally, since no interference or obstacles are present in *free space* (defined later), electromagnetic waves will spread uniformly in all directions from a point source. The wavefront is thus spherical, as shown in the cross sectional representation of Figure 1.

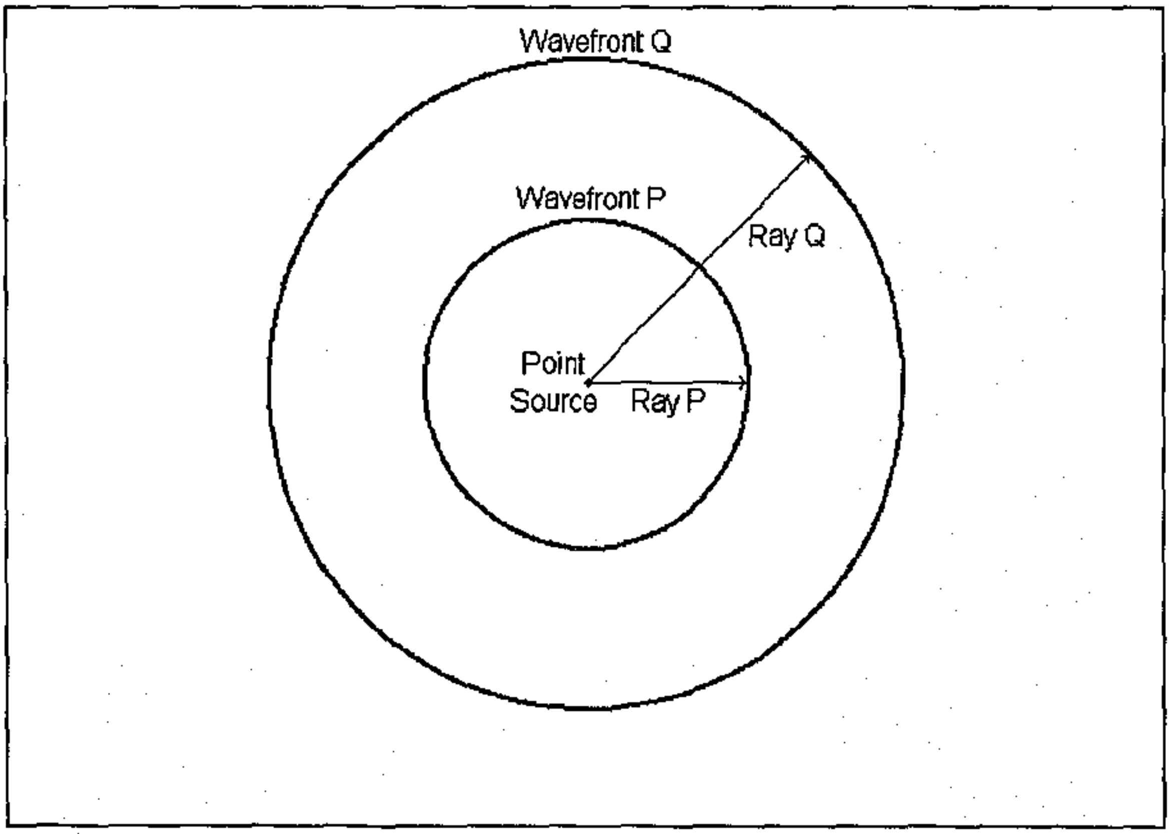

Figure 1 Spherical Wavefronts

To simplify this description even further, consider the description given by Kennedy et al. (1993, p.224); "*rays* are imagined which radiate from the point source in all directions. They are everywhere perpendicular to a tangential plane of the wave front, just like the spokes of a wheel."

Polarisation :

The polarisation of a radiowave is determined by the orientation of the electric and magnetic field vectors at a fixed point in space. A *linearly polarised wave* is a wave whose electric and magnetic field vectors always lie along fixed directions at a point in space as a function of time. The direction of the electric field vector determines the sense of the linear polarisation, ie., horizontal, vertical, or at a specified angle, with respect to a local reference.

A *circularly polarised wave* is a wave whose electric and magnetic field vectors rotate at the rate of the wave frequency and describe a circle at a fixed point, as a function of time. The sense of the circular polarisation, either clockwise, or counter-clockwise, is determined by the direction of rotation of the electric field vector as seen by an observer looking in the direction of travel of the propagating wave.

An *elliptically polarised wave* is a wave whose electric and magnetic field vectors rotate at the rate of the wave frequency and describe an ellipse at a fixed point, as a function of time. The sense of the elliptical polarisation is defined in the same way as for circular polarisation.

3.3 EFFECTS OF THE PROPAGATION MEDIUM

3.3.1 FREE SPACE PROPAGATION

According to Kennedy et al. (1993, p.223), "free space is space that does not interfere with the normal radiation and propagation of radiowaves." Therefore, it has no magnetic or gravitational fields, no solid bodies, and no ionised particles. Aside from the fact that free space is unlikely to exist anywhere, it certainly does not exist in the area of concern; near the Earth. However, the concept of free space is used because it simplifies the approach to wave propagation, since it is possible to calculate the conditions if the space were free, and then *predict the effect of its actual properties*, in the instance of typical impairments. In addition, and with particular relevance to this project, propagating conditions sometimes do approximate those of free space, and this is particularly so at frequencies in the UHF region (0.3-3 GHz).

The propagation of signals on line of sight microwave radio paths is affected by both the atmosphere, and the intervening terrain, whether it be landscape outdoors, or building topologies indoors. The reference for describing propagation effects is the free space transmission loss. According to Ivanek (1989, p.124), "this is the loss that would occur if the antennae were replaced by isotropic antennae located in a perfect dielectric, homogeneous, isotropic and unlimited environment, with the distance between the antennae being retained." This relationship is restated by Ippolito (1986, p.14) to be :

$$L_{bf} = 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad (2)$$

where :

d = path length

λ = wave length.

In free space, the energy is assumed to propagate from the transmitting antenna to the receiving antenna, along a single ray path. This is known as the *direct ray* path, and an illustration derived from Ippolito (1986, p.15) is presented in Figure 2.

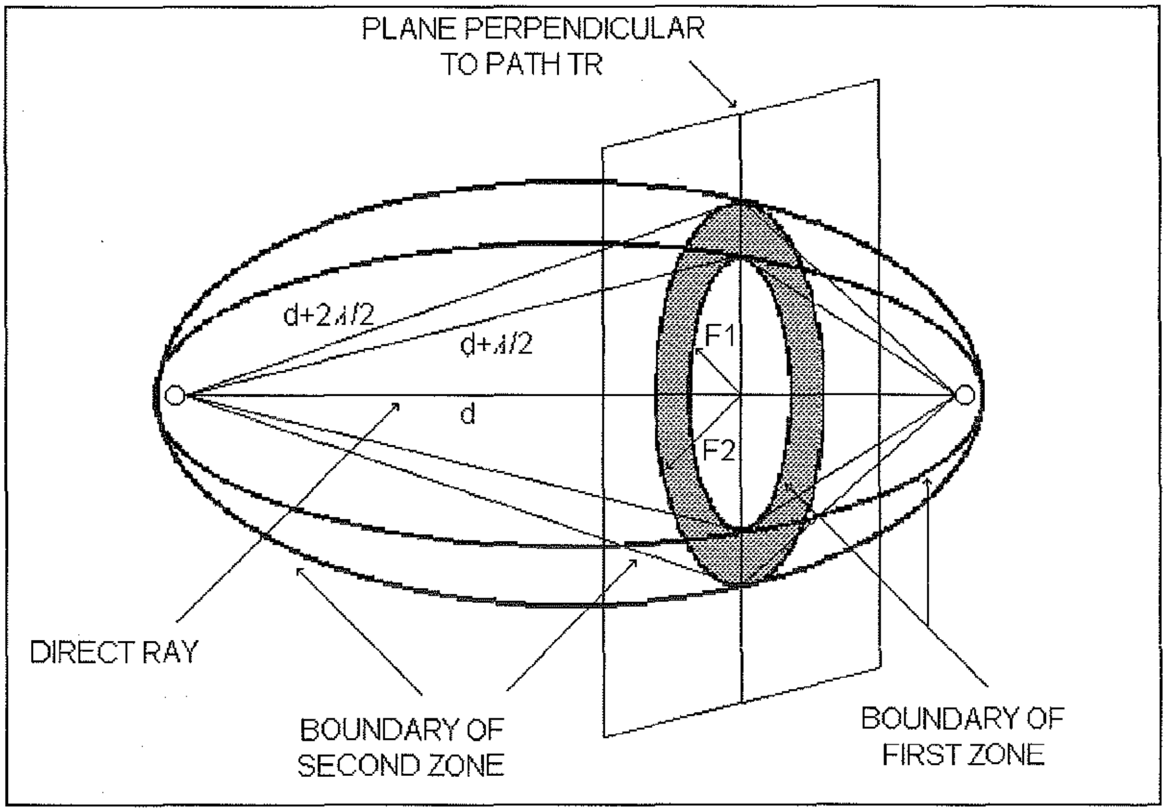

Figure 2 Line of Sight Path Showing Direct Propagation Ray and First Two Fresnel Zones

The effects of terrain or topology features on propagation conditions are usually related to the geometric position of these features with respect to the Fresnel zones of the path. While it is beyond the scope of this report to delve into Fresnel zones in great detail, an understanding of them is essential to considerations of path clearances. For instance, "since about half of the signal energy reaching the receiving antenna passes through the first Fresnel zone, obstructions that do not intrude into this zone cannot significantly alter the level of received signal" (Ivanek, 1989, p.124).

The first Fresnel zone is the region of space that contains all two segment paths that have a composite length exceeding that of the direct path by less than half a wavelength, $\lambda/2$. Clearly, the boundary of the first Fresnel zone is an ellipsoid; higher order Fresnel zones are defined in a similar manner. Thus, the second zone contains all those points that define two segment paths for which the length is greater than the direct ray path by more than $\lambda/2$, but less than $2\lambda/2$. "Hence, the Fresnel zones form a nested set of ellipsoidal shells" (Ivanek, 1989, p.125).

3.3.2 PROPAGATION IN A WELL MIXED ATMOSPHERE

When propagation near the Earth's surface is examined, several factors which did not exist in free space, must be considered :

1. Waves will be reflected by the terrain and buildings, as well as the general obstacles encountered in the propagation path.
2. They will be refracted as they pass through layers of the atmosphere which have differing densities, or differing degrees of ionisation.
3. Electromagnetic waves may be diffracted around particular objects.
4. Waves may also be absorbed by different media.
5. Waves may even interfere with one another, when two waves of the same source meet after having travelled by different paths.

This last point (5), in conjunction with the first point (1), is colloquially referred to as *multipath fading*, and is probably the most serious hindrance to propagation proceedings of indoor microwave LAN's. Lets now examine these phenomena in more detail.

Multipath Fading :

There is much similarity between the reflection of light by a mirror and the reflection of electromagnetic waves by reflective surfaces. In both instances, the angle of reflection is equal to the angle of incidence, as illustrated in Figure 3.

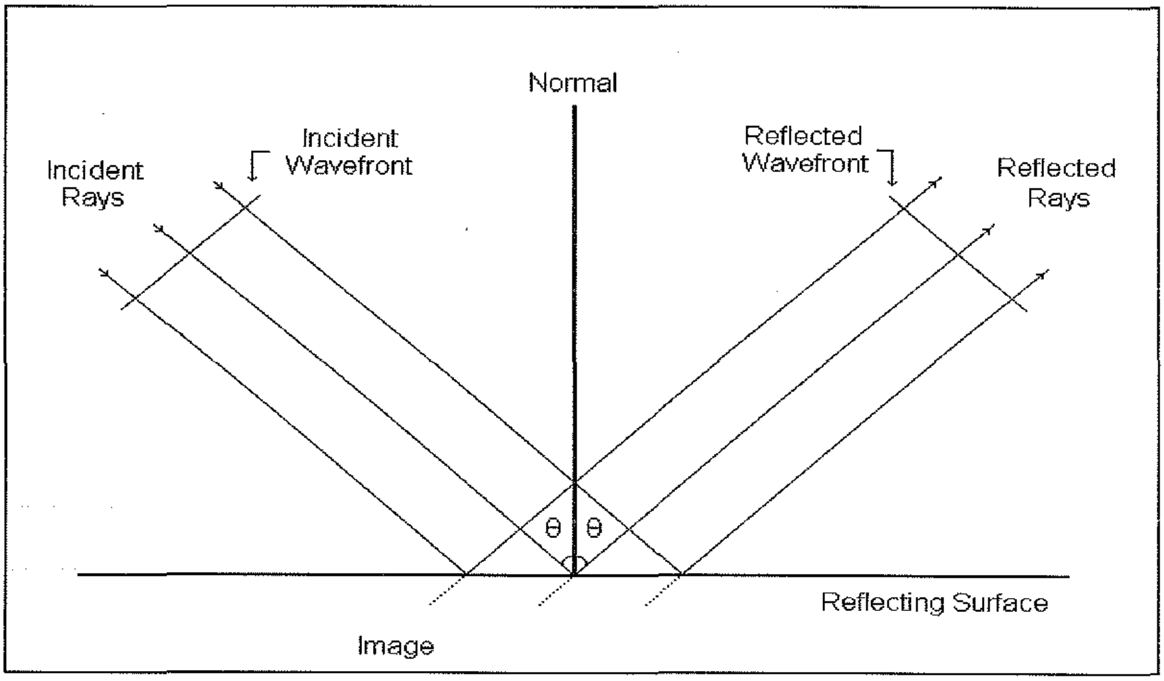

Figure 3 Reflection Of Waves

Again, as with the reflection of light, the incident ray, the reflected ray and the normal at the point of incidence are in the one plane.

Probably the most significant similarity can be drawn from the following example. If you are standing in front of a mirror, and there is a mirror behind you also (typical situation is a hairdressing salon), not only is there a large number of images present, but also their brightness is progressively reduced.

This is due to some absorption at each reflection; this also happens with radio waves.

Lets now examine multipath fading, as specific to communication systems. When a signal is transmitted through a channel, it often experiences reflections, as described above. This occurs whether the transmission is confined to a wire, or is in free space. It the wave reflects from some interface or object, and then reaches the receiver, it experiences a longer path than the direct path from the transmitter to the receiver. Therefore, the reflected signal is delayed relative to the direct path transmission. This results in the received waveform being a summation of the transmitted signal and "various weighted time shifts" (Roden, 1988, p.215) of that signal. This phenomenon is known as *multipath*, or *echo*. If the transmission takes place only over two major paths (one direct and one reflection), it is referred to as *specular multipath*. On the other hand, if there are multiple reflections with differing delays, the multipath is known as *diffuse*. A pictorial representation illustrating three paths of transmission is presented in Refer Figure 4.

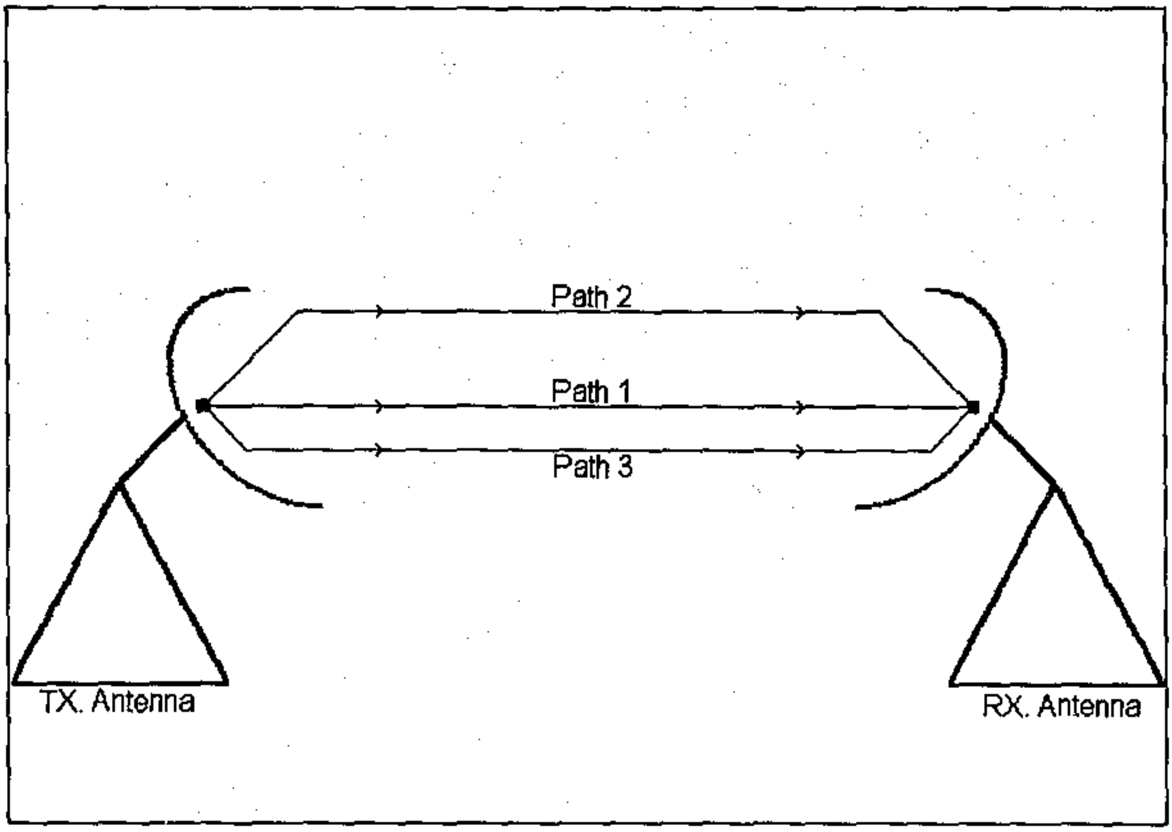

Figure 4 Multipath Fading

Multipath leads to *inter-symbol interference*, since the delayed version of the waveform will extend into the next sampling interval, for digital systems. This multipath effect is well known and observed in television, where it manifests itself as *ghost images.*

A final note for multipath, is that the fading depends upon the relative positions of the transmitter and receiver, and may change in nature over a fraction of a wavelength. This is particularly so for microwave LAN's, as a result of the short wavelengths employed. That is, shifts in relative antennae positions of the order of 10 cm, will alter the effect of multipath, and the subsequent received signal level.

Refraction :

As with light, refraction takes place when electromagnetic waves pass from one propagating medium, to a medium having different density. This situation causes the wavefront to acquire a new direction in the second medium, which is brought about by a change in the wave velocity. The simplest case of refraction, concerning two media with a plane, sharply defined boundary between them, is shown in Figure 5. This diagram is derived from Kennedy et al. (1993, p.230).

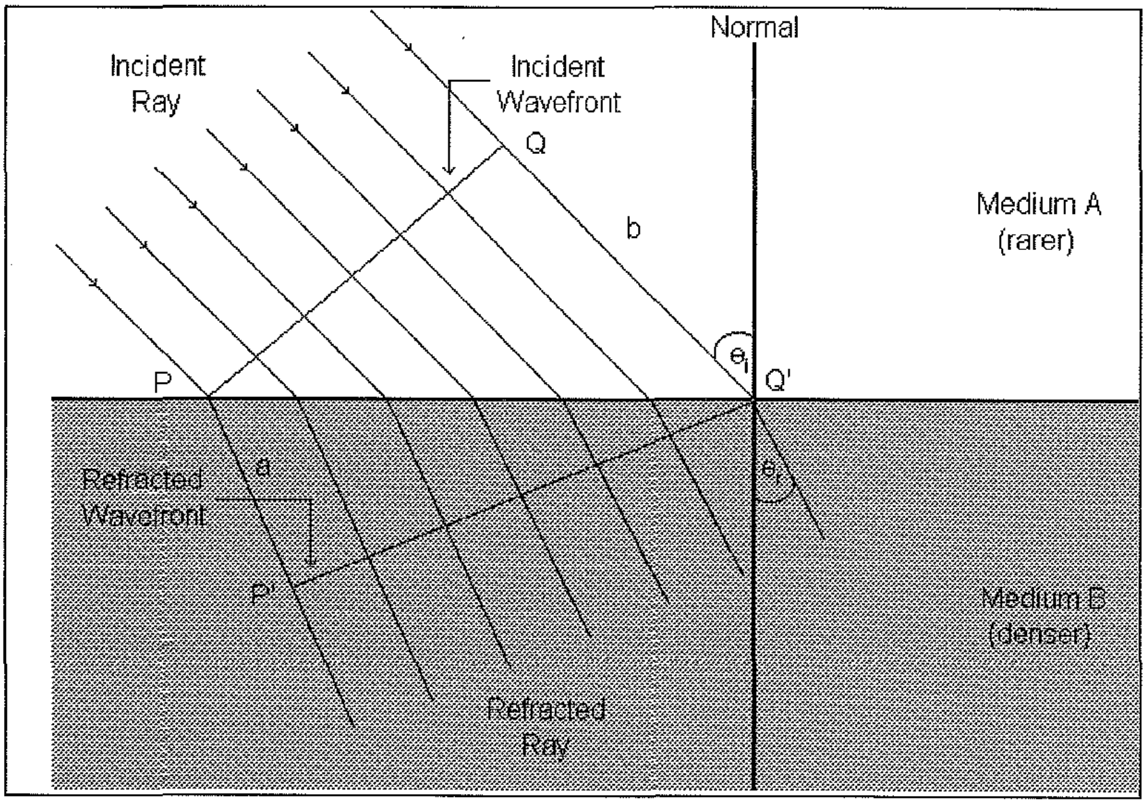

Figure 5 Reflection of Waves

In this situation, a wave passes from medium A to the denser medium B, and the incident rays strike the boundary at some angle other than 90°. The following is an extract from Kennedy et al. (1993, p.231).

Wavefront P-Q is shown at the instant when it is about to penetrate the denser medium, and wavefront P'-Q' is shown just as the wave has finished entering the second medium. Meanwhile, ray b has travelled entirely in the rarer medium, and has covered the distance Q-Q', proportional tc its velocity in this medium. In the same time, ray a, which travelled entirely in the denser medium, has covered the distance P-P'. This is shorter than Q-Q' because of the lower wave velocity in the denser medium. The in-between rays have travelled partly in each medium and covered total distances as shown; *the wavefront has been rotated.*

The relationship between the angle of incidence θ_i and the angle of refraction θ_r (Snell's Law), can be calculated with the aid of simple trigonometry and geometry, such that :

$$\frac{\sin\theta_r}{\sin\theta_i} = \frac{v_B}{v_A} \qquad (3)$$

where :

v_A = wave velocity in medium A

v_B = wave velocity in medium B

Diffraction :

Diffraction of radio waves is yet another property shared with optics, and concerns itself with the behaviour of electromagnetic waves, as affected by the presence of small slits in a conducting plane or sharp edges of obstacles (Serway, 1990, p.1073). In this case, the waves actually *bend* around obstacles, such that a receiver may pick up a signal with no line of sight path,

but with decreased magnitude of course. Diffraction was first discovered in the seventeenth century and put on a firm footing with the discovery of Huygen's principle fairly soon afterward.

According to Serway (1990, p.1074),

> Huygen's principle states that every point on a given (spherical) wavefront may be regarded as a source of waves from which further waves are radiated outwards. The total field at successive points away from the source is then equal to the vector sum of these secondary wavelets.

For normal propagation, there is no need to take Huygen's principle into account, but it must be used when diffraction is to be accounted for.

Diffraction is of importance to communications for two major reasons :

1. Signals propagated by means of space waves may be received behind obstacles, and other offending bodies that cause diffraction.
2. According to Kennedy et al. (1993, p.236), "in the design of microwave antennae, diffraction plays a major part in preventing the narrow pencil of radiation which if often desired, by generating unwanted side lobes."

3.4 PROPAGATION FACTORS

Before examining the major propagation factors that effect the characteristics of a radiowave, lets consider a few basic definitions not covered in Section 3.2.2, as well as brief descriptions of those in the preceding section. Most of these definitions are based upon the IEEE standard definitions of terms for radiowave propagation. These mechanisms are usually described in terms of variations in

the signal characteristics of the wave, as compared to the natural or free space values found in the absence of the mechanism.

Absorption. A reduction in the amplitude (field strength) of a radiowave caused by an irreversible conversion of energy from the radiowave to matter in the propagation path (IEEE Standard Definitions, 1977).

Diffraction. A change in the direction of propagation of a radiowave resulting from the presence of an obstacle, a restricted aperture, or other objects in the medium (IEEE Standard Definitions, 1977).

Refraction. A change in the direction of propagation of a radiowave resulting from the spatial variation of refractive index of the medium (IEEE Standard Definitions, 1977).

Scintillation. Rapid fluctuations of the amplitude and the phase of a radiowave caused by small scale irregularities in the transmission path(s) with time (IEEE Standard Definitions, 1977).

Fading. The variation of the amplitude of a radiowave caused by changes in the transmission path(s) with time. The terms fading and scintillation are often used interchangeably; however, fading is usually used to describe slower time variations, on the order of seconds or minutes, while scintillation refers to more rapid variations, on the order of fractions of a second in duration (IEEE Standard Definitions, 1977).

Multipath. The propagation condition that results in a transmitted radiowave reaching the receiving antenna by two or more propagation paths. Multipath

can result from refractive index irregularities, of from structural and terrain scattering on the Earth's surface (IEEE Standard Definitions, 1977).

Scattering. A process in which the energy of a radiowave is dispersed in direction due to interaction with inhomogeneities in the propagation medium (IEEE Standard Definitions, 1977).

Frequency Dispersion. A change in the frequency and phase components across the bandwidth of a radiowave, caused by a dispersive medium. A dispersive medium is one whose constitutive components (permittivity, permeability, and conductivity) depend on frequency (temporal dispersion) or wave direction, often referred to as spatial dispersion (IEEE Standard Definitions, 1977).

Many of the mechanisms described above can be present on the transmission path at the same time, and it is usually extremely difficult to identify the mechanism(s) which produce a change in the characteristics of the transmitted signal (Ippolito, 1986, p.19). This situation is illustrated in Figure 6, which indicates how the various propagation mechanisms affect the measurable parameters of a signal on a communications link (IEEE, 1977).

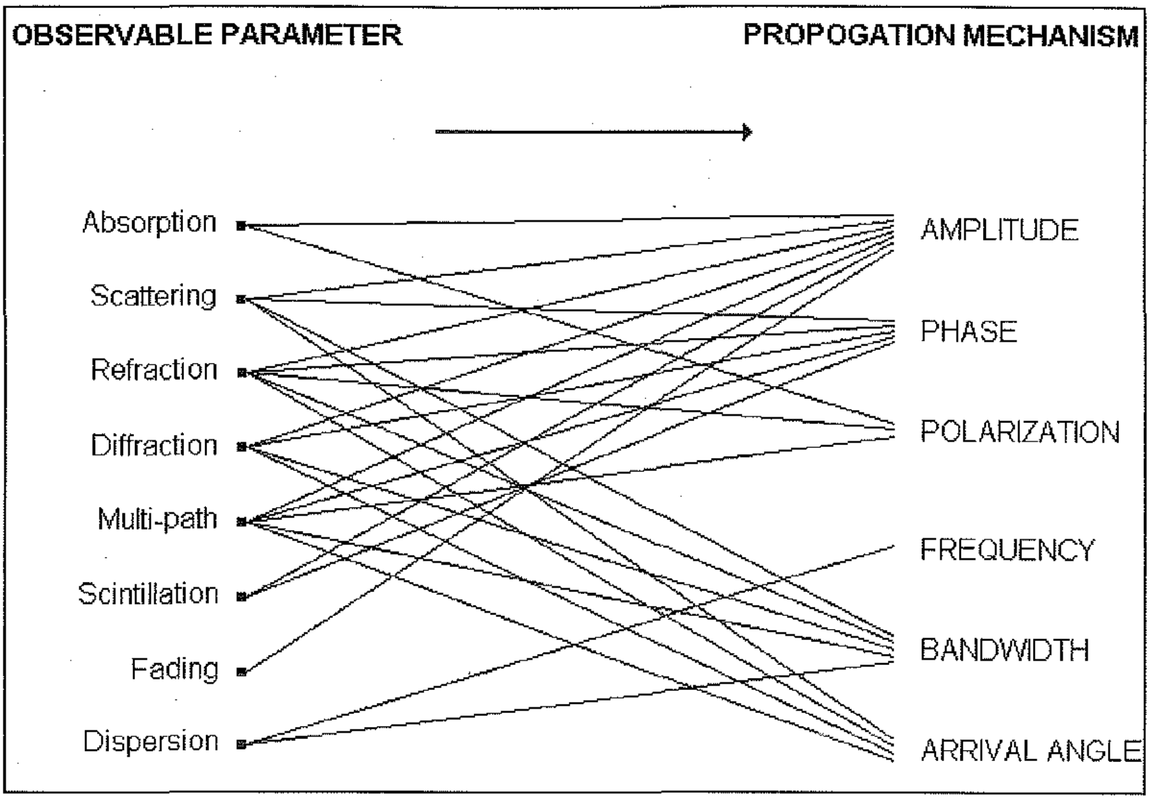

Figure 6 Radiowave Propagation Mechanisms and Their Impact on Signal Parameters

Each of the propagation mechanisms, if present in the path, will affect one or more of the signal parameters. Since all of the signal parameters, except for frequency, can be affected by several mechanisms, it is usually not possible to determine the propagation conditions from an observation alone. For example, if a reduction in signal amplitude is observed, it could be caused by absorption, scattering, refraction, diffraction, multipath, scintillation, fading, or a combination of the above.

Propagation effects on communications links are usually defined in terms of variations in the signal parameters. Hence one or several mechanisms could be present on the link. A reduction in signal amplitude caused by rain in the path for example, is the result of both absorption and scattering. Therefore, for the next section, it will be helpful to understand the distinction between the

propagation *effect* on a signal parameter, and the propagation *mechanisms* which produce the variation in that parameter.

3.5 FREQUENCY DEPENDENCE

Frequency plays a major role in the determination of the propagation characteristics of radiowaves. A brief, but non-explanatory classification of frequency dependence is as follows :

Propagation Factors Below 3 GHz :

The major propagation factors which can hinder radiowave communication at frequencies below 3 GHz, are :

- Ionospheric scintillation.
- Polarisation rotation.
- Group delay (propagation delay) - caused by free electrons in the radio path.
- Multipath fading and scintillation.
- Tropospheric refraction and fading.
- Radio noise - to be looked at greater detail in the next section.

Propagation Factors Above 3 GHz :

The major propagation factors which can hinder communications in the frequency bands above 3 GHz, are :

- Gaseous attenuation.
- Hydrometeor attenuation (rain, clouds, fog, snow, ice...).

- Depolarisation.
- Radio noise - examined next section.
- Angle of arrival variations - caused by refractive index variations.
- Bandwidth coherence.
- Antenna gain degradation - caused by phase de-correlation.

4. BACKGROUND NOISE

Generally, noise arises from unwanted signal energy being injected into the existing link, or from thermal noise generated from within the link. Signal behaviour within a channel is not nearly as well understood as it is within the transmitter and receiver, and for this reason we must study the effects that noise has upon a signal travelling within this prescribed channel.

There are numerous ways of classifying noise. One popular method is to subdivide the classification according to the type, source, effect, or relation to the receiver, depending upon the circumstances. I find it most convenient to divide noise into two broad groups: noise whose sources are external to the receiver, and noise created within the receiver itself. I make this distinction, as for the purpose of this study, we are essentially concerned with noise that is external to the receiver. Therefore, it is possible to disregard the noise due to active or passive devices in receivers (thermal agitation noise, shot noise, transmit-time noise, flicker, resistance and mixer noise, just to name a few), as it is removed from the scope of this project.

Noise generation can be attributed to four main areas :

1. Noise due to absorptive losses : attenuation and thermal noise generation as a result of atmospheric constituents.
2. Atmospheric noise.
3. Extraterrestrial noise : sunlight, cosmic noise and galactic noise.
4. Man-made noise.

Although all are significant, the most relevant to this study are categories two, three and four; atmospheric noise, extraterrestrial noise and man-made noise

respectively, because we are concerned mainly with noise that exists within a given channel, and not noise that is generated as a consequence of transmission. Background noise is a phenomenon that exists external to the communication system, and is not something that is usually generated as a result of the system interacting with the environment. As a result, category one will only be examined briefly, with the majority of effort being directed towards the other three categories.

In the diagram to follow, Figure 7, which was derived from Ippolito (1986, p.124), an illustration and summary of the minimum expected noise levels produced by sources of external radio noise in the frequency range applicable to the microwave band is presented. The components of this figure will be examined in greater detail, in the appropriate sections to follow. The noise is expressed in terms of a noise factor, F_a, in dB, restated by Ippolito (1986, p.125) as :

$$F_a = 10\log\left(\frac{t_a}{t_o}\right) \tag{4}$$

where :

t_a = equivalent noise temperature in °K

t_o = ambient reference temperature, set to 290°K.

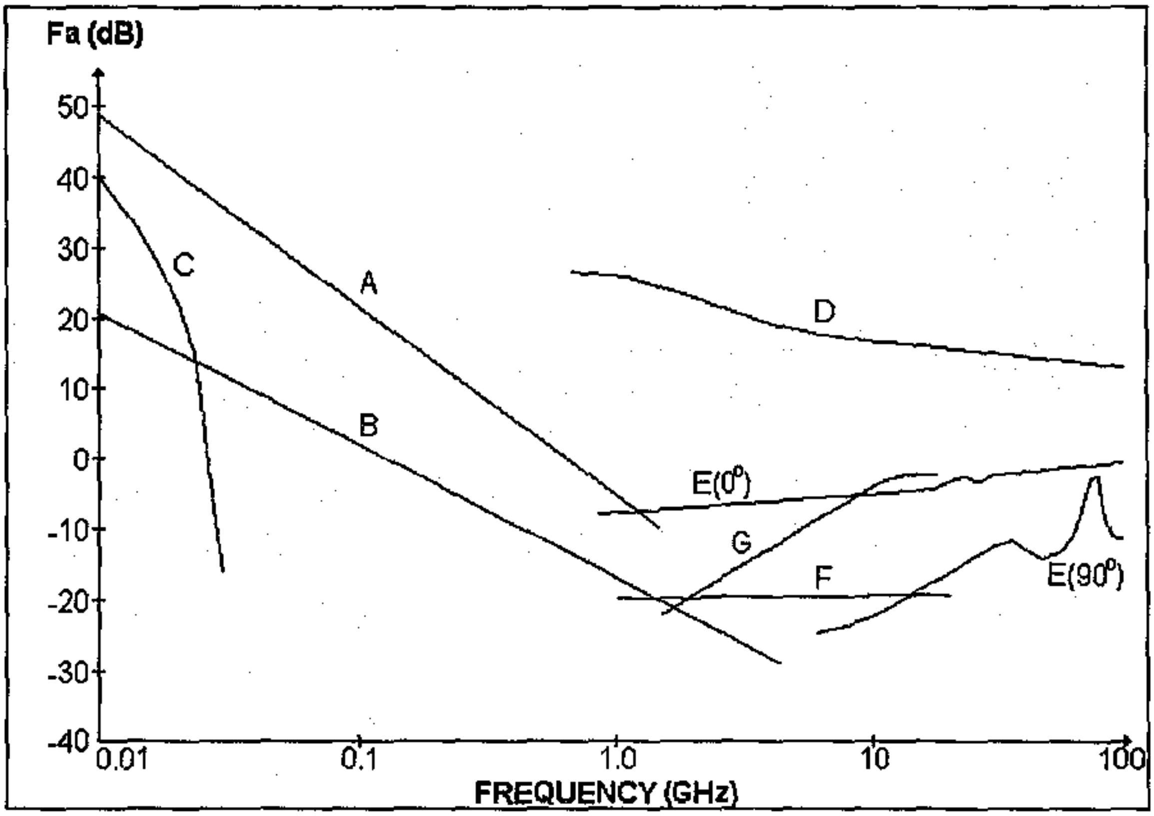

Figure 7 Minimum Expected External Noise from Man-Made and Natural Sources

Legend :

- A: External median business area man-made noise
- B: Galactic noise
- C: Atmospheric noise
- D: Quiet sun solar noise
- E: Sky noise due to oxygen and water vapour, with elevation angle[1]
- F: Cosmic noise
- G: Hydrometeor

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[1]Elevation angle refers to the direction of the ray line in accordance with the polarisation of the antenna. 0° is parallel to the horizon, while 90° is perpendicular to the horizon. The 0° level is higher because the antennas directivity remains in the densest part of the earths atmosphere, as opposed to the 90° level, which encounters progressively less dense medium as the height above ground increases. The peak in the 90° level around 90 GHz is due to absorption factors, whereby the dimensions of the water vapour etc, are similar to the wavelengths at these frequencies, so absorption is at a peak.

4.1 ABSORPTIVE LOSS NOISE (ATTENUATION)

Absorbing media within the earths atmosphere interact with electromagnetic waves via two effects : attenuation and thermal noise generation (Jackson, 1988). The specific frequencies at which these media radiate directly corresponds to their absorption bands. The sources of absorptive losses present within the atmosphere include rain, atmospheric gases and clouds.

Of particular relevance to the microwave bands in question, these sources are usually only of substantial significance at frequencies above 10 GHz (Couch II, 1993, p.13). Therefore, although not documented as a major concern, because of the proximity to the frequency band of significance, some consideration to absorptive losses must be given. According to Ivanek (1989, p.135), "rain is the most significant atmospheric phenomenon (other than refractivity effects) which can affect the propagation of microwave signals on line of sight paths." However, rainfall is unlikely to be of significance to microwave LAN's because of the predominantly indoor operational environment, but oxygen and water vapour are of relevance, though only minimally because of the inherently short transmission distances required for indoor communications.

The thermal noise temperature (T_{noise}) of an absorptive medium is related to the attenuation imposed by the medium; for example, Jackson (1988) states the relationship to be :

$$T_{noise} = T_m\left[1 - \frac{1}{L}\right] \quad (5)$$

where :

T_m = mean path temperature (^0K) through the medium.

L = attenuation of the medium.

The effect of multiple instances of absorptive loss on the total temperature is not additive as might be expected. Instead, the noise produced by each additional absorptive medium is a function of the attenuation imposed by the preceding medium (Jackson, 1988).

4.1.1 HYDROMETEOR

The effects of precipitation on the transmission path are of major concern to microwave systems; especially those operating above 10 GHz. Precipitation can have many forms in the atmosphere. *Hydrometeor* is the general term referring to the products of condensed water vapour in the atmosphere, observed as rain, clouds, fog, hail, ice or snow. The presence of hydrometeors in the radiowave path, particularly rain, can (as mentioned in Section 3.3) cause major impairments to system performance. The primary loss mechanism at microwave frequencies according to Ivanek (1989, p.135), is the scattering of energy due to the raindrops absorbing the carrier signal. Such attenuation is related to the rain intensity, or *rain rate*. Since the dimensions of the raindrops are comparable to the wavelength in question, this loss only becomes significant at frequencies near or above 10 GHz. Therefore, it can be substantiated that hydrometeor effects will have little bearing upon the performance of wireless indoor LAN's.

The relationship between rain rate and specific attenuation (dB/km) can be approximated by a power law. For example, Ivanek (1989, p.135) states this law as :

$$A_{rain} = kR^{a} \qquad \textbf{(6)}$$

where :

R = average rain rate in mm/hr

k & a = frequency and temperature dependent constants respectively.

4.1.2 ATMOSPHERIC GASES

A radiowave propagating through the Earths atmosphere will experience a reduction in signal level due to the gaseous components present in the transmission path. Signal degradation can be minor or severe, depending upon frequency, path length, temperature, pressure, and water vapour concentration.

There are many gaseous constituents in the Earths atmosphere which can interact with a radiowave link. "The principal components of the dry atmosphere, and their approximate percentage by volume, are; oxygen 21%; nitrogen 78%; argon 0.9%; and carbon dioxide 0.1% - all well mixed to a height of about 80 km" (Ippolito, 1986, p.25). Water vapour is the principal variable component of the atmosphere, and at sea level and 100% humidity it constitutes about 1.7% by volume.

The principal interaction mechanism involving the gaseous constituents and a radiowave, is suggested by Jackson (1988) to be *molecular absorption.* The absorption of microwave radiation results from a quantum level change in the rotational energy of the molecule, and occurs at a specific resonant frequency or narrow band of frequencies. The resonant frequency of interaction depends on the energy levels of the initial and final rotational energy states of the molecule. In the 1-100 GHz band, only molecular oxygen and water vapour have observable resonant frequencies; oxygen has a series of absorption lines centred around 60 GHz, while water vapour has a single line at 22.235 GHz (Ippolito, 1986, p.26).

Ippolito (1986, p.33) goes into detail with respect to modelling atmospheric attenuation as a function of frequency and related parameters, but it is beyond the scope of this report to outline the specifics. In addition, the preceding material exemplifies the fact that atmospheric gases and the related molecular absorption will be of minimal significance to indoor wireless LAN's. However, if more in depth information is required, a consultation of the appropriate reference will yield the desired information.

4.2 ATMOSPHERIC NOISE

Atmospheric noise is a result of spurious radiowaves which induce voltages in transmitting and receiving antennae. The majority of these radiowaves come from natural sources of disturbance. They collectively represent atmospheric noise, and are generally called static.

Static is caused by lightning discharges in thunderstorms and other natural electrical disturbances occurring in the atmosphere. "It originates in the form of amplitude modulated impulses," (Kennedy et al., 1993, p.15), and because such processes are random in nature, it is spread over most of the radio frequency spectrum.

Atmospheric noise consists of spurious radio signals with components distributed over a wide range of frequencies. It is propagated over the earth in the same way as ordinary radiowaves of the same frequencies, so that at any point on the ground, static will be received from all thunderstorms, local and distant. The static is likely to be more severe but less frequent if the storm is local. A particular characteristic of static worth noting, is that field strength is inversely proportional to frequency.

Kennedy et al. (1993, p.15) states that,

> This static noise consists of impulses, and these non-sinusoidal waves have harmonics whose amplitude falls off with subsequent increase in the harmonic order. Static from distant sources will vary in intensity according to the variations in propagating conditions. The usual increase in its level takes place at night.

Atmospheric noise becomes less severe at frequencies above 30 MHz because of two separate factors. First, the higher frequencies are limited to line of sight propagation. Secondly, the nature of the mechanism generating this noise is such that very little of it is created in the VHF range and above. Both of these factors are therefore relatively insignificant to this study, as the frequency range in question falls within this area of minimal severity.

4.3 EXTRATERRESTRIAL NOISE

Noise from extraterrestrial sources is also contributory to the overall noise temperature of a system. The strongest and most relevant of these sources is the sun. The sun radiates so many things in the direction of the Earth that we should not be too surprised to find that noise is noticeable among them.

Under normal *quiet* conditions, there is a constant noise radiation from the sun, simply because it is a large body at a very high temperature (over 6000°C on the surface). It therefore radiates over a very broad frequency spectrum which happens to include microwave frequencies. However, the sun is a constantly changing star which undergoes cycles of peak activity from which electrical disturbances erupt, such as corona flares and sunspots. Even though the additional noise produced comes from a limited portion of the sun's surface, it

may still be orders of magnitude greater than that received during quiet periods.

The solar cycle disturbances repeat themselves approximately every eleven years. In addition, "if a line is drawn to join these eleven year peaks, it is seen that a super-cycle is in operation, with peaks reaching an even higher maximum every 100 years or so" (Kennedy et al., 1993, p.16). Also, these 100 year peaks appear to be increasing in intensity. Since there is a correlation between peaks in solar disturbance and growth rings in trees, it has been possible to trace them back to the beginning of the eighteenth century. For example, past evidence has shown (Kennedy et al., 1993, p.16) that the year 1957 was not only a peak, but the highest such peak on record.

The solar noise temperature can be functionally derived from the "solar noise power density, which is a function of frequency" (Jackson, 1988).

Since distant stars are also suns and have high temperatures, they radiate radio frequency noise in the same manner as the sun, and what they lack in nearness they nearly make up in numbers which in combination can become significant. The noise received is called *thermal* (or *black-body*) noise, and is distributed fairly uniformly over the entire sky. This noise is colloquially termed *cosmic noise*.

Formally defined, "cosmic noise is the 2.7 °K background noise which is due to black-body radiation from the residual mass of the universe" (Jackson, 1988). The spectrum of cosmic noise is flat from 1.2 GHz to 20.8 GHz.

We also receive noise from the centre of our own galaxy (the Milky Way), from other galaxies, and from other virtual point sources such as *quasars* and

pulsars. This noise is known as *galactic noise*, and is formally defined as noise that is due to active galactic processes, including radio emissions from galactic gases as well as stars. It is only a factor below about 4.9 GHz.

This galactic noise is very intense, but it comes from sources which are only points in the sky. Two of the strongest sources, which were also two of the earliest discovered, are "Cassiopeia A and Cygnus A" (Kennedy et al., 1993, p.16).

As a summary, extraterrestrial noise is observable at frequencies in the range from about 8 MHz to those in excess of the gigahertz bands. Apart from man-made noise, it is the strongest component over the 20-120 MHz range. Not very much of it below 20 MHz penetrates down through the ionosphere, and of particular importance to this study (as its significance is minimal), it virtually disappears at "frequencies in excess of 1.5 GHz" (Kennedy et al., 1993, p.16), which is governed by the mechanisms generating it, and its absorption by hydrogen in interstellar space.

4.4 MAN-MADE NOISE

In general, the intensity of noise generated by human activity easily outstrips that created by any other source, internal or external to the receiver. Probably the most significant factor when considering the nature of man-made noise, is that it is extremely variable, and is difficult to analyse on any basis other than the statistical, which is what we intend to traverse.

The man made interference environment is the composite emission from four classes of human produced radio noise sources :

1. Coherent transmitters - greatest intensity.
2. Restricted radiation devices.
3. Industrial, Scientific and Medical equipment's.
4. Incidental radiation devices.

4.4.1 COHERENT TRANSMITTERS

According to Skomal (1978, p.1) :

> The noise class of greatest intensity consists of coherent transmitters used in the broadcast services; in the aerospace, land, and maritime mobile-radio services; in fixed point communication services; for radio navigation and position determination; for the transmission of standard time, standard frequencies, radio telemetry, and control signals; and in meteorological monitoring and observation.

Interference arising from out-of-band emissions of coherent transmitters, exists as the major wireless communication electromagnetic compatibility problem, because of its great potential for reception disruption. Such interference is a well researched and published area, and as a result a large and varied technology base exists, that is dedicated to minimising the adverse effects of coherent emissions upon sensitive receivers.

In nearly all instances, the level and variability of coherent interference is specifically related to the number and types of transmitters and receivers, and the nature of the transmission environment. Consequently, the man-made noise environment that arises from complexes of coherent transmitters is locally implementation unique and not amenable to a generalised solution; rather it requires specific treatment.

4.4.2 RESTRICTED RADIATION DEVICES

Restricted radiation devices are permitted to function without licensing constraints, and to produce moderate radiation fields within a limited area. In addition, restricted radiation devices often transmit modulated carrier frequencies, and therefore generate a typically broad interference spectrum. Examples of restricted radiation devices include short range radio control transmitters, and proximity-radio signposts, as employed in automatic vehicle location systems (Skomal, 1978). Furthermore, microwave ovens fall into this category.

Such devices are usually classified into two sub-groups; (1) low power communications devices such as radio controlled door openers, and (2) field disturbance sensors such as radio frequency intrusion sensors. Any defined member of either sub-group is prohibited from operating if it generates harmful interference to any radio service.

Because the locations of restricted radiation devices are uncontrolled, their radio emissions are geographically undifferentiable from the noise produced by the third and fourth classes mentioned previously (Skomal, 1978). Therefore, classes two, three and four coalesce to produce the ***composite, incoherent radiated noise fields***, as found in most urban environments.

4.4.3 INDUSTRIAL, SCIENTIFIC AND MEDICAL EQUIPMENT'S

Industrial, scientific and medical equipment's (ISM) that are functionally dependent upon the radiation of power have been provided with several allocations in the radio spectrum within which each may operate without restriction, contingent upon the exercise and principles of good design

practices that minimise the radiated fields. Because wireless microwave LAN's operate within a subset of these ISM bands, if such ISM equipment is within propagational proximity of the wireless networks, then the issue of interference must surely be of great concern.

ISM equipment with an operating frequency confined to one of the allocated bands is prohibited by law from adversely affecting the operation of authorised radio equipment in other portions of the spectrum. Because the out-of-band emissions of ISM equipment are diverse in modulation characteristics and signal level, much of the interference produced passes unnoticed into the ***composite noise*** environment of an urban area. "As licensing permits substantial latitude in the selection of the central operating frequency, ISM emissions may extend over many decades of the radio frequency spectrum" (Skomal, 1978, p.3).

A wide variety of industrial equipment exists that utilises radio frequency energy to perform their desired functions. All manufactured examples of these equipment's do not necessarily generate intense radiation fields, but sufficient numbers do so, to warrant attention. Dielectric or plastic processing apparatus, electric ovens, induction heating facilities, radio frequency welding and soldering tools, and electric discharge metal machining devices are production line machines that have received specific examination in the past, because of the inherently high levels of their radio frequency emissions. For example, radiated interference from dielectric and plastic processing apparatus is characterised by a "line spectrum containing an intense fundamental frequency component lying in either the HF or low VHF band, plus a harmonic spectrum whose amplitudes remain appreciable for frequencies well into the UHF band.

The largest sources of radiated noise among medical related electrical equipment are radio-diathermy machines. Such instruments are functionally similar to the dielectric heating equipment used in industrial fabrication and material processing. In these devices, radio frequency oscillators, either pulsed or continuous wave, provide the power needed to induce body tissue heating, which for diathermies range from 50 to 1000 W.

4.4.4 INCIDENTAL RADIATION DEVICES

Incidental radiation devices, the most common and troublesome encountered of which are automotive ignition systems and electric power lines, comprise the fourth class of human produced radio noise sources. For this class, the radiation of electric energy is unnecessary to the successful performance of the equipment. Typically, the radiation occurs because it is *less expensive for the manufacturer to accept its presence than to suppress its emission.* Prevailing incidental noise sources may produce broad band radiation arising from :

1. Impulsive current surges present in systems such as automotive ignition circuits.
2. Gas discharges and insulating film breakdown between high potential points, such as on power line supporting elements, collectively known as "gap breakdown noise" (Skomal, 1978, p.3).
3. General electrical appliances.

4.4.4.1 Automotive Noise

Impulsive noise from motor vehicles is generated by the ignition system, the battery charging circuitry, accessory motors, electric warning devices, and starter motors. Certain auxiliary devices, depending upon their design, may

also emit noticeable levels of unintentionally generated noise. However, because the operational duty of warning devices, accessory, and starter motors is extremely low, their contribution to the total automotive noise emission is negligible. It is primarily the ignition system of petrol engine vehicles and the battery charging components that are the major contributors to the emitted noise. Furthermore, since a battery circuit operates at a very low voltage, radiated noise intensity from generators and charging components is low, as long as the elements have not seriously deteriorated. Thus, the ignition system of a petrol engine remains as the only source of high potential and current functioning continuously during vehicle operation. Radiation produced by the presence of high pulse currents and voltages in cabling and at points of ignition circuit discontinuity are the primary source of automotive radio noise.

4.4.4.2 Electric Power Generation and Transmission Line Noise

Radio noise arising in electric power production, conversion and transport facilities, occurs within the spectral range extending from the fundamental generation facility, usually at 50-60 Hz, into the UHF range. Throughout this frequency interval, the radio noise intensity in the immediate vicinity of power transport facilities (at distances of 100 m or less) arises from one or both of the two types of noise sources, *gap breakdown* and *line conductor corona*. Either source emission level may be comparable to or greater than the noise levels of other man made noise sources. Furthermore, the resulting radiation may exceed atmospheric noise levels between sunrise and sunset when the daytime noise minimum usually occurs, which is related to the diurnal specification presented in Figure 8. "Levels of incidental radiated noise comparable to those observed on transmission and distribution lines and arising from identical causes originate from power conversion facilities such as local transformer substations" (Skomal, 1978, p.75).

The distance attenuation of radio interference field strength from any facility demonstrates a dependence upon separation distance *d*, which is proportional to d^{-n} where the range of *n* is $1 \leq n \leq 3$. The upper limit of *n* occurs for the smallest values of *d*, resulting in a rapid change of radiated field strength in the facility vicinity. At large values of the factor $\frac{2\pi d}{\lambda}$, where λ is the wavelength of the observation frequency, the exponent *n* assumes its lower limit of 1, remaining at this value for separation distances comparable to 1.5-2 km, depending upon the elevation of the noise source, and the topography. Although noise radiations from electric power generation, transformation, and transport facilities are measurable at separation distances in excess of 1.5 km for both fair and foul weather conditions, the resulting levels will usually be masked in metropolitan areas by natural and other man-made incidental noise sources.

The relative importance of the three types of electric power facilities as sources of man-made noise is established by their characteristic radiated field intensity and the prevalence of each. The existence of extensive power transport networks in all industrialised countries, places transmission and distribution lines ahead of power generation and transformation facilities as the principal electric power incidental radio noise emitter, and not industrial indifference toward improving the technology of power line noise suppression. Power transformation facilities which, because of their numbers and their common occurrence in metropolitan areas, are second only to power transport as applicable radio noise sources.

What follows now, is a description of gap discharges and corona discharges on power facilities, which are the major noise sources found on all electric power facilities.

Gap Discharges on Power Facilities :

Gap discharge radio noise is produced by the rapid flow of electric current in the air-gap existing between two points of unequal potential occurring on electric power equipment. The points of unequal potential may occur at a myriad of locations, "between metal members at interfaces coated with contaminants or partial oxide layers, between ceramic insulators and metal supporting members, or between metal mounting bolts and wooden members" (Nigol, 1964).

The conditions for gap discharge breakdown are created either by induction coupling or by degradation in the isolation resistance of the line insulators. Mechanical damage, aging fractures, and accumulation of conducting surface contaminants produce a redistribution of the potential drop along the supporting structure between the circuit point of maximum potential and circuit ground. The potential at the base of the insulator rises in an alternating current system at the beginning of each half cycle of line frequency, producing a current flow either through or on a contaminated insulator surface. Between the insulator base and the circuit ground point, mechanically contacting parts, each member of which is intended to function at approximately ground potential, experience a total potential increase and a potential gradient increase as well, if an insulating electrical discontinuity exists at their interface. The insulating discontinuity may take several forms, "such as an oil or wood preservative film, an oxide or sulfide layer, resinous inclusions, paint layer, or air" (Skomal, 1978, p.77). When the discontinuity is air or a form of one of the possible insulating materials, a potential difference is created in an air filled pocket between the contacting members. In the presence of the potential gradient, free electrons and ions in the air pocket begin to migrate towards the oppositely charged surfaces.

If the potential gradient is sufficiently great, inelastic collisions occur between the charge carriers (primarily electrons) and the neutral molecules of the air gap material, resulting in the production of additional ions and electrons, which separate into oppositely charged clouds. As the number of inelastic collisions increases with rising potential gradient, the electron production rate derived from collisions and photon produced molecular excitations, approaches the rate at which the current carriers are removed from the airspace through the combined processes of attachment to neutral molecules, diffusion beyond the high potential region, and recombination with oppositely charged ions. A further increase in the potential gradient across the gap yields on average, more electrons per collision than are lost by attachment, diffusion, and recombination. "At this threshold, an avalanche chain reaction is initiated, resulting in a current surge across the air-gap between the members" (Nigol, 1964).

Radiation from the current surge is observed as radio noise, and gas expansion produced by localised air heating as the source of the accompanying audible noise. The current surge deposits charge neutralising ions on the gap members, which briefly reduces the gap potential gradient below the threshold value. Once the available supply of electrons and gaseous ions has been expended or substantially diminished, the gap potential gradient commences to rise, and the surge process is repeated.

Corona Discharges on Power Facilities :

"Corona discharge is also a threshold transition process that requires that a minimum potential gradient in the vicinity of a charged object be exceeded before the effect is manifested" (Nigol, 1964). The charged object need not be an electrical conductor; dielectric objects are quite capable of producing

radiating corona discharges, although the threshold electric field will not be the same. "Neither is the occurrence of corona discharge restricted to alternating current, as opposed to the direct current power facilities; both will exhibit corona produced noise for either positive or negative polarity" (Nigol, 1964). Of course, the electric field thresholds for initiating noise generating corona discharges are unequal for the two polarities.

Unlike gap discharge breakdown, which is always associated with the presence of two oppositely charged surfaces, corona discharge requires but a single charged object at sufficiently high potential, either positive or negative. As the potential of the corona source point increases, the high mobility free electrons in the vicinity are accelerated by the local electric field either toward or away from the point. When the source point is negatively charged, with respect to the zero potential reference surface, electron movement away from the point affects (through inelastic collisions with the air molecules) the creation of excited molecules, positive ions, and electrons. The molecular excitations emit ionising photons, which produce additional free electrons, and together with those created by inelastic collisions, generate an avalanche current, if the electron loss rates from the process of attachment, diffusion, and recombination are exceeded by the electron production rate. The net electron production rate is a direct function of the potential gradient at the source point. Onset of charge avalanching coincides with corona threshold attainment and initiation of both radio noise and visible spectrum emissions. Visible radiation, which is bluish, is confined to the immediate vicinity of the source.

4.4.4.3 Electric Appliance Noise

In modern commerce, a multitude of electrically powered equipment exist that are known to incidentally generate radio frequency radiation. Most of the

radiation emitted by such commercial equipment is of low intensity; consequently, few measurements have been performed or reported. However, several types of electrical equipment employed in metropolitan commercial activities are known as radiators of substantial radio interference. Special attention has been accorded to the investigation of signals from area illumination and advertising light sources (fluorescent and neon), radio controlled door openers, and electrified trains and buses.

Fluorescent lights in commercial and residential use are typically designed with tungsten wire electrodes, separated by the length of a light column filled with a gas mixture containing argon and mercury. Radio emission is generated concurrently with the establishment of an alternating current electric discharge produced by pulses of high potential current from the electrodes. Pulsed current flow in the ionised gas column generates radio frequency noise originating from the high current density region of the electrodes, and which may be augmented in hot cathode tubes, by random and impulsive emissions from the material defects occurring on one of the electrode heaters.

"Bright spot emissions, which may occur in hot cathode tube designs, arise from heater material defects that produce pulse emissions of very short duration, and associated increases in the high frequency radio noise component" (Skomal, 1978, p.172). Noise suppression in such instances is achieved by the addition of electrode shunt capacitors, and the use of radio shielding around the lamp enclosure.

Remote controlling of building and garage doors may be affected using a VHF to UHF radio signal, which is detected by a sensitive receiver coupled via a switch to an electric drive motor. The VHF and UHF receivers presently in use contain sufficient positive feedback to initiate input circuit oscillation upon

reception of the correct frequency. The receiver, after breaking into oscillation when its excitation threshold is exceeded, is driven non-linear; the current saturates, and the high frequency oscillations are temporarily quenched until the charge stored in the feedback network is dissipated. This *super-regenerative* action is reflected in the current variations present in the input circuit, which, because it is usually directly connected to the receiving antenna, gives rise to signal re-radiation into the surrounding space, thus becoming a source of radio noise. Although these receivers are tuned to respond to a single VHF or UHF band frequency, non-linear super-regenerative oscillations produce a distributed noise spectrum centred at the tuned frequency and extending several megahertz to either side.

4.5 CHARACTERISTICS OF UNINTENTIONAL NOISE

4.5.1 PREVALENCE AND GEOGRAPHICAL DISTRIBUTION

Unintentional Man-Made Noise can be considered to be an amalgamation of the characteristics of the interference produced by restricted radiation, ISM equipment and incidental radiation devices. "Unintentionally generated man-made noise has been observed beneath, on and above the surface in industrialised and urbanised areas" (Skomal, 1978, p.3). At sub-surface points, the noise signal produced by surface located sources is normally heavily attenuated by the soil, or other obstructing media. Therefore, the signal is usually very low under such circumstances. Where appreciable underground noise levels do occur (ie : underground mines), the sources can probably be traced to power distribution facilities and to generalised equipment within the subterranean infrastructure.

Surface distributions of unintentionally generated noise always coincide with the regional penetration of industrialisation and urbanisation, varying in proportion to the density of the major sources. Typically, the metropolitan noise maxima exist at the centre of an urban area coincident with the greatest concentration of either vehicular traffic or industrial facilities. With increasing distance from an urban centre, unintentionally generated noise decreases, although not necessarily in a uniform manner.

With particular relevance to wireless LAN's, localised concentrations of noise sources prevailing at suburban business centres and industrial facilities, perturb the inverse dependence of noise level upon urban centre separation distance.

In remote rural areas (with obvious limited application to wireless LAN's), large unintentionally generated noise levels occur near major roadways and electric power generation and distribution facilities. In addition, farm equipment, mainly petrol engine driven, raises the noise level of an otherwise uncontaminated region.

Finally, remote installations provided with transportation, electrification and construction equipment create localised man-made noise environments. Therefore, the existence of polar, desert, military and scientific research stations has extended the unintentionally generated man-made noise environment to all continents.

The dominant population of man-made noise sources, which produce the unintentionally generated noise of a metropolitan area, are located either at or within 100 m of the earths surface. The source radiation fields possess little directivity and, in conjunction with structure and surface reflections, cause the

noise to envelop the space above an urban area. The resulting noise levels over metropolitan centres are large even at modern aircraft cruising altitudes.

4.5.2 Spectral Distribution

Unintentionally generated noise of a metropolitan area may arise within any portion of the radio spectrum between the 30 Hz and upper GHz bands. The character of the noise waveform shows distinctive variations with spectral interval as the relative intensities of the sources that create the composite interference environment shift. "Impulsive emission patterns (that is, aperiodically occurring transients) are present throughout most of the spectrum with impulse widths and magnitudes noticeably greater at the lower frequencies" (Skomal, 1978, p.5). Fortunately, this therefore bears no relevance to our study. However, the trade-off is that the average occurrence rate of the largest pulses may indeed increase, as frequency increases.

With increasing frequency, composite unintentionally generated noise displays a decrease in peak electric field strength and average power. The spectral level variation is not uniform, and it arises, as do signal pattern changes, from dissimilar alterations in the emissions generated by the several noise source types coexisting in a particular environment.

4.5.3 Temporal Distribution

Temporal variations in unintentionally generated man-made noise in urban areas are traditionally observed to occur in synchronism with two cyclical processes; business activity and meteorological changes.

Business activity variations in automotive traffic density and numbers of operating industrial electrical equipment, gives rise to a periodic change in urban noise level. Figure 8 illustrates a typical noise level mapping relative to time of day. In the case of this study, this figure may well not typify the temporal characteristics of noise power for the frequency bands of interest. In fact, as further perusal will show, such temporal variation is remarkably different from this common distribution presented in Figure 8.

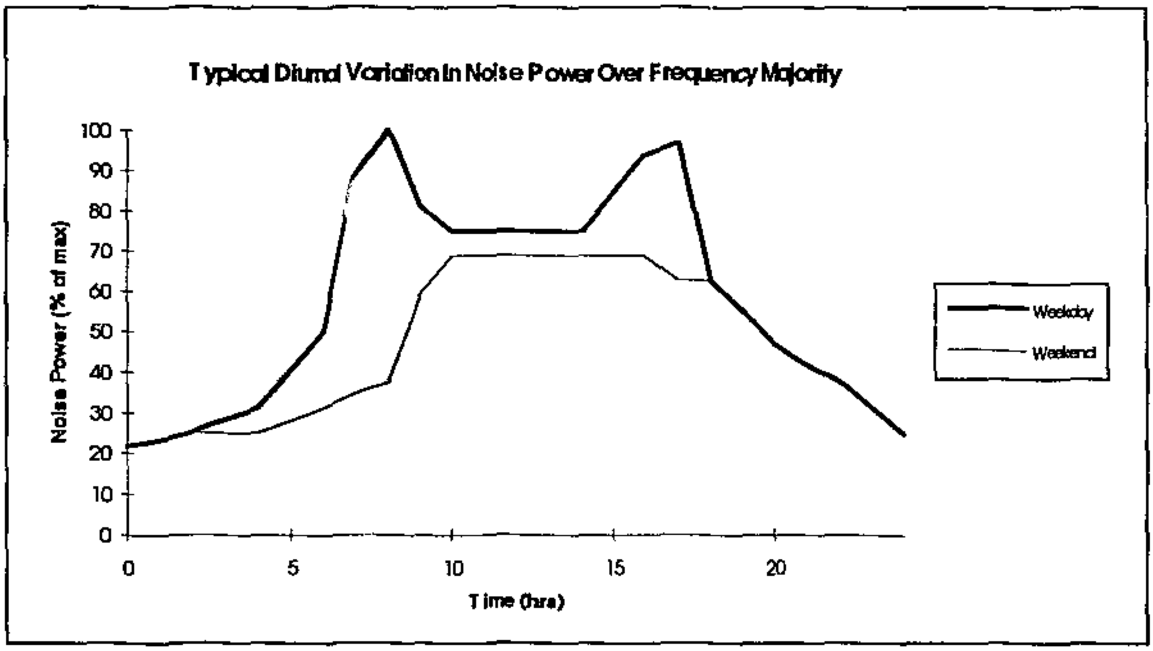

Figure 8 Typical Diurnal Variation of Incidental Noise Power (Skomal, 1978, p.6)

Meteorological produced changes in unintentionally generated man-made noise arise from the effects of rain, moisture and sunlight upon power distribution and transmission lines. Gap breakdown and corona discharge noise generation mechanisms are affected differently by the natural processes.

Gap discharge breakdown, requiring for its initiation a high potential between two electrically insulated points, is suppressed during rain and high relative humidity because of the short-circuiting action caused by the appearance of

water films on insulating surfaces and across miniature gaps in line supporting hardware.

Condensed droplets produce the converse effect upon corona discharges associated with high voltage transmission lines. The presence of water droplets resting on high potential conductors or falling in their immediate vicinity increases the electric field in the neighbouring airspace as a consequence of the dielectric field displacement occurring in the water. An increase in the point electric field of a conductor elevates both the corona discharge rate and radiated pulse rate. Upon cessation of a rain shower, high voltage lines normally display reduced interference levels caused by the cleansing action that has removed contaminant particles from the conductors and towers.

4.6 BACKGROUND NOISE SUMMARY

Examination of radio frequency radiation intensity, spectral distribution, and temporal variations in the major categories of the sources of radio noise, is necessary to the regulation and suppression of radio noise fields that can adversely affect the performance of sensitive wireless equipment; in this case, wireless microwave LAN's. The abundance and extensive distribution of all such sources, including noise due to absorptive losses, atmospheric noise, extraterrestrial noise, and the complex and diverse offender, man-made noise, necessitates a thorough study of the phenomenon of background noise.

The great abundance of noise sources in most metropolitan areas contributes significantly to the extension of their radiations well beyond the urban core. Geographically varying mixes of the dominant noise sources randomly produce appreciable location dependent changes in the total received noise level. In addition, the distinctive and contrasting spectra of the major noise classes

create a total background noise spectral pattern possessing a complex magnitude variation with frequency.

As mentioned above, the noise emission levels and temporal variance of these sources vary with frequency for the most important source types. The emission level frequency variation is unique to each category of sources and sufficiently disparate to produce a reordering of the dominant sources within different portions of the radio spectrum. It is possible however to provide an approximate ranking of noise emission intensity, which can be used as a useful guide for assessing the potential impact that the many known man-made noise sources may have upon a particular transmission system. This is illustrated in Table 1.

TABLE 1 : Ranking of Unintentional Man-Made Radio Noise Sources

1. Automotive Sources
   - Ignition circuitry
   - Alternators, generators and electric motors
   - Buzzers, switches, regulators and horns
2. Power Transport and Generating Facilities
   - Distribution lines
   - Transmission Lines
   - AC transformer substations
   - DC rectifier stations
   - Generator stations
3. Industrial Equipment
   - RF stabilised arc welders
   - Electric discharge machines
   - Induction heating equipment
   - RF soldering machines

Dielectric welder and cutting machines

Silicon control rectifiers

Circuit breakers / switches

Microwave heaters

General electronic office machines

4. Consumer Products

Appliance motors

Microwave ovens

Fluorescent, sodium vapour, and mercury vapour lights

Spurious emissions from citizen band AM transmitters

Electronic door openers

Television local oscillator radiation

5. Lighting Systems

Neon, mercury, argon and sodium vapour lights

Fluorescent light fixtures

6. Medical Equipment

Diathermy

7. Electric Trains and Buses

The most important factor that can be weaned from the analysis in section 4., is that a great majority of man-made sources of noise diminish in intensity as frequency increases. This is of particular relevance to this project (in the sense that they can largely be ignored), as the microwave bands under examination are towards the upper bounds of the radio frequency spectrum.

What remains to be seen, is exactly what sources of noise exist within the bands in question, and their relative intensities. It will be interesting to note

what effect taking measurements in various operating environments has on the background noise level.

Being able to accurately measure the level of background noise at various locations, and apply the appropriate statistical analysis will subsequently provide an array of mathematical models that can be used for general applications when attempting to analyse future and current wireless LAN topologies.

5. MEASUREMENTS

5.1 PLAN OVERVIEW

The measurement plan for this project, was based upon collecting and collating measurement data from various sites, that are viewed to be typical of appropriate application environments. The aim was to not only establish the contributory sources to the noise environment, by means of classification according to location, but also the background noise power levels present at various sites, and to further these findings by completing the appropriate statistical analyses (ie: mean, variance, standard deviation, etc..), so that accurate and relevant background noise models may be developed.

In an effort to effectively realise this plan, it was necessary to obtain sufficient measurements, to ensure a sufficiently large population of sample data that could subsequently warrant accuracy in the derived models. Such methodology would also pre-empt consideration to diurnal effects, such that one is able to account for temporal variations in measured background noise levels.

I also envisaged that measurements taken in a relatively clean environment, with respect to radio emissions within the band of interest, would be useful in determining to what extent man-made noise contributes to the level of background noise in urban environments. By establishing the minimum noise level generated by natural sources, this determination can be used as a reference model for other noise measurement scenarios, in which man-made noise is a significant factor.

Most importantly, it was necessary to follow the strict guidelines with respect to the measurement procedures being in accordance with published standard

measurement practices. If the results of this project are to be awarded merit from both internal and external bodies, it is important that all measurements obey these standards.

Delving into greater detail as to what is meant by standards, I proposed to and subsequently followed the guidelines as outlined in the following publication, which is a reference of the ANSI standard C63.4.

- Electrical and electronic equipment in the range of 9 kHz to 40 GHz - Methods of measurement of radio-noise emissions from low-voltage.

This document is a collection of material specifying measurement equipment to be used, the appropriate calibration procedures, and measurement techniques relative to a particular measurement strategy. A full referential listing of this document is indicated in the references.

It is worth illustrating at this point, that the antennae chosen for measurements only covered the 2.4-2.485 GHz band, as a result of antenna tuning. These antennae can still be used to explore the higher 5.5-5.585 GHz band (or lower as in the case of mobile telephony), and if they revealed the need for further investigation, then appropriate arrangements may be made to secure the relevant equipment. This procedure was in an effort to minimise costs, by only having to purchase an additional set of antennae to undertake the higher frequency measurements if deemed necessary.

In conjunction with the antennae, a spectrum analyser with appropriate frequency range was used, and a printer interface option was ordered and installed. I envisaged that this option would prove to be very useful in allowing

a simple but permanent recording of spectrum output, in addition to the internal memory storage capability of the analyser.

As a final note, before conducting measurements at the proposed sites as indicated in section 5.3, thorough in house testing of equipment was mandatory, as it ensured all equipment was functional, and appropriate calibration procedures could be undertaken.

5.2 MEASUREMENT EQUIPMENT

5.2.1 ANTENNAE

In determining the appropriate antennae needed to successfully undertake and complete the required measurements, it was decided that both omnidirectional and selective field measurements would be necessary.

The omnidirectional measurements primarily served to determine the actual background noise levels in the various operating environments, which is the essential data required in order to fulfil the requirements of the statistical analysis and modelling. Such measurements necessitated the use of an omnidirectional (colinear) antenna operating in the appropriate frequency band.

Selective measurements, utilising a directional (corner reflector) antenna, enabled the identification of the most intensive noise sources present in the various operating environments and within the allocated bandwidth. This procedure was typified by the selection of appropriate measurement sites. Such information proved most useful in determining what potential disruptive elements exist within the various operating environments of the allocated bandwidth, and to what extent. For offending devices determined through

selective measurements, it proved particularly useful to locate multiple instances of these devices, and determine the range of noise powers that they radiate, with respect to both frequency and time in collaboration.

The antennae chosen for this task, and their specifications are as follows :

Model : VO10-2325

Features :

- Omnidirectional.
- Vertical polarisation.
- Fibreglass Radome enclosed - reduces precipitation static.
- No assembly or tuning required.
- Ground driven element for lightning protection.
- Rugged construction, lightweight design.

Specifications :

Electrical		
Frequency Range	(GHz)	2.304-2.484
Gain (Midband)	(dBi)	10.2
Bandwidth for 1.5:1 VSWR	(GHz)	Full
Polarisation	Vertical	
Pattern	Refer Diagram	
Maximum Power Input	(Watts)	100
Lightning Protection	Direct Ground	
Termination	Type N Socket	
Mechanical		
Overall Length	(m)	1.5
Diameter	(mm)	48
Weight	(kg)	2.1
Radome Material	Fibreglass	
Support Pipe Material	Aluminium	
Effective Wind Area	(m^2)	0.62
Rated Wind Velocity	(km/h)	240
Shipping Weight	(kg)	5.0
Shipping Volume	(m^3)	0.005
Shipping Dimensions	(cm)	130 x 6 x 6

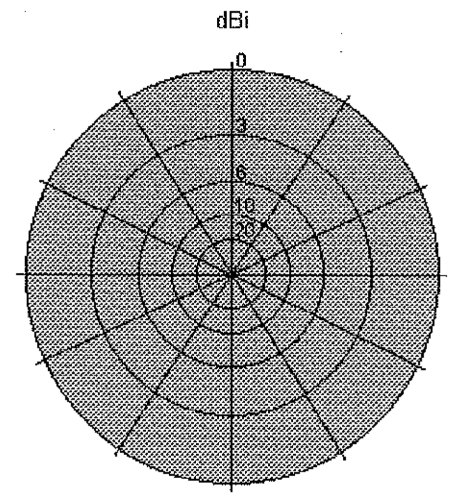

Figure 9 Radiation Pattern for VO10-2325 Antenna

Model : DRT 2415

Features :

- Broadband - suitable for diplexed and multi-coupled systems.
- High front-to-back ratio - reduces co-channel interference in multiple hop systems.
- Low side lobes - provide additional protection against interference.
- Tolerance to ice - impedance and gain parameters are largely unaffected by ice build up.
- Supplied dismantled to minimise transport cost.

Specifications :

Electrical		
Frequency Range	(GHz)	2.3-2.5
Gain	(dBi)	15
Bandwidth for 1.4:1 VSWR	(GHz)	Full Band
Polarisation	Horizontal or Vertical	
Pattern 3 dB Beam Width	(deg)	
E Plane		47
H Plane		55
Maximum Power Input	(Watts)	100
Front-to-Back Ratio	(dB)	>25
Crossed Polarisation	(dB)	>25
Lightning Protection	Direct Ground	
Termination	Type N Socket	
Mechanical		
Reflector Size	(m)	
Height		0.25
Length		0.37
Depth		0.25
Weight	(kg)	1.5
Radome Material	ABS	
Reflector Material	Aluminium	
Wind Loading Area	(m^2)	0.14
Rated Wind Velocity	(km/h)	200
Mounting Hardware	Suitable for mounting to 25-42mm Ø support pipe	
Shipping Weight	(kg)	2
Shipping Volume	(m^3)	0.011
Shipping Dimensions	(cm)	30 x 30 x 12

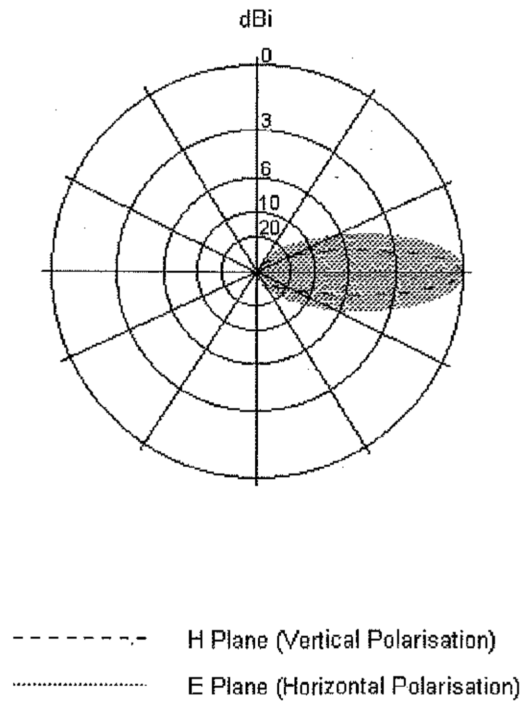

Figure 10 Radiation Pattern for DRT 2415 Antenna

The antennae are produced by **Radio Frequency Systems (RFS)**, and were ordered from **Hills Industries Limited : 10 Katanning Street Bayswater 6053**, the local distributor. The arrival date of the antennae was 15th August, 1995.

5.2.2 Spectrum Analyser

- Hewlett Packard Spectrum Analyser : Model # 8595E.
- Input frequency range : 9 kHz - 6.5 GHz.

5.2.3 Miscellaneous Equipment

Cables :

- 2 x 2m RG-213 Coaxial Cable.
  - These coaxial cables were used as *tails* for connection to the antennae, and the spectrum analyser. RG-213 was chosen because of its ease of use, thanks largely to its inherent flexibility, and the minimal cost associated with its purchase. The major drawback of this cable is its relatively high loss characteristics, but at lengths of 2m, this loss could be considered quite acceptable, at least relative to the gains of the antennae.
- 1 x 20m RG-213 Coaxial Cable.
  - This cable was chosen in the advent that longer lengths would be required at any given measurement location, due to factors such as topography, power availability, or any other circumstance that would render the 2m cables unsuitable.
- 1 x 2m LDF-450 Feeder Cable.
  - This cable was chosen in the advent that nett system gains were marginal, and a lower loss cable was required to maximise this gain.

Note : Cable calibration figures are given in Section 6.1.

Tripod Stands :

- Two tripod stands, similar to those used for photographic purposes, were employed to provide a secure and stable mounting position for the antennae. Inclusive with the tripods were mounting clamps and brackets.
  - The advantage of using these stands was that they provided an accurate means of altering the height of the antennae, in a manner that was repeatable. The stands also provided the avenue for a *hands free* measurement environment.

Plotter :

- The Hewlett Packard Plotter (Model # 7550 PLUS) was utilised in conjunction with the spectrum analyser to provide the hard-copy output of traces obtained at measurement sites.

Portable Power Supply :

- A portable power supply was utilised at Edgewater train station, where no mains power was available.

5.2.4 SETUP

5.2.4.1 Connection

As suggested, the measurement apparatus was fully portable, and only took a few minutes to prepare at any location. This was an extremely valuable and useful characteristic, considering the high degree of mobility that the nature of the measurements demanded.

The basic setup consisted of either the omnidirectional or directional antenna (at any instance) mounted on a tripod, providing a direct feed via the RG-213 coaxial cable to the spectrum analyser. A pictorial representation of this configuration is illustrated in Figure 11.

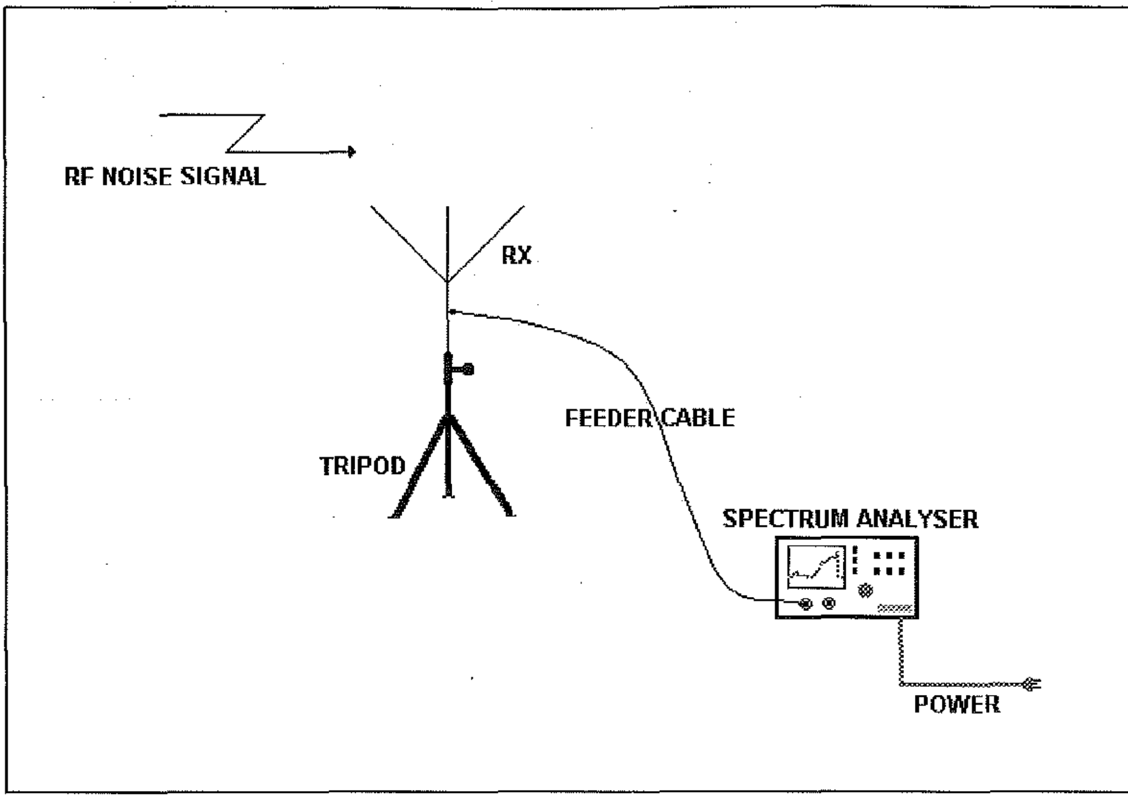

Figure 11 Setup Of Measurement Equipment

5.2.4.2 Spectrum Analyser Configuration

The parameter settings for the spectrum analyser were as follows :

Full Band Measurements (200 MHz) :

- Centre frequency : 2.4 GHz.
- Frequency Span : 200 MHz.
  - Start frequency : 2.3 GHz.
  - Stop frequency : 2.5 GHz.
- Resolution bandwidth : 100 kHz.
- Video bandwidth : 30 kHz.
- Sweep time : 200 ms.

- Scale : log10 dB.

Sub-band Measurements (10 MHz) :

- Parameters as above, except frequency settings. Frequency span was 10 MHz, with start and stop frequencies set according to sub-band of interest. All sub-band measurements were within the 200 MHz span, from 2.3 GHz to 2.5 GHz, as microwaves are published to radiate in the 2.35-2.5 GHz spectral range, according to Jahn and Lutz (1994). As an aside, I discovered that microwaves in general, radiate over a greater frequency range, with an extension in the lower range to 2.3 GHz.

Miscellaneous Measurements :

- Any miscellaneous measurements (mobile telephony, Pay TV), utilised the same parameter settings as the above instances, with the obvious exception of variations in frequency intervals.

5.3 MEASUREMENT SITES

The proposed measurement sites for this project, were chosen under the guidelines of convenience, with respect to access and proximity to the Joondalup campus of Edith Cowan University, as well as applicability to possible application examples. The sites are as follows :

- Edith Cowan University Joondalup Campus Library.
- Edith Cowan University Joondalup Campus Computing Centre.
- Whitford City Shopping Centre.
- Wilson's Engraving Works.

- Edgewater Electric Train Station.

As a result of preliminary investigations, additional measurements sites were considered and duly tended to, with respect to necessity and supervisory requests. These additional sites were :

- Edith Cowan University Joondalup Campus PABX Room.
- Mobile Phone Cellular Network Station.
- Pay TV location (Wanneroo Road and South Perth foreshore).

Letters requesting permission to enter premises and conduct the measurement practices were duly written and forwarded to the appropriate authorities, and are listed in the Appendices. May I digress for a moment, to say that it was truly encouraging to witness the immeasurable support provided by all persons and organisations in question, and to them I convey my utmost appreciation. (Letters of thanks were sent to all the above mentioned authorities).

5.4 MEASUREMENT PROCEDURE

5.4.1 PRELIMINARY MEASUREMENTS

The purpose of this phase of the project, was to initially determine the general characteristics of the noise prevalent within the band in question, as well as expose the most intensive noise sources. Such methodology required an investigation of all the above mentioned measurement sites (Section 5.4), to determine their relative worth and importance. This brief analysis could then be utilised to resolve the avenues of future effort, in terms of what environments need to be explored further, and in particular, how to further develop the characterisation of relevant noise sources.

In the instance of this project, as a result of the preliminary analysis, it was found that the major catalyst for subsequent effort, revolved around accurately characterising instances of microwave ovens, both in single and multiple operational environments. This decision was formulated because it was not only the major noise source evident within the band of interest, but its random nature and large spectrum coverage (relative to other sources) necessitated a comprehensive and thorough collation of sample data.

As a consequence, I considered both a single microwave oven in a logical and applicable operating environment (Edith Cowan University Joondalup Campus Staff Room), and multiple instances of microwave ovens, also within the bounds of a typical operating environment. The appropriate location for this phase of the measurement procedure was chosen to be Whitford City Shopping Centre Food Hall, which is a large and typical (operationally speaking) environment.

The following section provides full details on the measurement procedure for the above mentioned pertinent circumstances.

5.4.2 COMPLETE MEASUREMENT PROCEDURE

5.4.2.1 Single Microwave Oven

This procedure involved the operation of a single microwave oven in an enclosed room. The measurement technique attempted to exploit the fact free space propagation obeys an inverse square law, as stated by Parsons and Gardiner (1989, p.71), such that received power decreases by 6 dB for every doubling in effective propagation distance. Therefore, by conducting the measurements at different distances, one would not only be able to determine

the effective radiated noise power from the microwave oven at various distances, but also to determine if the measured levels did in fact obey this fundamental law of propagation.

Measurements were conducted utilising both antennae at distances of 2m and 10m from the source. A pictorial representation of the measurement site and configuration is given in Figure 12. Although two microwave ovens were present at the measurement site, only one was considered (operating during data collection), as it was a recent model and would typify those found throughout the majority of society. The specifications of the microwave oven under examination are detailed below.

Microwave Oven Specifications :

- Sharp Carousel Model # : R7280 (Serial # 70807041).
- Rated Output Power : 650 W.
- Operating Frequency : 2.45 GHz.
- Input Voltage : 240 V.
- Operating Current : 5.5 A.

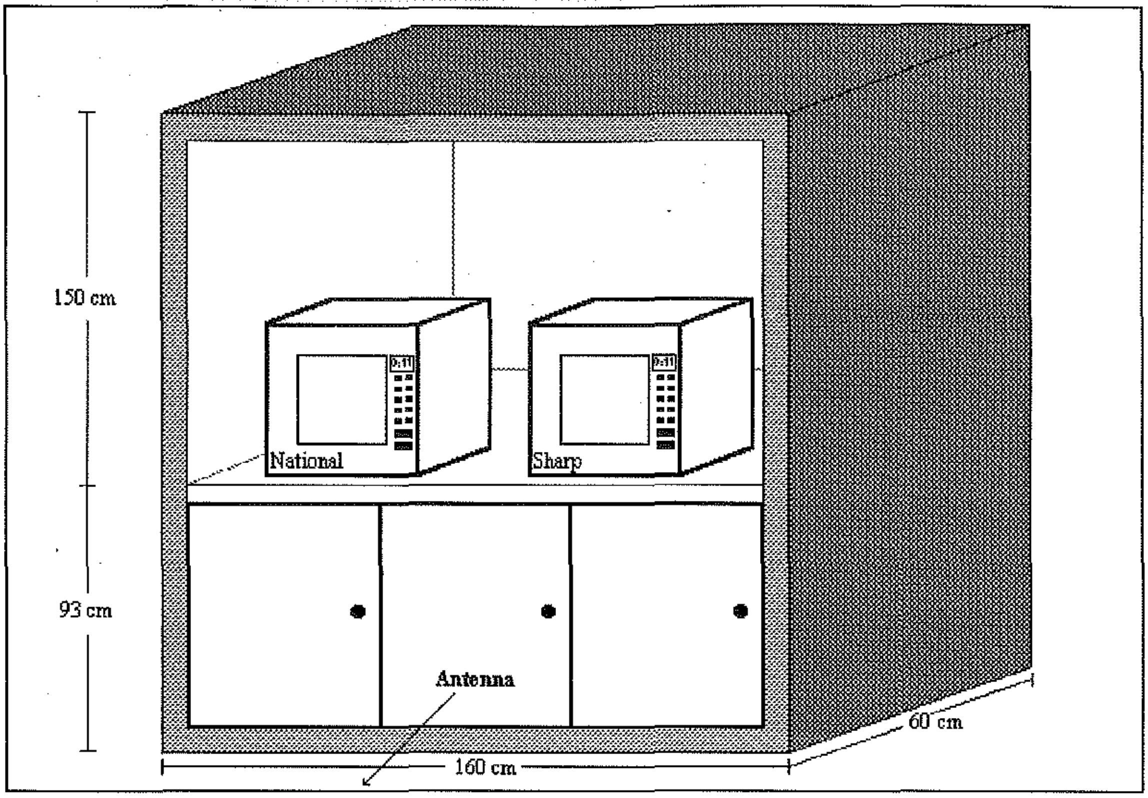

Figure 12 Measurement Site Configuration For Single Microwave Oven

The specifics of the measurement procedure will be presented shortly, but first we will consider the intricacies of what analysis is to be performed, and how the appropriate measurement data was obtained to support the analysis.

In order to obtain relevant data, it was first necessary to clarify how the data must be collated to produce the most useful results. Typical measurement procedures for this nature of analysis would require both an average peak noise power level over the band of interest, as well as a peak hold noise power level representation. In addition, more advanced analyses would also bestow consideration to diurnal effects; that is how the noise power varies with respect to time of day.

For the purpose of characterisation of a single microwave oven, average peak noise power and peak hold noise power (2 minute) are a necessity, and in addition I also considered average peak hold noise power (2 minute) (these noise classifications are explained later). Diurnal variation however bears no relevance to this phase of the analysis, because it is unreasonable to consider that the characteristic noise output would vary with respect to different times of day. Of course its use would be more common during relevant periods such as lunchtime, but the statistical analysis of the amount of use during different periods of the day (better described as frequency of use, which leads to the total operating time in a given time span), is an entirely different study and is beyond the scope of this project. However, by characterising the actual noise output of the microwave oven while in operation, this data could then be used in collaboration with the statistical study of operational time to determine the mean occupancy (noise power) of the spectrum by the microwave oven with respect to time of day. I will leave this matter here to suggest that this could be a future effort for interested parties.

Examining the numerical classification in greater detail, in order to develop relevant statistical models, a problem existed in that a sample over the entire 200 MHz span from 2.3-2.5 GHz would provide an excellent graphical representation of the signature of the output spectrum, but could not provide useful data upon which to base the statistical analysis.

The solution to this problem involved dissecting, or partitioning the 200 MHz measurement band into twenty succinct 10 MHz bands. A full analysis could then be performed on each of the sub-bands, and the results combined to produce a model representative of the entire 200 MHz band.

Although the lower band of interest only covers 85 MHz (2.4-2.485 GHz), I felt it was necessary to extend the boundary of the analysis to not only uncover what noise lay in adjacent bands, but also to fully classify the microwave output spectrum in its entirety, and not just a sub-section. Let us now consider in greater detail the procedure followed for each of the three data classifications.

Note : The following description applies identically to both the omnidirectional and directional antennae.

Average Peak Noise Power :

This classification of noise power is probably the most important, as it exemplifies what level of noise we can expect from a microwave oven, on the average, during its interval of operation. I state that this facet is the most important with respect to system performance, because it represents directly the hindrance provided to wireless LAN's during normal operation.

The basis of this classification revolves around utilisation of the *view function* feature of the spectrum analyser, which correspondingly freezes the output of the spectrum analyser at any time instant (screen capture). In essence, the classification could be considered as the average instantaneous peak noise power, whereby any signals above the noise floor of the spectrum analyser that were observed in a particular snap-shot of the system (no matter what the level - small or large), were accounted for by taking their peak amplitude.

The basic procedure for attainment of this data was as follows :

1. The antenna was located at the recorded distance from the microwave oven, the distance measured with a suitable measurement device (tape measure).
2. The effective height of the antenna from the ground, and the microwave from the ground, were duly recorded.
3. The spectrum analyser was configured for sub-band measurements as outlined in Section 5.2.4.2 (Spectrum Analyser Configuration). The first sub-band was 2.3-2.31 GHz.
4. Full power operation of the microwave oven was commenced. (A one litre bowl of water was placed inside the microwave at all times during operation).
5. Using the *view function* of the spectrum analyser, the corresponding amplitude (in dBm) of any signal peaks were recorded, utilising the *peak search* function.
6. Step 5 was repeated until 50 data samples had been obtained. If the number of peaks in the last screen capture resulted in the number of data samples exceeding 50, successively highest and lowest samples were taken in turn until the 50 sample point had been reached.
7. All data was tabularised for future analysis, outlined in Section 6.

Average Peak Hold Noise Power (2 minute) :

This classification of noise power provides a realistic mechanism of determining the worst case scenario for operation of microwave LAN's. I have included this procedure as a result of the sub-band measurement process, which I feel necessitates an average of the highest peaks (recorded over two minutes) within the 10 MHz frequency span, to most accurately represent the peak noise power within this band. If it were not for this sub-band procedure, such a classification would probably not have been necessary.

The basis of this classification revolves around utilisation of the *peak hold* function of the spectrum analyser, which as the name suggests holds maximum peak values across the spectrum, and only updates the trace if a higher peak is registered at the same spectral location of an existing peak. Therefore, no complete refreshment (rewrite) of the screen takes place. The effect of this is to illustrate the maximum amplitude of all frequency values across the spectrum, with respect to the resolution of the spectrum analyser.

The basic procedure for attainment of this data was as follows :

1. The antenna was located at the recorded distance from the microwave oven, the distance measured with a suitable measurement device (tape measure).
2. The effective height of the antenna from the ground, and the microwave from the ground, were duly recorded.
3. The spectrum analyser was configured for sub-band measurements as outlined in Section 5.2.4.2 (Spectrum Analyser Configuration). The first sub-band was 2.3-2.31 GHz.
4. Full power operation of the microwave oven was commenced. (A one litre bowl of water was placed inside the microwave at all times during operation).
5. The *peak hold* function of the spectrum analyser was initiated and allowed to run for two minutes while the microwave was operating.
6. The 50 highest samples were duly recorded, utilising the *peak search* function of the spectrum analyser. If more than 50 peaks were evident, only the highest 50 were considered.
7. Step 6 was repeated for each successive 10 MHz sub-band until the full 200 MHz spectrum had been covered.
8. All data was tabularised for future analysis, outlined is Section 6.

Peak Hold Noise Power (2 minute) :

This classification of noise power drew upon the resources of the previous classification (average peak hold noise power [2 minute]), and provides us with an absolute worst case scenario for each frequency sub-band in question. Although not entirely indicative of a real world scenario, due to the spectral spreading, I felt it was necessary to include this classification in order to aid completeness of the statistical model.

- This data was obtained simply by using the *peak hold* function of the spectrum analyser as in the previous classification, but only the highest peak in each sub-band was recorded. In fact, this data was obtained in tandem with the average peak noise measurements, and was simply the highest value recorded in each case of the average peak hold noise power (2 min).

Statistical analysis of this data (mean, variance and standard deviation) bears no relevance as a consequence of only one data sample being utilised in each case. The analysis was thus based upon producing a plot of noise power with respect to frequency.

5.4.2.2 Multiple Instances Of Microwave Ovens

This procedure differed from that outlined in Section 5.4.2.1 (Characterisation Of Single Microwave Oven), in that no individual source could be identified. Rather, the noise output was an amalgamation of various microwave ovens operating at random, in an indiscriminate environment by nature. As mentioned previous, the environment in question was the Whitford City Shopping Centre Food Hall.

The main purpose of this classification was to determine the dependence between noise power and time of day, as this may have a significant impact on the performance of wireless LAN's if such a dependance actually exists. It is a well published fact throughout literature, that noise power commonly varies with respect to time of day, in a predictable manner. This manner depends both upon the frequency range in question, and the particular noise sources if applicable. For example, a general approximation of radio noise as shown in Figure 8 previously, tends to exhibit peaks mid-morning and mid-afternoon, which is relative to peaks in general business activity. If we consider mobile phones however, (I state this tentatively) through my studies at Telstra during vacation employment, I found that peak traffic occurred at the beginning and conclusion of the business day, as most people tended to use their phones while travelling to and from work. Unfortunately I do not have any supporting material to submit to substantiate this claim, other than that I personally observed and measured this phenomenon as a result of a suggestion from my supervisor at the time, as to why the spread spectrum modems that I was testing at the time were suffering significant performance reductions during these times of peak mobile phone activity.

Returning from this digression, one would *expect* that the noise power from microwave ovens in the food hall to exhibit a maximum in the vicinity of the lunch time period, and as you will see in Section 6, this was in fact the case.

The method behind this classification was similar in nature to that utilised for a single microwave oven (noise power classifications are the same), except that measurements were conducted in specified time slots, and their was little dependence upon distance from sources, due to their multiplicity, and surrounding nature. By surrounding nature I mean that the food hall could basically be considered a 360° enclosure, with microwaves present throughout

its entirety. I can state however, that the antenna was located at least 20m from any particular microwave oven.

All measurements conducted during this phase were done so using the omnidirectional antenna, as this was most relevant to the system in question, because we wished to determine the noise power evident within the environment in question as a whole, rather than from any particular source.

The basic procedure for attainment of this data was as follows :

1. The omnidirectional antenna was positioned as high above ground level as possible (approximately 1m base above ground).
2. The first set of measurements were commenced at 9am, and had to be completed within the hour.
3. The spectrum analyser was configured for sub-band measurements as outlined in Section 5.2.4.2 (Spectrum Analyser Configuration). The first sub-band was 2.3-2.3 GHz.

Average Peak Noise Power :

4. Utilising the *view function* of the spectrum analyser, the corresponding amplitude of any existing peaks were recorded, utilising the peak search function.
5. Step 4 was repeated until 50 data samples had been obtained. If the number of peaks in the last screen capture resulted in the number of data samples exceeding 50, successively highest and lowest samples were taken in turn until the 50 sample point had been reached.

Average Peak Hold Noise Power (2 minute) :

6. The *peak hold* function of the spectrum analyser was initiated and allowed to run for two minutes.
7. The highest 50 samples were duly recorded (or the trace saved to memory if time did not permit), and were determine via the *peak search* function. If more than 50 peaks were evident, only the highest 50 were considered.

Peak Hold Noise Power (2 minute) :

8. The maximum peak value was duly noted and recorded.
9. All steps from Step 3 were repeated for each successive sub-band until the full 200 MHz spectrum had been covered.
10. All steps from Step 2 were repeated, for each successive hour, until 9am to 5pm measurements had been fully completed.

Note : Due to timing constraints, all measurements (average peak noise power, average peak hold noise power (2 min), and peak hold noise power [2 min]) had to be completed within the hour. As a result, the maximum hold trace measurements were saved to the memory of the spectrum analyser, and the data retrieval was completed at a later date.

Procedures outlined, it is now time to examine the results, and develop statistical models.

6. RESULTS COLLATION

The following material is divided into appropriate subsections, according to the type of measurements. In some cases, graphs may be depicted in more than one format, in order to facilitate understanding, depending upon which representation an individual finds easiest to comprehend and interpret.

All measurement data was analysed using Microsoft Excel 4.0. Nett dBm figures (procedure presented in Section 6.1.1) were calculated from the raw measurement data, and adjusted accordingly, considering system losses (feeder cable loss) and system gains (antenna gain), which means that all stated figures and statistical analyses are quoted as such. Cable calibration figures are presented in Section 6.1, and antennae gains were assumed to be as stated by the manufacturer.

Statistical results are represented in both dBm and micro-Watts as appropriate, with variance and standard deviation results being normalised to the sample mean.

Statistical analyses were performed in micro-Watts (linear scale), in the case of calculation of mean, variance and standard deviation. At the conclusion of the analysis, the values for these three figures were converted back to dBm (logarithmic scale) where appropriate.

As a final note, an analysis of the measurement results will be given for each noise group, with comparisons between various classifications entered into where appropriate. The significance of these findings will be considered in Section 7. The main purpose of this brief analysis is to determine whether the data obtained as a result of the analysis efforts, conforms with expectations.

6.1 CABLE CALIBRATION

Feeder cables were calibrated by setting up a transmitter/receiver link, with known measured losses and gains, and received signal power (measured on the spectrum analyser). To determine the loss (attenuation) factors for the various cables, they were introduced to the network, and the resultant received signal power recorded. The effect of the cable could then be catered for, by subtracting the measured signal power from the reference signal power. The resultant difference directly yielded the loss of the cable, in dB.

In measuring received signal power levels, the resolution of the output scale was brought down to 0.1 dB per division, to ensure accuracy was maintained. The cable calibration figures are shown in Table 2.

Table 2 : Cable Calibration Figures

Cable	Length (m)	Frequency (GHz)	Attenuation (dB)
RG-213	2	2.3	1.2
	..	2.4	1.2
	..	2.5	1.2
RG-213	20	2.3	8.4
	..	2.4	8.8
	..	2.5	9.0
LDF-450	2	2.4	0.35

In all instances of noise measurements, the 2m length of RG-213 feeder cable was used to connect either antenna to the spectrum analyser.

6.1.1 MEASUREMENT DATA BIAS

What follows is an explanation of how the raw measurement data was adjusted to cater for system gains and losses (antenna gain and feeder loss). Antenna gain figures were assumed (as mentioned in the introduction of Section 6) to be as stated in the specifications; 10.2 and 15 dBi for the omnidirectional and directional antennae respectively.

Omnidirectional Measurements :

Actual received signal power (dBm) = measured value - (nett system gain) **(7)**

∴ Corrected Level (dBm) = measured value - (+ antenna gain - feeder loss)

$$Y = X - (10.2 - 1.2)$$

where :

X = measured value (dBm).

Y = corrected value (dBm).

Example :

If measured value (X) = -35.12 dBm,

$$Y = -35.12 - (10.2 - 1.2) = -44.12 \text{ dBm.}$$

Directional Measurements :

Utilising equation (7),

∴ Corrected Level (dBm) = measured value - (+ antenna gain - feeder loss)

$$Y = X - (15.0 - 1.2)$$

where :

X = measured value (dBm).

Y = corrected value (dBm).

Example :

If measured value (X) = -35.12 dBm,

$$Y = -35.12 - (15.0 - 1.2) = -48.98 \text{ dBm}.$$

6.1.2 CONVERSION FACTORS

Conversion between dBm and mW is governed by the following relationship :

$$\text{dBm} = 10\log[\text{Power(mW)}].$$

For the case of the statistical analyses, all power levels were represented in μ W, which involved as simple multiplication of mW by a factor of 10^3.

6.2 CHARACTERISATION OF SINGLE MICROWAVE OVEN

6.2.1 2M MEASUREMENTS

As mentioned previous, these measurements consisted of omnidirectional and directional data, thus they are treated separately, from which a comparison and other relevant conclusions can be drawn.

A typical spectrum analyser trace obtained from the 2m measurements, using the directional corner reflector antenna, is shown in Figure 13. This figure, and other similar figures that follow, are raw data only. If one wishes to derive information direct from the trace, then it is necessary to account for system gains and losses. This was the procedure followed for all measurement analyses, as outlined in Section 6.1.1.

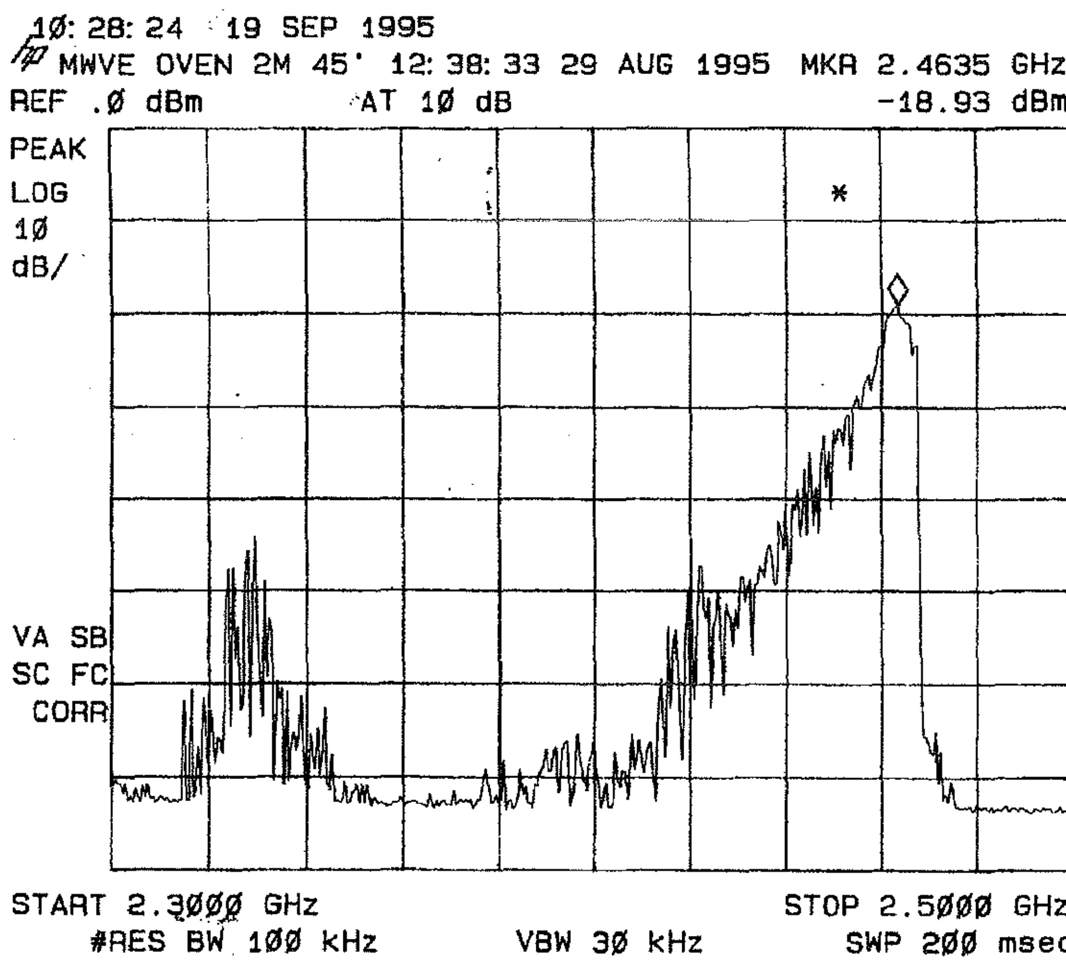

Figure 13 Sample Spectrum Analyser Output For Single Microwave Oven At 2m Using Directional Corner Reflector Antenna

Probably the most significant material that can be obtained from this trace, is that the highest power level of the output from the microwave, is spectrally

located between 2.4-2.47 GHz, which is directly coincident with the band of interest for microwave wireless LAN's. The significance of this will be illustrated in Section 7, once the full statistical analysis is complete.

Another useful facet of information that can be weaned from this trace, is that it shows a typical *signature* of the leakage output spectrum for a microwave oven. Brief analysis of two other microwave ovens, demonstrated that they at least (and presumably most others) share a similar signature, or leakage output spectrum, both in intensity (related to efficiency and sealing of microwave) and spectrum occupation. Although to be discussed further in Section 7, such a signature aids in determining the source of other instances of noise, by comparing the received spectrum to that of a microwave oven. Such an instance occurred in the Edith Cowan Library in the photocopier section, whereby while running measurements, a similar trace was obtained to that shown in Figure 13. Investigations yielded that a microwave oven some 20m away, but not visible to the eye (in a separate enclosure), was in operation at the time. Therefore, the signal received was in fact from the microwave oven, and not the photocopiers as first impressions led us to believe.

6.2.1.1 2m Omnidirectional

From the 50 data samples per frequency sub-band, the statistical analyses are presented in the following tables and graphs. The graphs (Figures 14-16) dictate the relevant noise powers, measured in dBm, for each 10 MHz frequency slot over the range of 2.3-2.5 GHz.

Note : The formulae utilised in the calculation of mean, variance and standard deviation for the following statistical tables, are presented in the Appendicies

(A.1 Statistical Formulae). The conversion between µW and dBm, is as per Section 6.1.2 Conversion Factors.

Average Peak Noise Power :

Table 3 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	6.76E-06	-81.69783672	3.12E-05	-75.06339425	0.176534783	-37.53169713
2.31-2.32	8.69E-06	-80.61221201	4.10E-04	-63.87680414	0.639970261	-31.93840207
2.32-2.33	9.27E-06	-80.33057696	9.01E-05	-70.45064468	0.300239457	-35.22532234
2.33-2.34	7.84E-06	-81.05874189	5.85E-05	-72.32547235	0.241950421	-36.16273618
2.34-2.35	8.88E-06	-80.51381309	9.25E-05	-70.33819107	0.304151839	-35.16909553
2.35-2.36	7.46E-06	-81.26996019	8.59E-05	-70.65959877	0.293102863	-35.32979939
2.36-2.37	6.41E-06	-81.93076448	6.05E-05	-72.1815877	0.245991791	-36.09079385
2.37-2.38	6.23E-06	-82.05721787	4.56E-05	-73.41406731	0.213450234	-36.70703366
2.38-2.39	7.37E-06	-81.32468273	2.86E-05	-75.437267	0.169097291	-37.7186335
2.39-2.40	8.10E-06	-80.91598614	8.03E-05	-70.95030817	0.283455306	-35.47515408
2.40-2.41	7.78E-06	-81.09229515	2.90E-04	-65.36883554	0.538962095	-32.68441777
2.41-2.42	1.18E-05	-79.28491256	1.46E-03	-58.35997157	1.207817789	-29.17998578
2.42-2.43	3.21E-05	-74.93666311	1.83E-03	-57.38450406	1.351371629	-28.69225203
2.43-2.44	2.26E-05	-76.45819884	1.66E-03	-57.80262301	1.287860578	-28.90131151
2.44-2.45	2.71E-05	-75.67050395	4.01E-03	-53.97136964	2.001849933	-26.98568482
2.45-2.46	0.000968413	-60.13939384	4.54E-03	-53.42857651	2.13093977	-26.71428825
2.46-2.47	0.004451651	-53.51478921	3.48E-03	-54.58660361	1.86496128	-27.2933018
2.47-2.48	8.23E-06	-80.84565567	2.99E-04	-65.24201384	0.546889151	-32.62100692
2.48-2.49	7.99E-06	-80.97682938	6.88E-05	-71.62536312	0.262259871	-35.81268156
2.49-2.50	7.78E-06	-81.09050839	8.12E-05	-70.90509132	0.284934761	-35.45254566

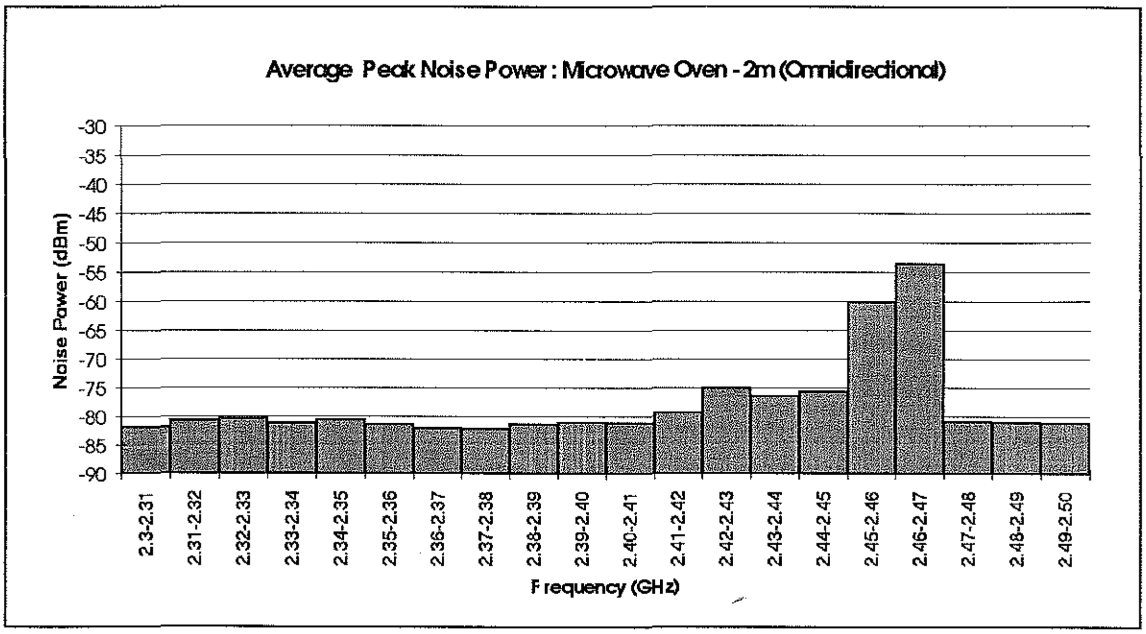

Figure 14 Average Peak Noise Power For Microwave Oven At 2m (Omnidirectional)

Average Peak Hold Noise Power (2 minute) :

Table 4 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	9.14E-06	-80.39261632	3.36E-05	-74.73034579	0.183435214	-37.3651729
2.31-2.32	1.07E-05	-79.70479887	4.12E-04	-63.8553691	0.64155153	-31.92768455
2.32-2.33	1.05E-05	-79.80765908	1.22E-04	-69.13277385	0.3494309	-34.56638693
2.33-2.34	1.03E-05	-79.89239785	6.10E-05	-72.1469159	0.246975689	-36.07345795
2.34-2.35	1.15E-05	-79.39100977	9.09E-05	-70.41327626	0.301533929	-35.20663813
2.35-2.36	8.89E-06	-80.51148587	8.30E-05	-70.81059229	0.288051662	-35.40529615
2.36-2.37	8.87E-06	-80.5196317	5.75E-05	-72.40204358	0.23982686	-36.20102179
2.37-2.38	8.90E-06	-80.50432482	4.58E-05	-73.38923551	0.214061332	-36.69461776
2.38-2.39	9.25E-06	-80.33652262	3.00E-05	-75.22798379	0.173221107	-37.61399189
2.39-2.40	1.20E-05	-79.21517012	7.64E-05	-71.16686875	0.276475443	-35.58343437
2.40-2.41	1.52E-05	-78.19511375	2.91E-04	-65.35451225	0.539851594	-32.67725612
2.41-2.42	3.42E-05	-74.66202306	1.48E-03	-58.29855227	1.216388726	-29.14927614
2.42-2.43	0.000112796	-69.4770506	1.87E-03	-57.27930511	1.367838251	-28.63965256
2.43-2.44	5.43E-05	-72.65515617	1.65E-03	-57.82219182	1.284962369	-28.91109591
2.44-2.45	0.000160683	-67.94029936	3.96E-03	-54.02759786	1.988932788	-27.01379893
2.45-2.46	0.003814338	-54.18580862	4.26E-03	-53.71088899	2.062792532	-26.8554445
2.46-2.47	0.026198818	-45.81718296	3.17E-03	-54.98745626	1.780849369	-27.49372813
2.47-2.48	1.79E-05	-77.46347796	3.16E-04	-65.00877906	0.561773239	-32.50438953
2.48-2.49	1.26E-05	-78.99203949	7.06E-05	-71.51459431	0.265625818	-35.75729716
2.49-2.50	1.01E-05	-79.95409705	8.29E-05	-70.81694134	0.287841184	-35.40847067

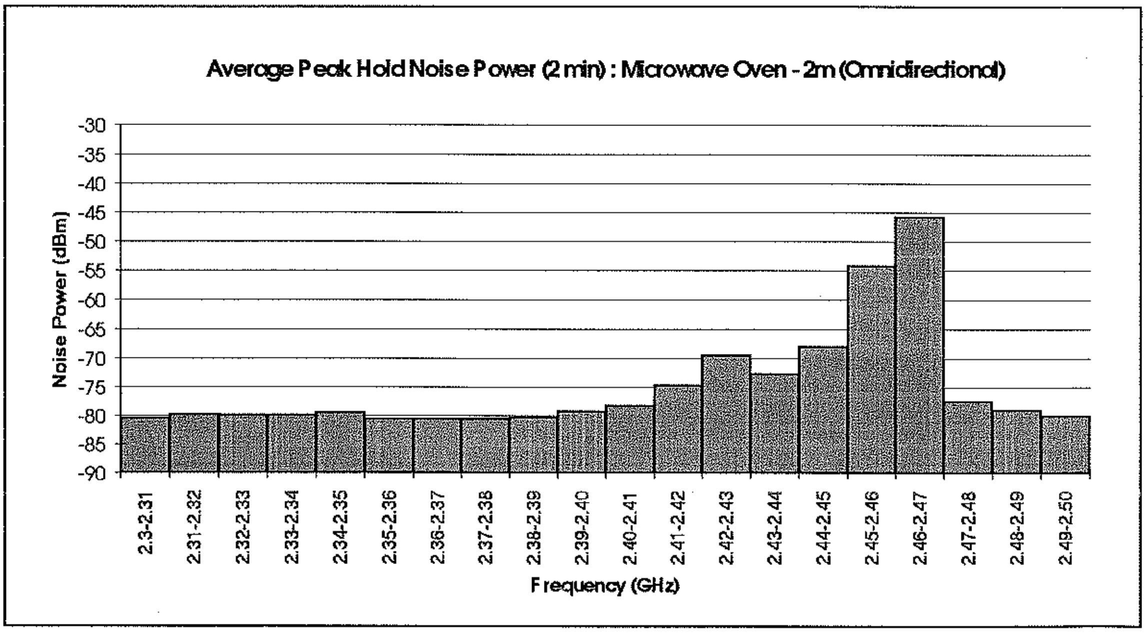

Figure 15 Average Peak Hold Noise Power (2 min) For Microwave Oven At 2m (Omnidirectional)

Peak Hold Noise Power (2 minute) :

Table 5 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	0.000125893	-69
2.31-2.32	0.000431519	-63.65
2.32-2.33	0.000188799	-67.24
2.33-2.34	0.000132434	-68.78
2.34-2.35	0.000160694	-67.94
2.35-2.36	0.000122744	-69.11
2.36-2.37	0.000120226	-69.2
2.37-2.38	0.00011246	-69.49
2.38-2.39	9.95E-05	-70.02
2.39-2.40	0.000160325	-67.95
2.40-2.41	0.000524807	-62.8
2.41-2.42	0.002398833	-56.2
2.42-2.43	0.005597576	-52.52
2.43-2.44	0.003019952	-55.2
2.44-2.45	0.015631476	-48.06
2.45-2.46	0.265460556	-35.76
2.46-2.47	1.659586907	-27.8
2.47-2.48	0.00060256	-62.2
2.48-2.49	0.000172584	-67.63
2.49-2.50	0.000139637	-68.55

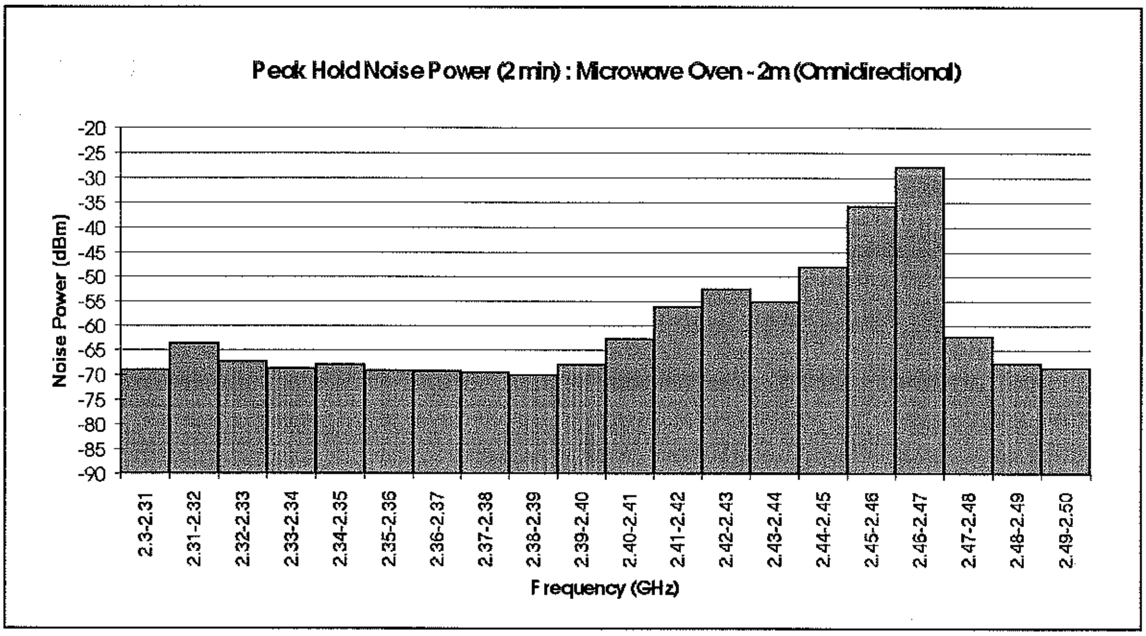

Figure 16 Peak Hold Noise Power (2 min) For Microwave Oven At 2m (Omnidirectional)

Probably the most obvious information that can be weaned from Figures 14 through 16, is that the shape of the plotted spectrum with respect to intensity (noise level), mimic's the analyser trace shown in Figure 13. This is especially the case for Figure 16, which is an illustration of the peak hold noise power (2 min) at a distance of 2m from the microwave oven, using the omnidirectional antenna. This is exactly the representation of Figure 13, which utilised the peak hold function of the analyser to create the trace. From examination of these figures, it is noted that the majority of the high level noise measured, occurs within the spectrum that the microwave LAN's are proposed to operate.

In addition, the results are much as expected with respect to the fact that the mean noise powers for each frequency sub-band increase for each successive plot. This is in support of the fact that the peak hold noise power (2 min) should be higher than the average peak hold noise power (2 min), which in turn should be higher than the average peak noise power.

Finally, the statistical inference that can be drawn from variance and standard deviation shows that the highest values obtained for these factors occurred in conjunction with the highest mean power levels. This is as to be expected, as the variation in samples from portions of the spectrum that produced low power levels, would obviously be lower than the variation in samples from portions of the spectrum that exhibit higher power levels, as these portions are more subject to change due to the random and sporadic nature of the measured signals.

6.2.1.2 2m Directional

From the 50 data samples per frequency sub-band, the statistical analyses are presented in the following tables and graphs. The graphs (Figures 17-19)

dictate the relevant noise powers, measured in dBm, for each 10 MHz frequency slot over the range of 2.3-2.5 GHz.

Average Peak Noise Power :

Table 6 :

Frequency(GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	5.39E-06	-82.68766841	2.85E-04	-65.45406014	0.533699742	-32.72703007
2.31-2.32	1.14E-05	-79.42735627	1.07E-03	-59.70793703	1.034196702	-29.85396852
2.32-2.33	1.54E-05	-78.11950995	8.72E-03	-50.59673373	2.952319218	-25.29836686
2.33-2.34	2.79E-06	-85.54325547	8.22E-05	-70.85380379	0.28662219	-35.4269019
2.34-2.35	3.08E-06	-85.11396952	8.95E-05	-70.48393557	0.299090915	-35.24196778
2.35-2.36	2.50E-06	-86.01294358	7.89E-05	-71.02757884	0.280944839	-35.51378942
2.36-2.37	2.08E-06	-86.82277035	4.85E-05	-73.14404201	0.220190156	-36.572021
2.37-2.38	2.07E-06	-86.83991477	3.69E-05	-74.33405893	0.191998154	-37.16702947
2.38-2.39	2.42E-06	-86.16501826	2.52E-05	-75.99113424	0.158651173	-37.99556712
2.39-2.40	5.07E-06	-82.95123659	2.48E-04	-66.05966378	0.497756352	-33.02983189
2.40-2.41	1.04E-05	-79.84176637	3.27E-04	-64.85854254	0.571574537	-32.42927127
2.41-2.42	6.03E-05	-72.19558543	4.18E-03	-53.79052354	2.043966733	-26.89526177
2.42-2.43	0.000208088	-66.81752651	2.25E-03	-56.48711269	1.498457279	-28.24355634
2.43-2.44	0.000133711	-68.73832045	2.87E-03	-55.42212084	1.693924143	-27.71106042
2.44-2.45	0.000179777	-67.45266822	7.76E-03	-51.09866374	2.786549825	-25.54933187
2.45-2.46	0.006803391	-51.67274571	5.20E-03	-52.83949168	2.280475527	-26.41974584
2.46-2.47	0.04396116	-43.56930853	3.04E-03	-55.17488151	1.742833602	-27.58744075
2.47-2.48	1.74E-05	-77.59370276	1.01E-02	-49.96227961	3.17604041	-24.9811398
2.48-2.49	2.85E-06	-85.45319456	7.37E-05	-71.32480865	0.271493582	-35.66240433
2.49-2.50	2.64E-06	-85.78562702	7.97E-05	-70.98685553	0.282265126	-35.49342776

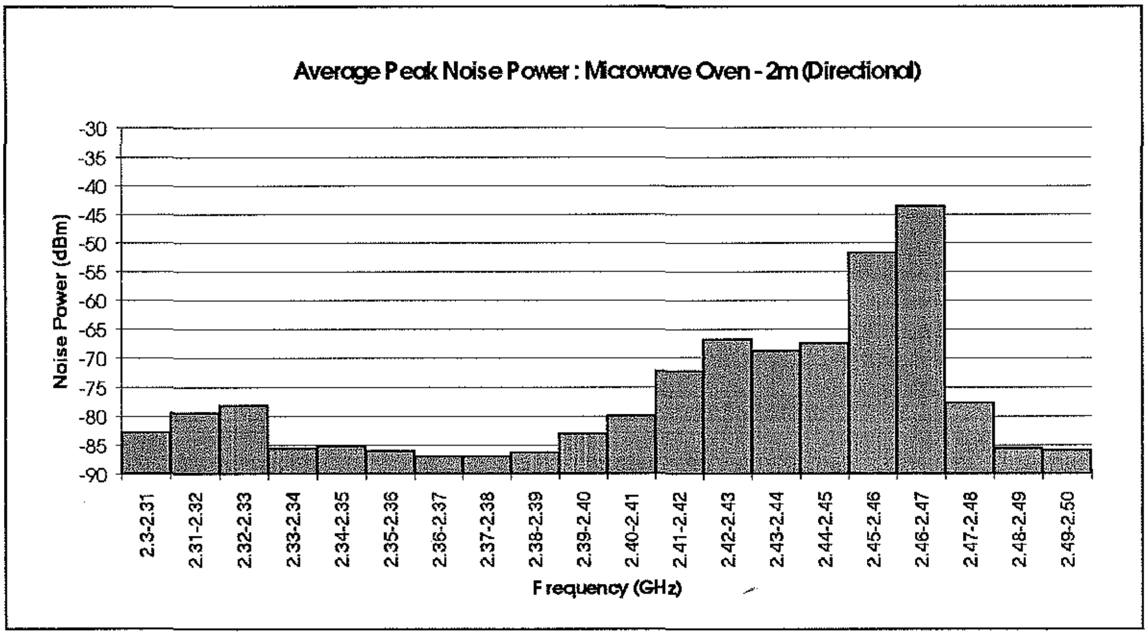

Figure 17 Average Peak Noise Power For Microwave Oven At 2m Directional

Average Peak Hold Noise Power (2 minute) :

Table 7 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.67E-05	-77.76232803	3.01E-04	-65.20877596	0.548985915	-32.60438798
2.31-2.32	3.35E-05	-74.75260531	8.19E-04	-60.86884903	0.904810327	-30.43442451
2.32-2.33	9.41E-06	-80.26572612	3.28E-04	-64.84559767	0.572427008	-32.42279883
2.33-2.34	2.93E-06	-85.32620499	2.48E-04	-66.05313591	0.498130581	-33.02656795
2.34-2.35	2.66E-06	-85.75931125	1.70E-04	-67.70742048	0.411745609	-33.85371024
2.35-2.36	2.31E-06	-86.36216245	3.23E-05	-74.90294073	0.179826198	-37.45147037
2.36-2.37	2.08E-06	-86.82945881	9.41E-06	-80.26317497	0.097015528	-40.13158748
2.37-2.38	2.02E-06	-86.95423184	6.60E-06	-81.80573082	0.08122944	-40.90286541
2.38-2.39	1.14E-05	-79.41231645	1.52E-03	-58.19288877	1.231276417	-29.09644439
2.39-2.40	5.42E-05	-72.66145339	1.28E-04	-68.94124948	0.357221448	-34.47062474
2.40-2.41	1.30E-05	-78.86063796	3.27E-04	-64.85540772	0.571780861	-32.42770386
2.41-2.42	0.000206555	-66.84965292	2.01E-04	-66.96413415	0.448531855	-33.48206708
2.42-2.43	0.000703606	-61.52670367	1.02E-04	-69.90287788	0.31978354	-34.95143894
2.43-2.44	0.000131298	-68.81740728	1.01E-03	-59.96921507	1.003550535	-29.98460753
2.44-2.45	0.003419862	-54.65991428	5.00E-04	-63.01400917	0.706804883	-31.50700459
2.45-2.46	0.124958217	-39.0323518	3.83E-04	-64.16883437	0.618811365	-32.08441719
2.46-2.47	0.046299146	-43.3442702	2.13E-03	-56.7170446	1.459310711	-28.3585223
2.47-2.48	8.52E-06	-80.6936632	7.17E-03	-51.44249389	2.678399192	-25.72124695
2.48-2.49	2.09E-06	-86.79298727	4.67E-06	-83.30542001	0.068348502	-41.65271
2.49-2.50	2.01E-06	-86.96784599	2.22E-06	-86.5289061	0.047157926	-43.26445305

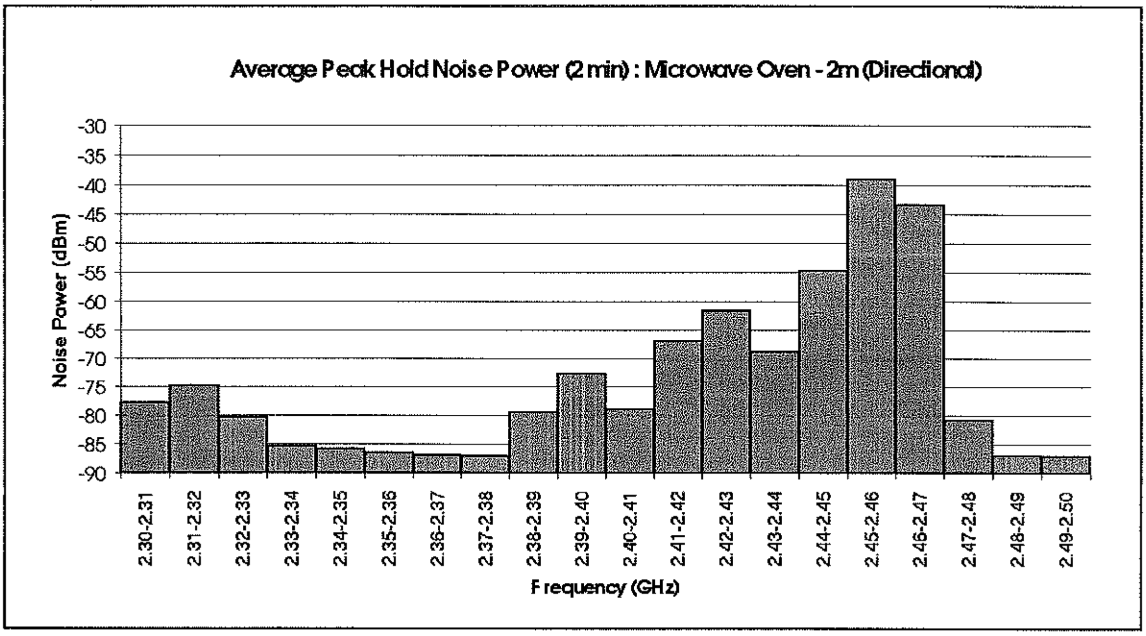

Figure 18 Average Peak Hold Noise Power (2 min) For Microwave Oven At 2m (Directional)

Peak Hold Noise Power (2 minute) :

Table 8 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	0.00164059	-57.85
2.31-2.32	0.003845918	-54.15
2.32-2.33	0.000719449	-61.43
2.33-2.34	0.000264241	-65.78
2.34-2.35	0.000195434	-67.09
2.35-2.36	8.73E-05	-70.59
2.36-2.37	6.14E-05	-72.12
2.37-2.38	6.01E-05	-72.21
2.38-2.39	0.001196741	-59.22
2.39-2.40	0.002654606	-55.76
2.40-2.41	0.00083946	-60.76
2.41-2.42	0.014621772	-48.35
2.42-2.43	0.042953643	-43.67
2.43-2.44	0.019054607	-47.2
2.44-2.45	0.267300641	-35.73
2.45-2.46	9.141132415	-20.39
2.46-2.47	6.918309709	-21.6
2.47-2.48	0.00389942	-54.09
2.48-2.49	5.65E-05	-72.48
2.49-2.50	5.19E-05	-72.85

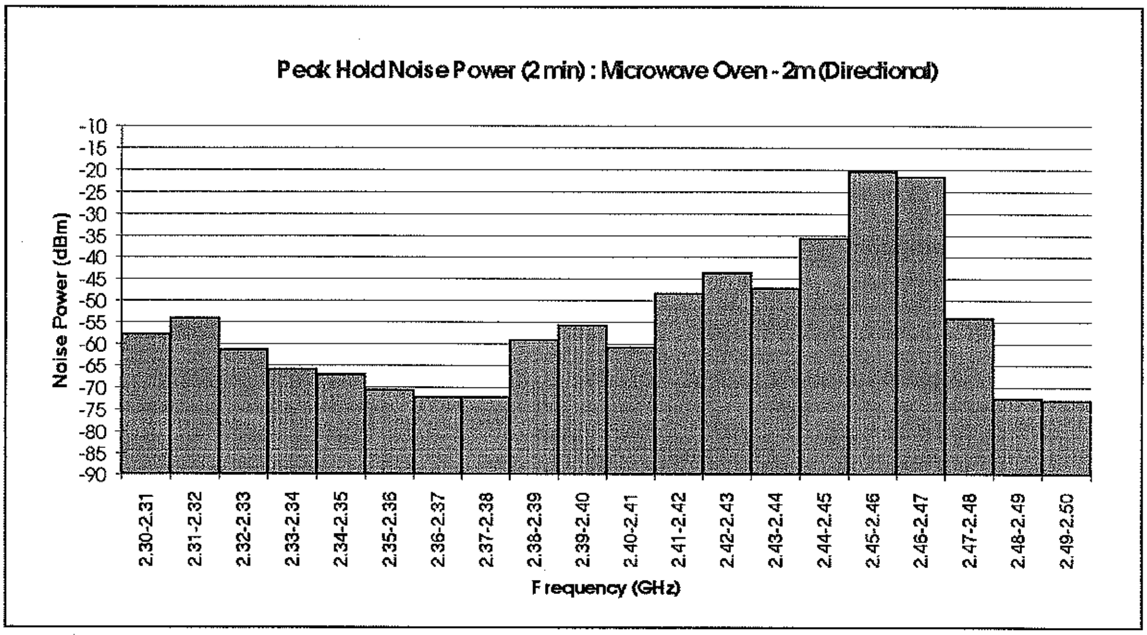

Figure 19 Peak Hold Noise Power (2 min) For Microwave Oven At 2m (Directional)

6.2.2 10M MEASUREMENTS

As discussed previously, these measurements consisted of omnidirectional and directional data, thus they are treated separately, from which a comparison and other relevant conclusions can be drawn.

6.2.2.1 10m Omnidirectional

From the 50 data samples per frequency sub-band, the statistical analyses are presented in the following tables and graphs. The graphs (Figures 20-22) dictate the relevant noise powers, measured in dBm, for each 10 MHz frequency slot over the range of 2.3-2.5 GHz.

Average Peak Noise Power :

Table 9 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	7.55E-06	-81.22087256	4.83E-05	-73.16145157	0.21974926	-36.58072578
2.31-2.32	7.47E-06	-81.26490038	3.71E-05	-74.31148188	0.19249786	-37.15574094
2.32-2.33	7.26E-06	-81.3902246	5.06E-05	-72.95885435	0.224935127	-36.47942718
2.33-2.34	6.99E-06	-81.55397121	4.48E-05	-73.49018105	0.211587958	-36.74509053
2.34-2.35	7.47E-06	-81.26571415	5.09E-05	-72.93603334	0.225526891	-36.46801667
2.35-2.36	7.20E-06	-81.4287127	6.50E-05	-71.87241083	0.254905648	-35.93620542
2.36-2.37	6.88E-06	-81.62354578	4.72E-05	-73.26293147	0.217196802	-36.63146574
2.37-2.38	7.22E-06	-81.41396296	5.01E-05	-73.00563755	0.223726858	-36.50281877
2.38-2.39	7.38E-06	-81.31925925	4.53E-05	-73.43928453	0.212831435	-36.71964227
2.39-2.40	7.03E-06	-81.53001972	6.71E-05	-71.73132329	0.259079968	-35.86566165
2.40-2.41	6.95E-06	-81.58166124	4.50E-05	-73.46609758	0.212175445	-36.73304879
2.41-2.42	9.80E-06	-80.08802263	1.46E-04	-68.35507992	0.382160682	-34.17753996
2.42-2.43	7.17E-05	-71.44337982	8.83E-04	-60.53918	0.93981203	-30.26959
2.43-2.44	7.56E-05	-71.21230259	2.03E-03	-56.91676191	1.426139157	-28.45838096
2.44-2.45	3.97E-05	-74.01579219	9.40E-04	-60.27080187	0.96930378	-30.13540093
2.45-2.46	0.001183853	-59.26702306	3.70E-03	-54.31631185	1.923908474	-27.15815593
2.46-2.47	0.00879111	-50.55956289	1.68E-03	-57.7517178	1.295430476	-28.8758589
2.47-2.48	8.50E-06	-80.70413481	5.31E-04	-62.74533659	0.729009471	-31.3726683
2.48-2.49	7.41E-06	-81.30002349	3.41E-05	-74.67516262	0.184604324	-37.33758131
2.49-2.50	7.13E-06	-81.46834866	4.28E-05	-73.68210137	0.206964058	-36.84105069

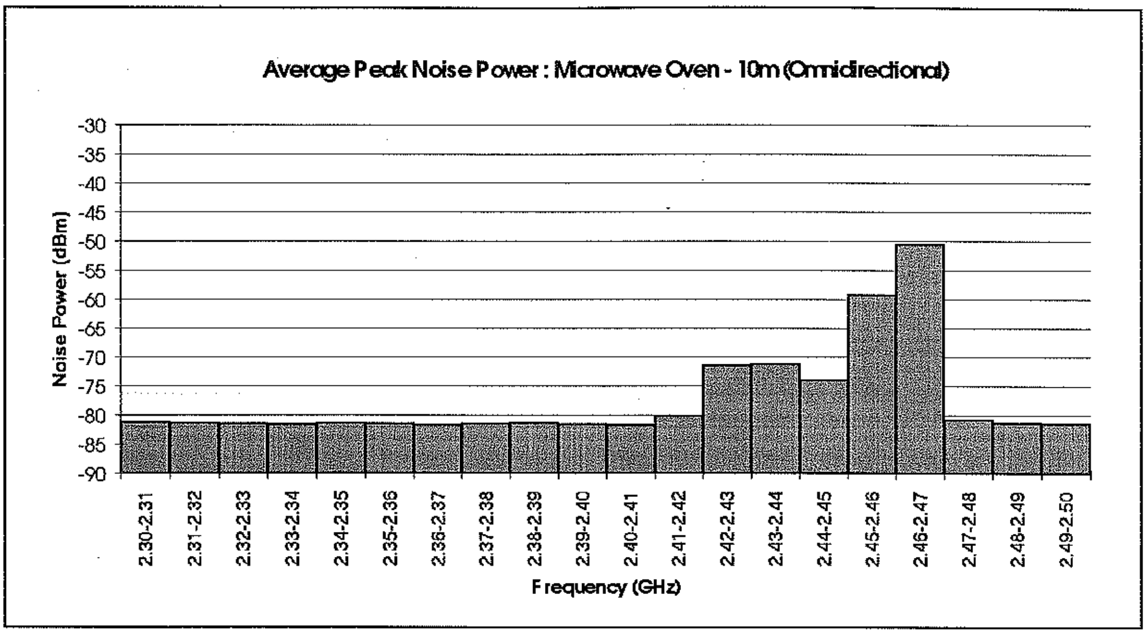

Figure 20 Average Peak Noise Power For Microwave Oven At 10m (Omnidirectional)

Average Peak Hold Noise Power (2 minute) :

Table 10 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	8.54E-06	-80.68673617	7.58E-05	-71.20414195	0.275291564	-35.60207098
2.31-2.32	6.95E-06	-81.57822455	5.59E-05	-72.52263077	0.236520322	-36.26131538
2.32-2.33	8.05E-06	-80.94134595	9.32E-05	-70.30556739	0.305296363	-35.15278369
2.33-2.34	7.40E-06	-81.30785885	7.08E-05	-71.50095918	0.266043125	-35.75047959
2.34-2.35	7.41E-06	-81.30307849	7.23E-05	-71.40669931	0.268945966	-35.70334965
2.35-2.36	8.27E-06	-80.82254064	8.16E-05	-70.88244526	0.285678618	-35.44122263
2.36-2.37	7.81E-06	-81.07456272	6.84E-05	-71.6482015	0.2615712	-35.82410075
2.37-2.38	7.74E-06	-81.11080129	9.65E-05	-70.1560999	0.31059539	-35.07804995
2.38-2.39	8.17E-06	-80.87521498	6.33E-05	-71.98424193	0.251644767	-35.99212097
2.39-2.40	7.25E-06	-81.39589419	6.33E-05	-71.98343492	0.251668148	-35.99171746
2.40-2.41	7.48E-06	-81.26067202	4.47E-05	-73.49267413	0.211527235	-36.74633707
2.41-2.42	1.99E-05	-77.017926	4.93E-04	-63.07547869	0.701820525	-31.53773935
2.42-2.43	0.000217666	-66.62209083	7.39E-05	-71.31182849	0.271899604	-35.65591425
2.43-2.44	0.000887648	-60.51759059	9.37E-05	-70.28385662	0.306060419	-35.14192831
2.44-2.45	0.000226556	-66.44824981	1.15E-04	-69.38417409	0.339462102	-34.69208704
2.45-2.46	0.016075775	-47.9382808	1.92E-04	-67.16628501	0.438213497	-33.5831425
2.46-2.47	0.021581547	-46.65917423	6.41E-04	-61.93135264	0.800630937	-30.96567632
2.47-2.48	7.97E-06	-80.9880723	9.31E-05	-70.30972804	0.305150157	-35.15486402
2.48-2.49	7.67E-06	-81.15091681	7.16E-05	-71.4522293	0.267539884	-35.72611465
2.49-2.50	7.46E-06	-81.27320803	8.96E-05	-70.47654807	0.299345405	-35.23827403

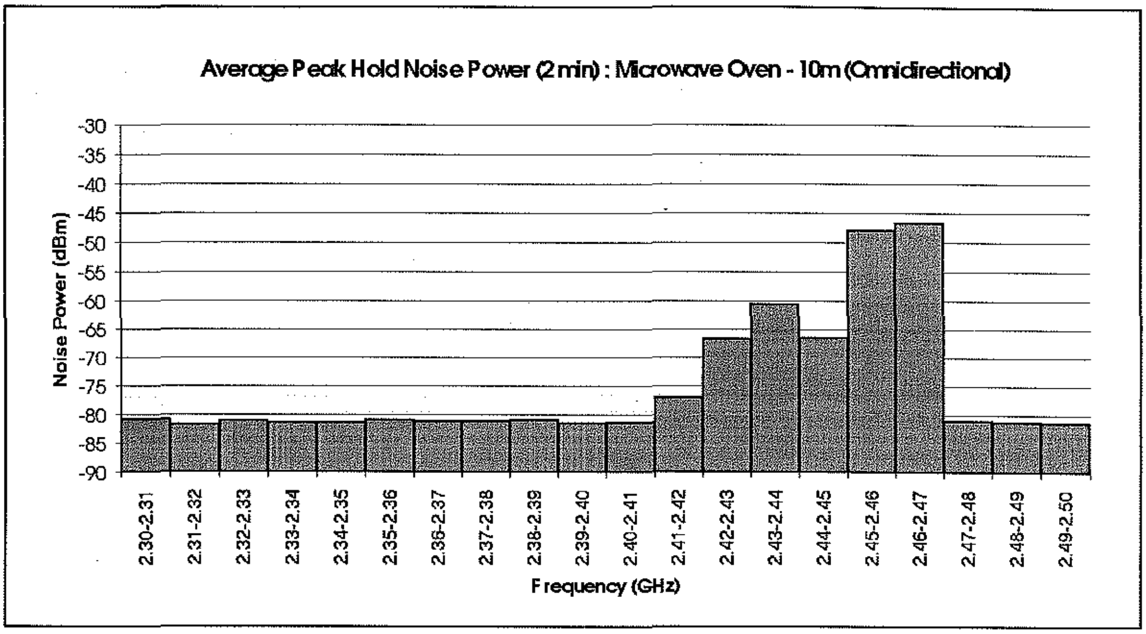

Figure 21 Average Peak Hold Noise Power (2 min) For Microwave Oven At 10m (Omnidirectional)

Peak Hold Noise Power (2 min) :

Table 11 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	0.000105439	-69.77
2.31-2.32	0.000100693	-69.97
2.32-2.33	0.000144877	-68.39
2.33-2.34	0.000107647	-69.68
2.34-2.35	0.000100693	-69.97
2.35-2.36	0.000107399	-69.69
2.36-2.37	0.000107647	-69.68
2.37-2.38	0.00012388	-69.07
2.38-2.39	0.000107399	-69.69
2.39-2.40	0.000100693	-69.97
2.40-2.41	0.0001	-70
2.41-2.42	0.00053827	-62.69
2.42-2.43	0.003221069	-54.92
2.43-2.44	0.013182567	-48.8
2.44-2.45	0.003539973	-54.51
2.45-2.46	0.334965439	-34.75
2.46-2.47	0.417830367	-33.79
2.47-2.48	0.000107399	-69.69
2.48-2.49	0.0001	-70
2.49-2.50	0.00012388	-69.07

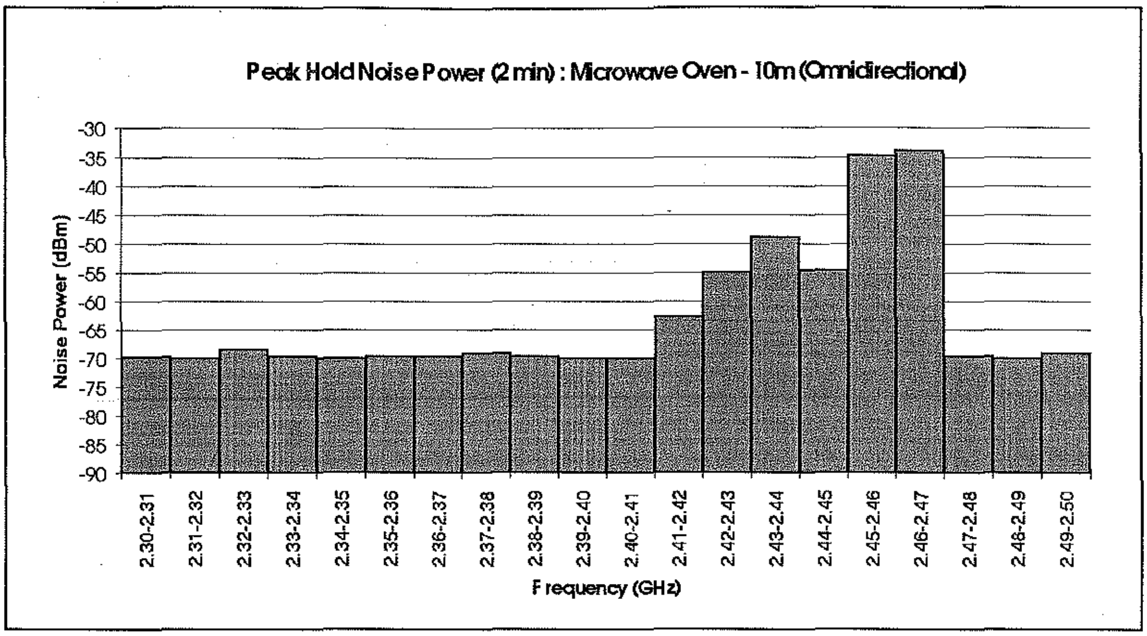

Figure 22 Peak Hold Noise Power (2 min) For Microwave Oven At 10m (Omnidirectional)

Similar to the 2m measurements, the majority of the noise power is found in the spectrum from 2.41-2.47 GHz. The noticeable difference between the two sets of data however, is that there is a reduction in the noise power levels. This is to be expected however, because for every doubling in distance, there should be a 6 dB drop in received power level. As to whether this phenomenon occurs to the same level in the measurement data, consideration of this will be given in Section 7. However, a tentative conclusion is given to suggest the received signal power level was higher than one would expect, given the data obtained in the 2m case.

6.2.2.2 10m Directional

From the 50 data samples per frequency sub-band, the statistical analyses are presented in the following tables and graphs. The graphs (Figures 23-25) dictate the relevant noise powers, measured in dBm, for each 10 MHz frequency slot over the range of 2.3-2.5 GHz.

Average Peak Noise Power :

Table 12 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	2.39E-06	-86.2095487	1.77E-04	-67.52830577	0.420324506	-33.76415289
2.31-2.32	2.70E-06	-85.68797821	7.96E-04	-60.99104531	0.892170244	-30.49552266
2.32-2.33	2.33E-06	-86.32251713	2.08E-04	-66.81832432	0.456124903	-33.40916216
2.33-2.34	1.88E-06	-87.25317991	6.38E-05	-71.94999217	0.252638999	-35.97499608
2.34-2.35	2.02E-06	-86.95333484	5.91E-05	-72.28498587	0.243080828	-36.14249293
2.35-2.36	1.81E-06	-87.42039553	9.27E-05	-70.32897399	0.304474763	-35.16448699
2.36-2.37	1.49E-06	-88.26467807	7.70E-05	-71.13381076	0.277529697	-35.56690538
2.37-2.38	1.76E-06	-87.55441139	4.10E-05	-73.86881416	0.202562614	-36.93440708
2.38-2.39	1.73E-06	-87.62513039	1.02E-04	-69.90100735	0.319852414	-34.95050368
2.39-2.40	3.76E-06	-84.2433786	7.10E-05	-71.4901248	0.266375182	-35.7450624
2.40-2.41	3.32E-06	-84.78997968	3.47E-04	-64.59615587	0.589104318	-32.29807794
2.41-2.42	3.95E-06	-84.03597382	6.90E-04	-61.6139978	0.830424417	-30.8069989
2.42-2.43	1.92E-05	-77.15893996	7.62E-05	-71.17771273	0.27613049	-35.58885637
2.43-2.44	6.04E-05	-72.18785682	1.13E-04	-69.48597418	0.335506772	-34.74298709
2.44-2.45	2.89E-05	-75.38755363	1.21E-04	-69.18715478	0.347250005	-34.59357739
2.45-2.46	0.000600607	-62.21409673	1.98E-04	-67.0306577	0.445109758	-33.51532885
2.46-2.47	0.001075925	-59.68218096	7.56E-04	-61.21507653	0.869453126	-30.60753827
2.47-2.48	3.79E-06	-84.21573386	3.78E-03	-54.22913214	1.943315852	-27.11456607
2.48-2.49	1.85E-06	-87.3227365	5.54E-05	-72.56559164	0.235353368	-36.28279582
2.49-2.50	2.03E-06	-86.91696147	8.65E-05	-70.62804879	0.294169445	-35.3140244

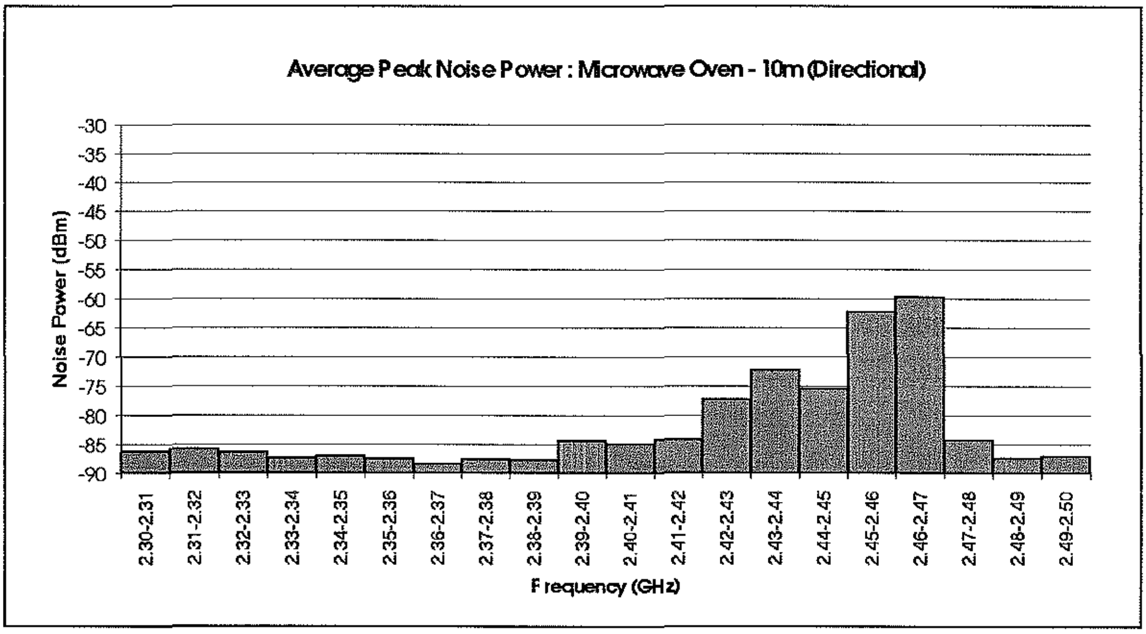

Figure 23 Average Peak Noise Power For Microwave Oven At 10m (Directional)

Average Peak Hold Noise Power (2 minute) :

Table 13 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	3.11E-06	-85.0712896	1.75E-04	-67.55868708	0.418856873	-33.77934354
2.31-2.32	3.40E-06	-84.68323123	8.50E-04	-60.70360918	0.922188158	-30.35180459
2.32-2.33	2.98E-06	-85.26412873	2.41E-04	-66.18065476	0.490870872	-33.09032738
2.33-2.34	2.26E-06	-86.45851128	5.63E-05	-72.49118694	0.237378102	-36.24559347
2.34-2.35	2.71E-06	-85.671229	6.18E-05	-72.09146176	0.248557523	-36.04573088
2.35-2.36	2.66E-06	-85.74648402	9.87E-05	-70.05646432	0.314178733	-35.02823216
2.36-2.37	2.28E-06	-86.4244116	7.49E-05	-71.25444658	0.273701811	-35.62722329
2.37-2.38	2.16E-06	-86.65936283	4.41E-05	-73.55247802	0.210075835	-36.77623901
2.38-2.39	3.57E-06	-84.47447238	7.44E-05	-71.28622103	0.272702393	-35.64311052
2.39-2.40	9.23E-06	-80.34972086	7.30E-05	-71.36427003	0.270262941	-35.68213502
2.40-2.41	6.39E-06	-81.94658765	4.08E-04	-63.89139232	0.638896316	-31.94569616
2.41-2.42	6.15E-06	-82.10799889	6.79E-04	-61.68445222	0.823715786	-30.84222611
2.42-2.43	7.23E-05	-71.40899381	7.21E-05	-71.42329024	0.268432742	-35.71164512
2.43-2.44	0.000291212	-65.35791104	1.01E-04	-69.94844179	0.318110431	-34.9742209
2.44-2.45	7.23E-05	-71.40679649	1.15E-04	-69.37923361	0.33965524	-34.68961681
2.45-2.46	0.005323189	-52.7382808	1.92E-04	-67.16628501	0.438213497	-33.5831425
2.46-2.47	0.006569548	-51.82464504	7.43E-04	-61.28838156	0.862146207	-30.64419078
2.47-2.48	5.83E-06	-82.34501327	3.31E-03	-54.80805278	1.818014577	-27.40402639
2.48-2.49	2.40E-06	-86.19783421	5.47E-05	-72.61911531	0.233907547	-36.30955765
2.49-2.50	2.48E-06	-86.05463919	8.16E-05	-70.88429869	0.285617666	-35.44214935

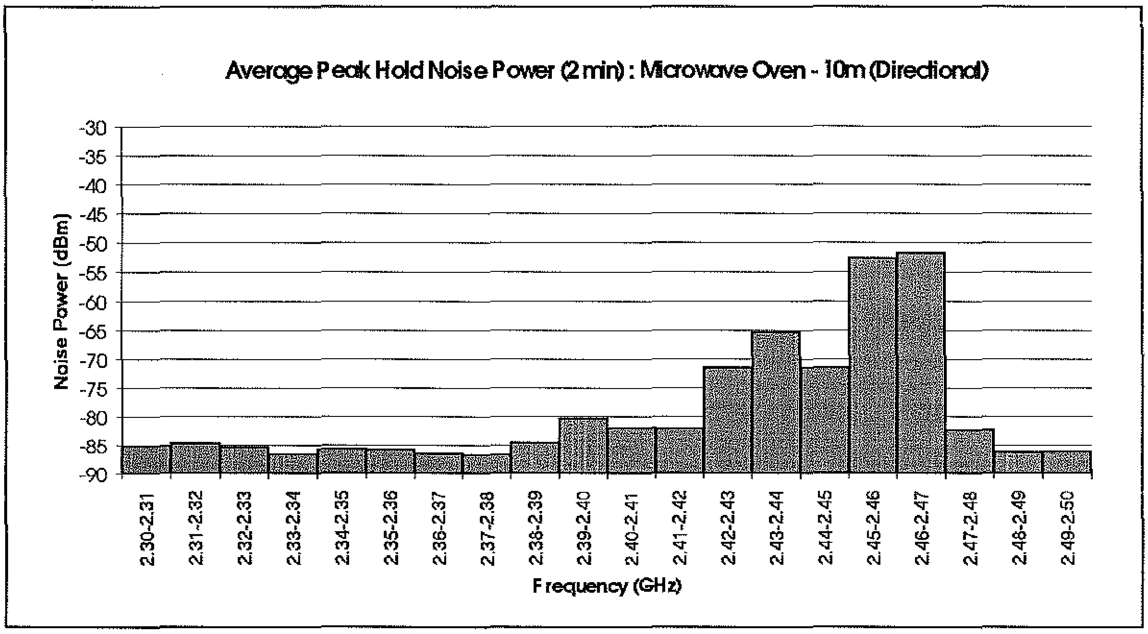

Figure 24 Average Peak Hold Noise Power (2 min) For Microwave Oven At 10m (Directional)

Peak Hold Noise Power (2 minute) :

Table 14 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	0.000175388	-67.56
2.31-2.32	0.000529663	-62.76
2.32-2.33	0.000213796	-66.7
2.33-2.34	9.68E-05	-70.14
2.34-2.35	0.000101625	-69.93
2.35-2.36	0.000144877	-68.39
2.36-2.37	0.000103276	-69.86
2.37-2.38	7.76E-05	-71.1
2.38-2.39	0.000212814	-66.72
2.39-2.40	0.000355631	-64.49
2.40-2.41	0.000591562	-62.28
2.41-2.42	0.000590201	-62.29
2.42-2.43	0.003221069	-54.92
2.43-2.44	0.013182567	-48.8
2.44-2.45	0.00334195	-54.76
2.45-2.46	0.334965439	-34.75
2.46-2.47	0.39536662	-34.03
2.47-2.48	0.001786488	-57.48
2.48-2.49	9.68E-05	-70.14
2.49-2.50	9.68E-05	-70.14

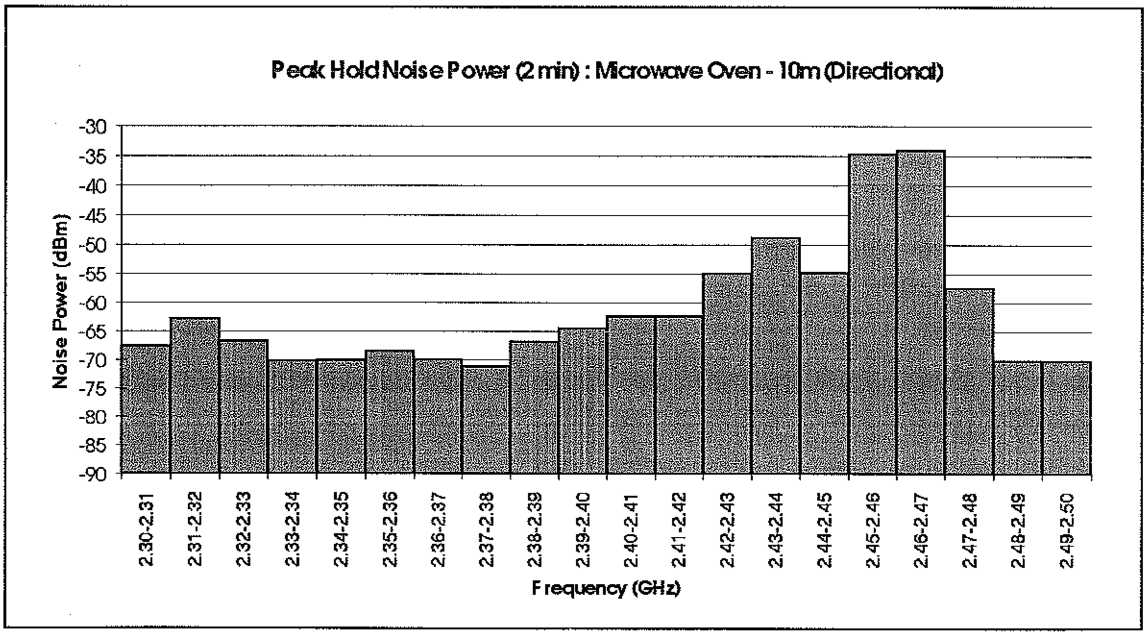

Figure 25 Peak Hold Noise Power (2 min) For Microwave Oven At 10m (Directional)

Once again, similar to the 2m measurements, the majority of the noise power is found in the spectrum from 2.41-2.47 GHz. Accordingly, there is also a reduction in the noise power levels with respect to the 2m directional measurements as expected. Similarly, the reduction in noise power is not quite as high as one may have expected given the increase in distance, but evidence suggests that the degree of reduction was greater than in the omnidirectional case. An explanation for this anomaly, is that it was probably due to the fact that the received power level with the omnidirectional antenna at 2m was lower than the directional antenna, consideration given to the difference in gains. As a result, the difference between the sets of measurements with respect to distance, is larger in the directional case than in the omnidirectional case.

Following on from this, the difference between the omnidirectional and directional measurements that existed for the 2m case, has been nullified. In this case, the omnidirectional measurements are not lower across the board, with respect to the directional measurements. In fact, closer inspection reveals that the reverse has actually occurred, with the noise power registered for the omnidirectional measurements generally exceeding the directional measurements. This is as to be expected however, as at a distance of 10m, the directional antenna is no longer capable of detecting the majority of the leakage signals, as a result of its limited beamwidth. Therefore, a percentage of received signals that occur as a result of bounces from walls and other reflective surfaces will not be received.

6.3 CHARACTERISATION OF MULTIPLE MICROWAVE OVENS

Considering microwave ovens operating in multiplicity, only omnidirectional measurements were taken, as there was little value to be gained from selective measurements. This was deemed so, because the multitude of signals had

many reflective surfaces from which to bounce in the Whitford City Shopping Centre Food Hall, which rendered it impossible to selectively determine the source of any one signal. Rather, the various microwave oven output spectra combined to produce a composite noise environment, that could only be measured with relevance with an omnidirectional antenna.

Rather than provide a separate graph for each classification of measurement data (as per Section 6.2), for successive hourly time frames, the spectral analysis consists of a combination of the average peak, average peak hold (2 min) and peak hold noise power (2 min) for each time frame. This was done in an effort to minimise the number of graphs presented, in such a manner that aids interpretation of the results. Too many graphs would render comparison between the various time intervals a difficult and tedious task.

Figure 26 shows a typical output trace for the food hall operating environment. Once again, the trace provides us with a signature of the environment, which has the usefulness of providing a good indication of what spectrum one can expect in such an topology, with respect to spectral variation and intensity. The trace is actually similar to the one presented in Figure 13, except that the noise is spread more evenly over the entire spectrum, as a result of the differing characteristics of the various microwave ovens. However, it is still possible to notice the peak in noise power between 2.4-2.47 GHz, which is directly coincident with the band of interest for microwave wireless LAN's.

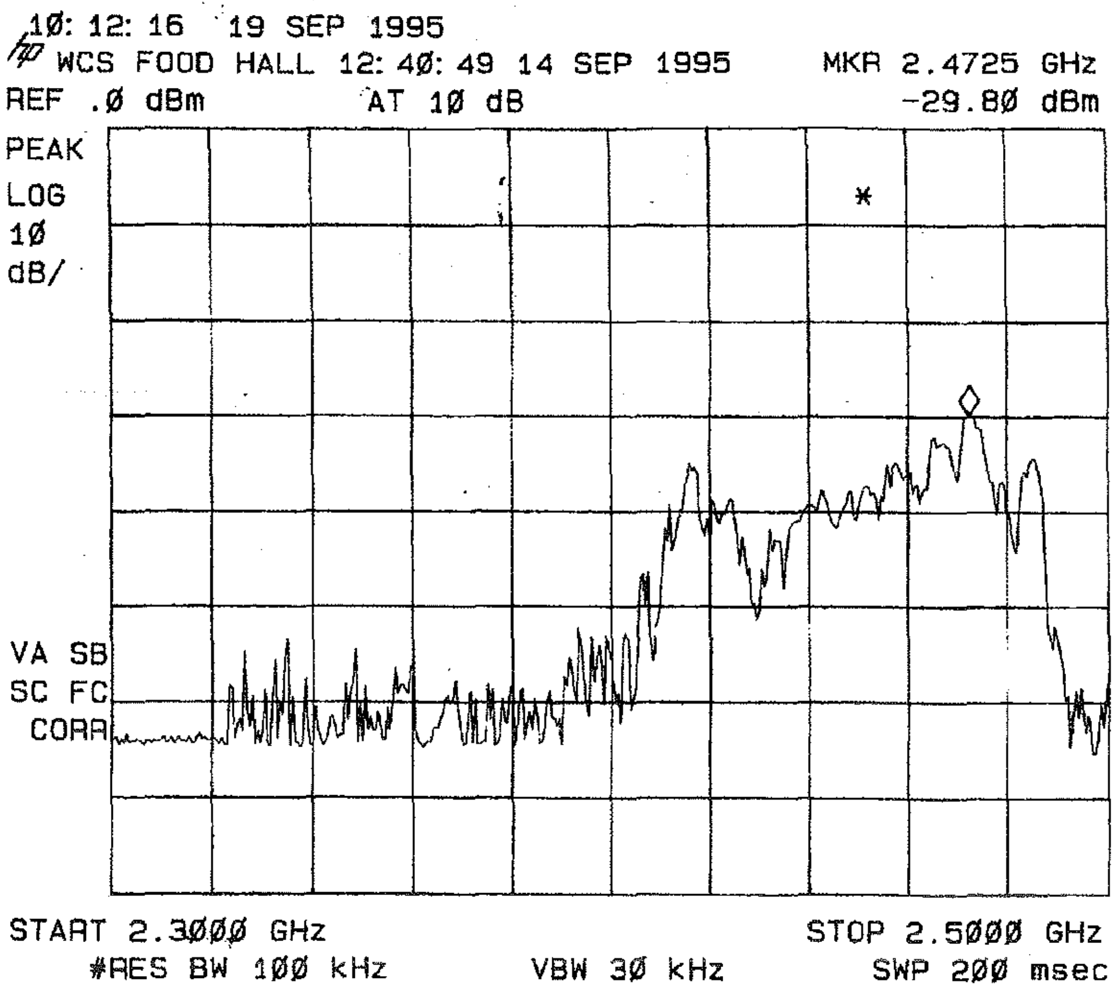

Figure 26 Sample Spectrum Analyser Output For Multiple Microwave Oven Environment At Whitford City Shopping Centre Food Hall Using Omnidirectional Colinear Antenna

6.3.1 Hourly Measurements

6.3.1.1 Time 9-10am

Average Peak Noise Power :

Table 15 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	7.67E-06	-81.1547105	4.07E-05	-73.90178022	0.201795273	-36.95089011
2.31-2.32	7.37E-06	-81.32585524	4.95E-05	-73.05323586	0.222504197	-36.52661793
2.32-2.33	2.70E-05	-75.68536598	9.05E-04	-60.43343219	0.951323863	-30.21671609
2.33-2.34	3.07E-05	-75.13403774	1.58E-03	-58.00291808	1.258502538	-29.00145904
2.34-2.35	2.03E-05	-76.92430477	1.05E-03	-59.7683356	1.027030214	-29.8841678
2.35-2.36	2.14E-05	-76.70386066	6.31E-04	-61.99961466	0.794363475	-30.99980733
2.36-2.37	2.03E-05	-76.9250788	1.00E-03	-60.00074512	0.999914218	-30.00037256
2.37-2.38	2.26E-05	-76.46019019	3.33E-04	-64.77348652	0.577199138	-32.38674326
2.38-2.39	2.48E-05	-76.05218118	2.31E-04	-66.36559654	0.480529631	-33.18279827
2.39-2.40	0.000181109	-67.42060846	1.36E-03	-58.66820209	1.165708319	-29.33410104
2.40-2.41	0.00056121	-62.50874231	4.17E-04	-63.79804585	0.645799505	-31.89902292
2.41-2.42	0.002246702	-56.48454545	3.42E-04	-64.665253	0.584436525	-32.3326265
2.42-2.43	0.001198762	-59.21267021	9.54E-04	-60.20330929	0.976864968	-30.10165465
2.43-2.44	0.001207339	-59.18170871	4.70E-04	-63.27831632	0.685621115	-31.63915816
2.44-2.45	0.002399375	-56.19901907	1.28E-04	-68.9419931	0.357190866	-34.47099655
2.45-2.46	0.005819084	-52.35145361	6.03E-05	-72.19599287	0.245584163	-36.09799644
2.46-2.47	0.006417448	-51.92637657	4.26E-04	-63.70257628	0.65293686	-31.85128814
2.47-2.48	0.014821287	-48.29114088	6.78E-05	-71.6870478	0.260403975	-35.8435239
2.48-2.49	0.001225987	-59.11514017	1.97E-03	-57.05371822	1.40382861	-28.52685911
2.49-2.50	1.48E-05	-78.29015618	4.28E-04	-63.68188259	0.654494303	-31.8409413

Average Peak Hold Noise Power (2 minute) :

Table 16 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.10E-05	-79.57055934	3.70E-05	-74.3128657	0.192467194	-37.15643285
2.31-2.32	1.12E-05	-79.51570055	3.61E-05	-74.4222562	0.190058453	-37.2111281
2.32-2.33	6.81E-05	-71.66732172	8.94E-04	-60.48522524	0.945668097	-30.24261262
2.33-2.34	7.86E-05	-71.04562734	1.50E-03	-58.25207333	1.222915174	-29.12603666
2.34-2.35	5.23E-05	-72.81750179	1.08E-03	-59.68163988	1.037332551	-29.84081994
2.35-2.36	5.49E-05	-72.60414272	6.23E-04	-62.05599434	0.789223999	-31.02799717
2.36-2.37	5.13E-05	-72.90044196	9.87E-04	-60.05649384	0.993517012	-30.02824692
2.37-2.38	5.80E-05	-72.36551263	3.43E-04	-64.64364441	0.585892285	-32.32182221
2.38-2.39	6.23E-05	-72.05189567	2.28E-04	-66.42713158	0.477137358	-33.21356579
2.39-2.40	0.000464283	-63.33217309	1.32E-03	-58.78015368	1.150780028	-29.39007684
2.40-2.41	0.002341876	-56.30436148	5.21E-04	-62.83266587	0.72171662	-31.41633293
2.41-2.42	0.011449537	-49.41212063	3.33E-04	-64.78182473	0.576645309	-32.39091237
2.42-2.43	0.00625139	-52.04023397	9.31E-04	-60.31143458	0.964779954	-30.15571729
2.43-2.44	0.006197662	-52.07772125	4.54E-04	-63.42710573	0.673976438	-31.71355286
2.44-2.45	0.012205114	-49.13458175	1.23E-04	-69.11498227	0.350147384	-34.55749114
2.45-2.46	0.037306483	-44.28215692	5.61E-05	-72.51350999	0.236768815	-36.256755
2.46-2.47	0.042347279	-43.73174494	4.13E-04	-63.835776	0.643000336	-31.917888
2.47-2.48	0.099503087	-40.02163447	5.72E-05	-72.42349287	0.239235352	-36.21174644
2.48-2.49	0.006175559	-52.09323715	1.78E-03	-57.50566503	1.332651979	-28.75283251
2.49-2.50	6.20E-05	-72.07489988	4.21E-04	-63.75798519	0.64878491	-31.8789926

Peak Hold Noise Power (2 minute) :

Table 17 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.59E-05	-77.99
2.31-2.32	1.47E-05	-78.33
2.32-2.33	0.000442	-63.55
2.33-2.34	0.000583	-62.34
2.34-2.35	0.000367	-64.35
2.35-2.36	0.000288	-65.4
2.36-2.37	0.000326	-64.87
2.37-2.38	0.000164	-67.84
2.38-2.39	0.000163	-67.87
2.39-2.40	0.003715	-54.3
2.40-2.41	0.00867	-50.62
2.41-2.42	0.035892	-44.45
2.42-2.43	0.027164	-45.66
2.43-2.44	0.017783	-47.5
2.44-2.45	0.022387	-46.5
2.45-2.46	0.05445	-42.64
2.46-2.47	0.099541	-40.02
2.47-2.48	0.147231	-38.32
2.48-2.49	0.035892	-44.45
2.49-2.50	0.000176	-67.54

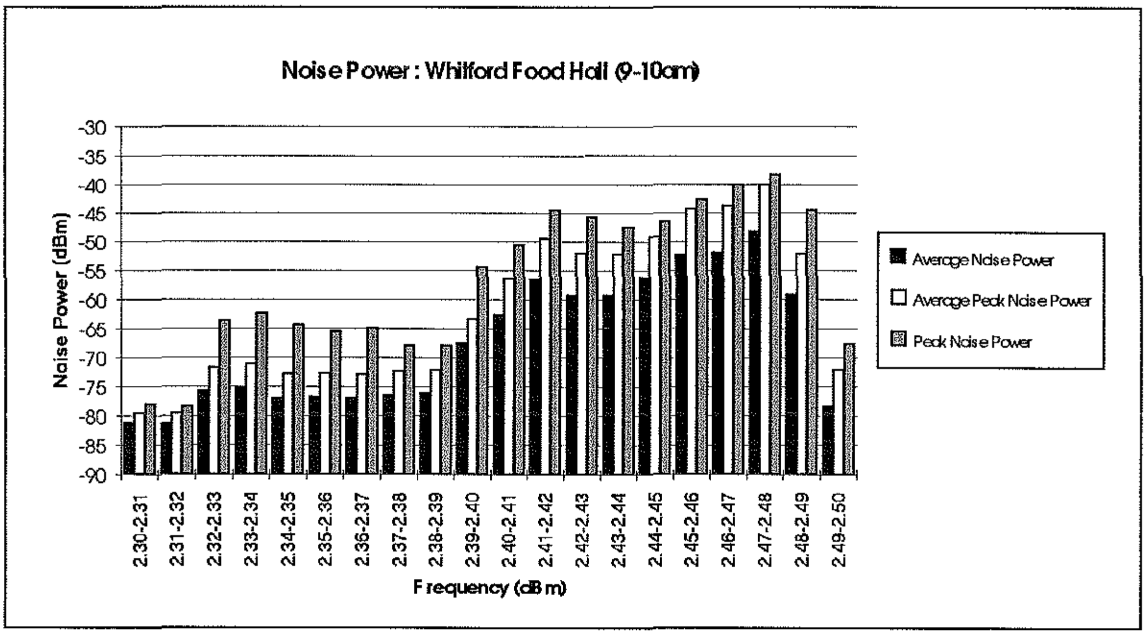

Figure 27 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (9-10am)

6.3.1.2 Time (10-11am)

Average Peak Noise Power :

Table 18 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	7.69E-06	-81.13859398	4.14E-05	-73.82667169	0.203547801	-36.91333585
2.31-2.32	7.38E-06	-81.31701249	4.82E-05	-73.17105895	0.219506332	-36.58552948
2.32-2.33	1.66E-05	-77.7988679	9.06E-04	-60.42703043	0.952025276	-30.21351521
2.33-2.34	1.81E-05	-77.4236366	1.59E-03	-57.97423778	1.262664908	-28.98711889
2.34-2.35	1.19E-05	-79.2459506	1.04E-03	-59.83878287	1.018734131	-29.91939143
2.35-2.36	1.28E-05	-78.91130079	6.34E-04	-61.9811806	0.796051143	-30.9905903
2.36-2.37	9.74E-06	-80.1162168	1.03E-03	-59.89064459	1.012669595	-29.94532229
2.37-2.38	1.08E-05	-79.64590059	3.49E-04	-64.57280198	0.590690384	-32.28640099
2.38-2.39	1.28E-05	-78.9198617	2.36E-04	-66.26366442	0.486202042	-33.13183221
2.39-2.40	7.32E-05	-71.35712851	1.39E-03	-58.5628679	1.179930982	-29.28143395
2.40-2.41	0.000228483	-66.41146371	4.04E-04	-63.93499284	0.635697287	-31.96749642
2.41-2.42	0.000468651	-63.29150468	3.11E-04	-65.07936564	0.557226444	-32.53968282
2.42-2.43	0.000248708	-66.04310252	9.57E-04	-60.1910431	0.978245469	-30.09552155
2.43-2.44	0.000248909	-66.03960058	4.80E-04	-63.18825517	0.692767079	-31.59412759
2.44-2.45	0.00049705	-63.03599996	1.26E-04	-69.00706554	0.354524884	-34.50353277
2.45-2.46	0.001202077	-59.20067535	5.80E-05	-72.36335906	0.240897364	-36.18167953
2.46-2.47	0.001343738	-58.71685357	4.49E-04	-63.47988614	0.669893391	-31.73994307
2.47-2.48	0.003077062	-55.11863702	7.27E-05	-71.38706223	0.269554688	-35.69353111
2.48-2.49	0.000247888	-66.057448	1.89E-03	-57.23668812	1.374565989	-28.61834406
2.49-2.50	9.13E-06	-80.39711435	4.26E-04	-63.70428212	0.652808641	-31.85214106

Average Peak Hold Noise Power (2 minute) :

Table 19 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.07E-05	-79.71968094	3.88E-05	-74.11390913	0.196926673	-37.05695456
2.31-2.32	1.08E-05	-79.67436728	3.76E-05	-74.24256883	0.194031195	-37.12128442
2.32-2.33	3.39E-05	-74.70234155	1.01E-03	-59.95793695	1.004854432	-29.97896848
2.33-2.34	4.21E-05	-73.75820553	1.49E-03	-58.25685261	1.222242467	-29.12842631
2.34-2.35	2.82E-05	-75.4961122	9.41E-04	-60.26352352	0.97011635	-30.13176176
2.35-2.36	3.37E-05	-74.72545579	6.29E-04	-62.01619769	0.792848329	-31.00809885
2.36-2.37	2.46E-05	-76.09322621	1.02E-03	-59.90993426	1.010423148	-29.95496713
2.37-2.38	2.66E-05	-75.74606568	3.25E-04	-64.87752961	0.570326458	-32.4387648
2.38-2.39	3.76E-05	-74.24831034	2.12E-04	-66.72705691	0.460942926	-33.36352846
2.39-2.40	0.000175516	-67.55682231	1.34E-03	-58.73207163	1.157168009	-29.36603581
2.40-2.41	0.000962809	-60.16460077	5.14E-04	-62.88921456	0.717033212	-31.44460728
2.41-2.42	0.003121763	-55.05600134	3.07E-04	-65.12290655	0.55444015	-32.56145328
2.42-2.43	0.001541061	-58.12180145	9.77E-04	-60.10004474	0.988548003	-30.05002237
2.43-2.44	0.001757356	-57.55140194	4.45E-04	-63.51194794	0.667425204	-31.75597397
2.44-2.45	0.003648286	-54.37911071	1.36E-04	-68.66162349	0.368908639	-34.33081174
2.45-2.46	0.014408517	-48.4138071	7.22E-05	-71.41400784	0.268719763	-35.70700392
2.46-2.47	0.013111071	-48.82361828	4.14E-04	-63.8317767	0.643296465	-31.91588835
2.47-2.48	0.024788164	-46.05755647	6.22E-05	-72.06394234	0.249346274	-36.03197117
2.48-2.49	0.002196203	-56.58327593	1.72E-03	-57.64623267	1.311258652	-28.82311633
2.49-2.50	3.28E-05	-74.84736396	4.11E-04	-63.8658628	0.640776919	-31.9329314

Peak Hold Noise Power (2 minute) :

Table 20 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.53E-05	-78.14
2.31-2.32	1.45E-05	-78.39
2.32-2.33	0.000232	-66.35
2.33-2.34	0.000313	-65.04
2.34-2.35	0.000182	-67.4
2.35-2.36	0.000178	-67.5
2.36-2.37	0.000155	-68.11
2.37-2.38	7.52E-05	-71.24
2.38-2.39	0.000101	-69.97
2.39-2.40	0.001413	-58.5
2.40-2.41	0.003573	-54.47
2.41-2.42	0.00857	-50.67
2.42-2.43	0.007379	-51.32
2.43-2.44	0.004467	-53.5
2.44-2.45	0.007691	-51.14
2.45-2.46	0.025119	-46
2.46-2.47	0.03062	-45.14
2.47-2.48	0.035727	-44.47
2.48-2.49	0.013032	-48.85
2.49-2.50	8.89E-05	-70.51

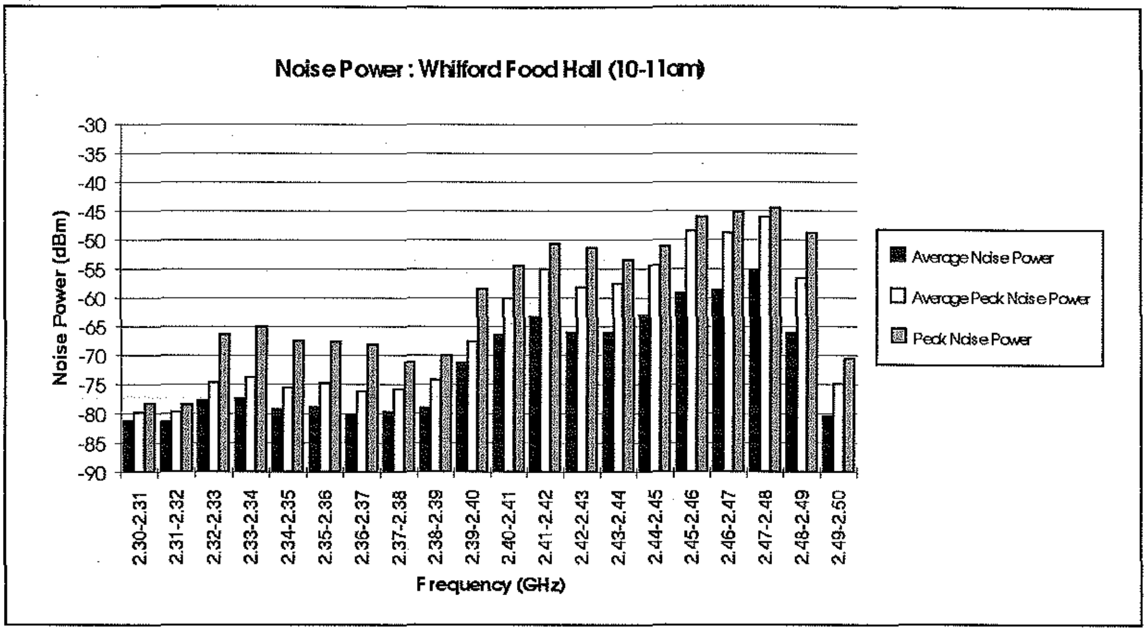

Figure 28 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (10-11am)

6.3.1.3 Time (11-12pm)

Average Peak Noise Power :

Table 21 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	9.39E-06	-80.27177075	4.32E-05	-73.64682934	0.207806215	-36.82341467
2.31-2.32	9.07E-06	-80.42500538	5.84E-05	-72.33661739	0.241640169	-36.1683087
2.32-2.33	3.89E-05	-74.10277764	9.11E-04	-60.40585103	0.954349496	-30.20292552
2.33-2.34	5.13E-05	-72.90061351	1.56E-03	-58.07217046	1.248508424	-29.03608523
2.34-2.35	3.21E-05	-74.92907356	8.82E-04	-60.54754784	0.938907067	-30.27377392
2.35-2.36	3.20E-05	-74.94849496	6.30E-04	-62.00424177	0.793940418	-31.00212089
2.36-2.37	2.84E-05	-75.45930363	9.87E-04	-60.057696	0.993379515	-30.028848
2.37-2.38	3.54E-05	-74.51230228	3.53E-04	-64.5249303	0.593954921	-32.26246515
2.38-2.39	3.99E-05	-73.98799835	2.38E-04	-66.22539351	0.488349024	-33.11269676
2.39-2.40	0.000337705	-64.71462562	1.35E-03	-58.70718709	1.160487978	-29.35359354
2.40-2.41	0.001033538	-59.85673359	4.57E-04	-63.39966644	0.676108939	-31.69983322
2.41-2.42	0.004209391	-53.7578078	3.74E-04	-64.27037355	0.611619499	-32.13518678
2.42-2.43	0.001816689	-57.40719318	1.01E-03	-59.94810165	1.005992904	-29.97405083
2.43-2.44	0.001908021	-57.19416837	4.64E-04	-63.3351802	0.681147222	-31.6675901
2.44-2.45	0.003875976	-54.11618947	1.28E-04	-68.92873406	0.357736536	-34.46436703
2.45-2.46	0.00973471	-50.1167697	6.14E-05	-72.11593629	0.247858139	-36.05796815
2.46-2.47	0.010973014	-49.59674073	4.44E-04	-63.52497464	0.66642498	-31.76248732
2.47-2.48	0.022415409	-46.49453342	6.84E-05	-71.64693128	0.261609455	-35.82346564
2.48-2.49	0.0018541	-57.31866915	1.95E-03	-57.09555501	1.397083133	-28.5477775
2.49-2.50	2.79E-05	-75.54496835	4.57E-04	-63.40223382	0.675909124	-31.70111691

Average Peak Hold Noise Power (2 minute) :

Table 22 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.31E-05	-78.84291847	3.95E-05	-74.03142368	0.198805693	-37.01571184
2.31-2.32	1.32E-05	-78.78601826	3.86E-05	-74.12932685	0.196577432	-37.06466343
2.32-2.33	0.000116974	-69.31912436	8.98E-04	-60.46483056	0.947891158	-30.23241528
2.33-2.34	0.000151629	-68.19216624	1.35E-03	-58.68590205	1.163335276	-29.34295103
2.34-2.35	8.34E-05	-70.78993079	1.16E-03	-59.36184804	1.076236205	-29.68092402
2.35-2.36	8.26E-05	-70.83176665	6.27E-04	-62.02484573	0.792059329	-31.01242286
2.36-2.37	8.36E-05	-70.77950292	1.08E-03	-59.65841145	1.040110373	-29.82920572
2.37-2.38	9.57E-05	-70.19245535	3.45E-04	-64.61661988	0.587718019	-32.30830994
2.38-2.39	0.000107701	-69.67780387	2.25E-04	-66.47549546	0.474487993	-33.23774773
2.39-2.40	0.000931473	-60.30829778	1.35E-03	-58.69829351	1.161676822	-29.34914676
2.40-2.41	0.004727888	-53.25332779	5.44E-04	-62.64672793	0.737332885	-31.32336396
2.41-2.42	0.026539999	-45.76099095	3.62E-04	-64.41677561	0.601396948	-32.2083878
2.42-2.43	0.01504534	-48.22597999	9.21E-04	-60.35726683	0.959702571	-30.17863342
2.43-2.44	0.01577159	-48.02124513	4.43E-04	-63.5402143	0.665256742	-31.77010715
2.44-2.45	0.034307123	-44.64615698	1.27E-04	-68.95027726	0.356850358	-34.47513863
2.45-2.46	0.09762095	-40.1045697	5.52E-05	-72.57780977	0.235022538	-36.28890488
2.46-2.47	0.102365969	-39.89844397	4.07E-04	-63.90122675	0.638173348	-31.95061337
2.47-2.48	0.241292602	-36.17455993	6.09E-05	-72.15478267	0.246752105	-36.07739134
2.48-2.49	0.013171345	-48.80369866	1.80E-03	-57.45006137	1.341210459	-28.72503068
2.49-2.50	0.000101221	-69.94727963	4.03E-04	-63.95233521	0.634429311	-31.97616761

Peak Hold Noise Power (2 minute) :

Table 23 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.91E-05	-77.19
2.31-2.32	1.85E-05	-77.33
2.32-2.33	0.000741	-61.3
2.33-2.34	0.001016	-59.93
2.34-2.35	0.000586	-62.32
2.35-2.36	0.000436	-63.61
2.36-2.37	0.000578	-62.38
2.37-2.38	0.000274	-65.62
2.38-2.39	0.000282	-65.49
2.39-2.40	0.007516	-51.24
2.40-2.41	0.018281	-47.38
2.41-2.42	0.081658	-40.88
2.42-2.43	0.064863	-41.88
2.43-2.44	0.042855	-43.68
2.44-2.45	0.06792	-41.68
2.45-2.46	0.140281	-38.53
2.46-2.47	0.241546	-36.17
2.47-2.48	0.349945	-34.56
2.48-2.49	0.077268	-41.12
2.49-2.50	0.000277	-65.57

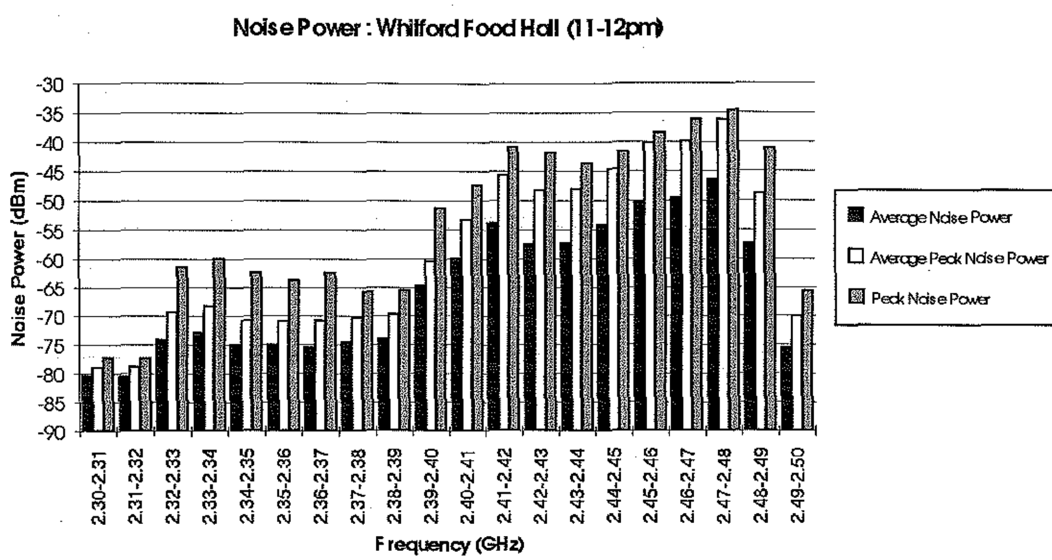

Figure 29 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (11-12pm)

6.3.1.4 Time (12-1pm)

Average Peak Noise Power :

Table 24 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.03E-05	-79.89172485	4.57E-05	-73.3965826	0.213880342	-36.6982913
2.31-2.32	9.99E-06	-80.00247507	5.45E-05	-72.63279587	0.233539425	-36.31639794
2.32-2.33	5.16E-05	-72.87075385	9.04E-04	-60.43637149	0.951001989	-30.21818575
2.33-2.34	6.97E-05	-71.56950028	1.58E-03	-58.00854921	1.257686906	-29.00427461
2.34-2.35	4.84E-05	-73.15321147	8.91E-04	-60.49934244	0.944132349	-30.24967122
2.35-2.36	4.35E-05	-73.61393232	6.32E-04	-61.99439569	0.794840917	-30.99719784
2.36-2.37	3.88E-05	-74.11571921	9.62E-04	-60.16725792	0.980927938	-30.08362896
2.37-2.38	5.27E-05	-72.78335551	3.57E-04	-64.46895646	0.597794861	-32.23447823
2.38-2.39	6.34E-05	-71.98181201	2.36E-04	-66.27441535	0.48560062	-33.13720768
2.39-2.40	0.000537606	-62.69536105	1.50E-03	-58.22735133	1.226400823	-29.11367567
2.40-2.41	0.001436244	-58.42771626	4.55E-04	-63.41623294	0.674820633	-31.70811647
2.41-2.42	0.00642203	-51.92327647	3.71E-04	-64.31071951	0.608785114	-32.15535976
2.42-2.43	0.002082559	-56.81402609	1.07E-03	-59.70093728	1.035030472	-29.85046864
2.43-2.44	0.002846594	-55.45674509	4.76E-04	-63.22038459	0.690209243	-31.61019229
2.44-2.45	0.00569677	-52.44371296	1.30E-04	-68.848993	0.361035868	-34.4244965
2.45-2.46	0.01263496	-48.98426121	7.93E-05	-71.00798324	0.281579373	-35.50399162
2.46-2.47	0.017083417	-47.67425246	4.30E-04	-63.66067319	0.656094414	-31.8303366
2.47-2.48	0.02728929	-45.64007758	7.34E-05	-71.34182564	0.270962205	-35.67091282
2.48-2.49	0.002258644	-56.46152262	2.00E-03	-56.99512045	1.413331301	-28.49756023
2.49-2.50	3.05E-05	-75.15342626	4.62E-04	-63.35295175	0.679755003	-31.67647587

Average Peak Hold Noise Power (2 minute) :

Table 25 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.41E-05	-78.51414307	4.16E-05	-73.80843654	0.203975578	-36.90421827
2.31-2.32	1.50E-05	-78.23139329	4.15E-05	-73.81879766	0.203732407	-36.90939883
2.32-2.33	0.000141997	-68.47720986	8.11E-04	-60.90816177	0.900724366	-30.45408089
2.33-2.34	0.00017625	-67.53871824	1.38E-03	-58.61298246	1.173142793	-29.30649123
2.34-2.35	0.0001085	-69.64571806	1.01E-03	-59.97019793	1.003436983	-29.98509896
2.35-2.36	9.57E-05	-70.18892834	6.35E-04	-61.96953273	0.797119371	-30.98476637
2.36-2.37	8.74E-05	-70.58338279	1.06E-03	-59.75185455	1.028980803	-29.87592728
2.37-2.38	0.000130628	-68.83962078	3.34E-04	-64.75834135	0.578206451	-32.37917068
2.38-2.39	0.000172133	-67.64134832	2.33E-04	-66.31992647	0.483062892	-33.15996323
2.39-2.40	0.00143251	-58.43902407	1.35E-03	-58.69585147	1.162003474	-29.34792574
2.40-2.41	0.006566125	-51.82690882	5.47E-04	-62.61790863	0.739783377	-31.30895432
2.41-2.42	0.024147976	-46.1711927	3.48E-04	-64.58685403	0.589735537	-32.29342701
2.42-2.43	0.01807553	-47.42908969	9.16E-04	-60.37950678	0.957248426	-30.18975339
2.43-2.44	0.026920425	-45.69918087	4.47E-04	-63.49700412	0.668574478	-31.74850206
2.44-2.45	0.061815707	-42.08901162	1.22E-04	-69.14672703	0.348870019	-34.57336351
2.45-2.46	0.115387946	-39.37839558	5.53E-05	-72.57377384	0.235131767	-36.28688692
2.46-2.47	0.138941443	-38.57168194	4.05E-04	-63.92753559	0.636243298	-31.9637678
2.47-2.48	0.256066162	-35.91647808	5.97E-05	-72.24365086	0.244240375	-36.12182543
2.48-2.49	0.022462028	-46.4855103	1.78E-03	-57.49315335	1.334572994	-28.74657668
2.49-2.50	0.000119465	-69.22759019	4.05E-04	-63.92863343	0.636162886	-31.96431671

Peak Hold Noise Power (2 minute) :

Table 26 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	2.09E-05	-76.79
2.31-2.32	2.14E-05	-76.7
2.32-2.33	0.000853	-60.69
2.33-2.34	0.001194	-59.23
2.34-2.35	0.000689	-61.62
2.35-2.36	0.000508	-62.94
2.36-2.37	0.000603	-62.2
2.37-2.38	0.000377	-64.24
2.38-2.39	0.000451	-63.46
2.39-2.40	0.011561	-49.37
2.40-2.41	0.025468	-45.94
2.41-2.42	0.068707	-41.63
2.42-2.43	0.077804	-41.09
2.43-2.44	0.072111	-41.42
2.44-2.45	0.11246	-39.49
2.45-2.46	0.167494	-37.76
2.46-2.47	0.327341	-34.85
2.47-2.48	0.372392	-34.29
2.48-2.49	0.132739	-38.77
2.49-2.50	0.000323	-64.91

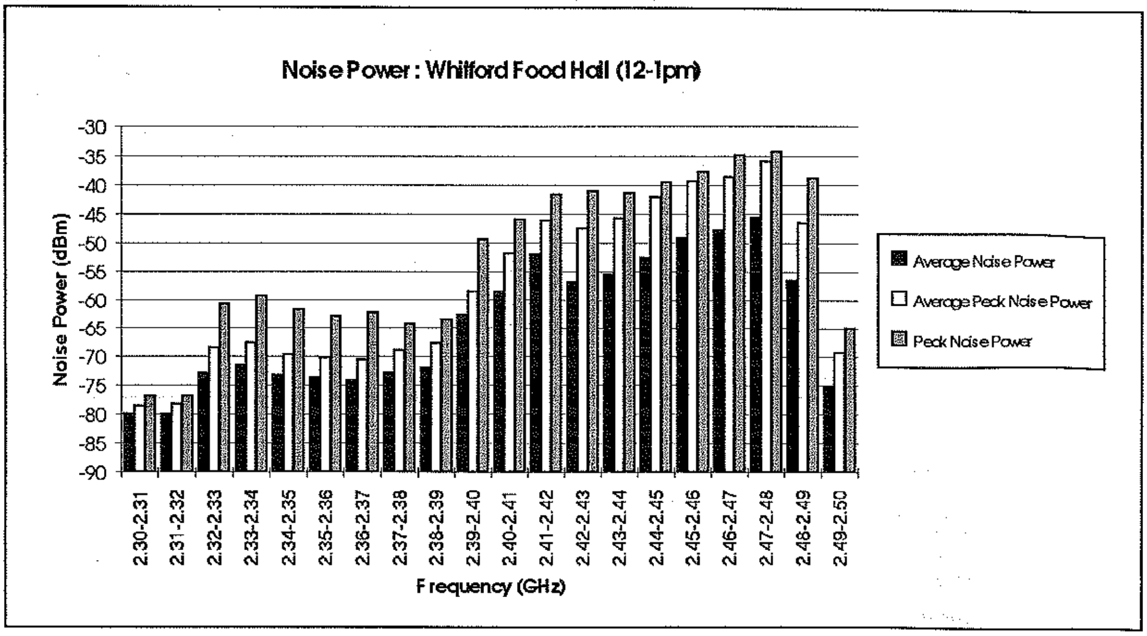

Figure 30 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (12-1pm)

6.3.1.5 Time (1-2pm)

Average Peak Noise Power :

Table 27 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	9.45E-06	-80.24429327	4.48E-05	-73.48470411	0.211721418	-36.74235205
2.31-2.32	9.16E-06	-80.3804799	5.77E-05	-72.38967258	0.24016868	-36.19483629
2.32-2.33	4.22E-05	-73.74202808	8.66E-04	-60.62485214	0.930587882	-30.31242607
2.33-2.34	5.68E-05	-72.45367904	1.61E-03	-57.93292653	1.268684615	-28.96646327
2.34-2.35	3.50E-05	-74.55728517	9.05E-04	-60.43285925	0.951386616	-30.21642962
2.35-2.36	3.49E-05	-74.5755329	6.12E-04	-62.13330315	0.782230675	-31.06665157
2.36-2.37	2.99E-05	-75.24897684	9.34E-04	-60.29492252	0.966615765	-30.14746126
2.37-2.38	3.79E-05	-74.21830946	3.38E-04	-64.71081645	0.581378782	-32.35540822
2.38-2.39	4.42E-05	-73.54648849	2.34E-04	-66.30445907	0.483923872	-33.15222954
2.39-2.40	0.000377875	-64.22651466	1.34E-03	-58.72232342	1.158467433	-29.36116171
2.40-2.41	0.001134558	-59.45173411	4.54E-04	-63.43252719	0.673555893	-31.7162636
2.41-2.42	0.004675767	-53.30147141	3.76E-04	-64.24728945	0.613247135	-32.12364472
2.42-2.43	0.001995152	-57.00023977	9.94E-04	-60.02500639	0.997125173	-30.01250319
2.43-2.44	0.002091087	-56.79627873	4.47E-04	-63.49799415	0.668498277	-31.74899708
2.44-2.45	0.004278097	-53.68749378	1.26E-04	-68.9820129	0.355548913	-34.49100645
2.45-2.46	0.010791617	-49.66913489	5.88E-05	-72.30939218	0.242398758	-36.15469609
2.46-2.47	0.012144231	-49.15629981	4.37E-04	-63.59713015	0.66091178	-31.79856507
2.47-2.48	0.024734549	-46.06696004	6.27E-05	-72.02934945	0.250341314	-36.01467473
2.48-2.49	0.002000877	-56.98779582	1.97E-03	-57.05734481	1.403242596	-28.52867241
2.49-2.50	2.93E-05	-75.33349256	4.29E-04	-63.67281191	0.655178149	-31.83640595

Average Peak Hold Noise Power (2 minute) :

Table 28 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.95E-05	-77.11080726	6.39E-04	-61.94186981	0.799662093	-30.9709349
2.31-2.32	1.37E-05	-78.63736135	3.65E-05	-74.3754119	0.191086236	-37.18770595
2.32-2.33	0.0001309	-68.83060139	9.82E-04	-60.07867747	0.990982823	-30.03933873
2.33-2.34	0.000162891	-67.88102995	1.35E-03	-58.68843342	1.162996289	-29.34421671
2.34-2.35	9.27E-05	-70.32979669	1.25E-03	-59.03971239	1.11690023	-29.5198562
2.35-2.36	9.18E-05	-70.37026979	6.96E-04	-61.57129672	0.834516953	-30.78564836
2.36-2.37	8.62E-05	-70.64270455	1.07E-03	-59.72084785	1.032660601	-29.86042392
2.37-2.38	0.000101869	-69.91956095	3.26E-04	-64.86752717	0.570983609	-32.43376359
2.38-2.39	0.000121597	-69.15077932	2.22E-04	-66.54305474	0.470811718	-33.27152737
2.39-2.40	0.000991321	-60.03785491	1.39E-03	-58.58274469	1.177233916	-29.29137234
2.40-2.41	0.005141835	-52.88881846	5.49E-04	-62.60512343	0.740873103	-31.30256172
2.41-2.42	0.028243895	-45.49075419	3.42E-04	-64.6580049	0.584924423	-32.32900245
2.42-2.43	0.016672733	-47.77993216	9.79E-04	-60.09322882	0.989324032	-30.04661441
2.43-2.44	0.01697035	-47.70309204	4.36E-04	-63.60224455	0.660522738	-31.80112228
2.44-2.45	0.036872542	-44.33296919	1.25E-04	-69.03926201	0.353213179	-34.51963101
2.45-2.46	0.105143912	-39.78215869	5.30E-05	-72.75337516	0.230319783	-36.37668758
2.46-2.47	0.1075957	-39.68205083	3.82E-04	-64.17907999	0.618081864	-32.08953999
2.47-2.48	0.257804142	-35.88710109	5.88E-05	-72.30632432	0.242484389	-36.15316216
2.48-2.49	0.013955531	-48.55253622	1.81E-03	-57.4133735	1.346887508	-28.70668675
2.49-2.50	0.000102937	-69.87428001	3.95E-04	-64.03932392	0.628107247	-32.01966196

Peak Hold Noise Power (2 minute) :

Table 29 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	6.38E-05	-71.95
2.31-2.32	1.88E-05	-77.25
2.32-2.33	0.000869	-60.61
2.33-2.34	0.001096	-59.6
2.34-2.35	0.000671	-61.73
2.35-2.36	0.000507	-62.95
2.36-2.37	0.000593	-62.27
2.37-2.38	0.000284	-65.47
2.38-2.39	0.000319	-64.96
2.39-2.40	0.008147	-50.89
2.40-2.41	0.019953	-47
2.41-2.42	0.085114	-40.7
2.42-2.43	0.073621	-41.33
2.43-2.44	0.046026	-43.37
2.44-2.45	0.072277	-41.41
2.45-2.46	0.148936	-38.27
2.46-2.47	0.247742	-36.06
2.47-2.48	0.377572	-34.23
2.48-2.49	0.082985	-40.81
2.49-2.50	0.00028	-65.53

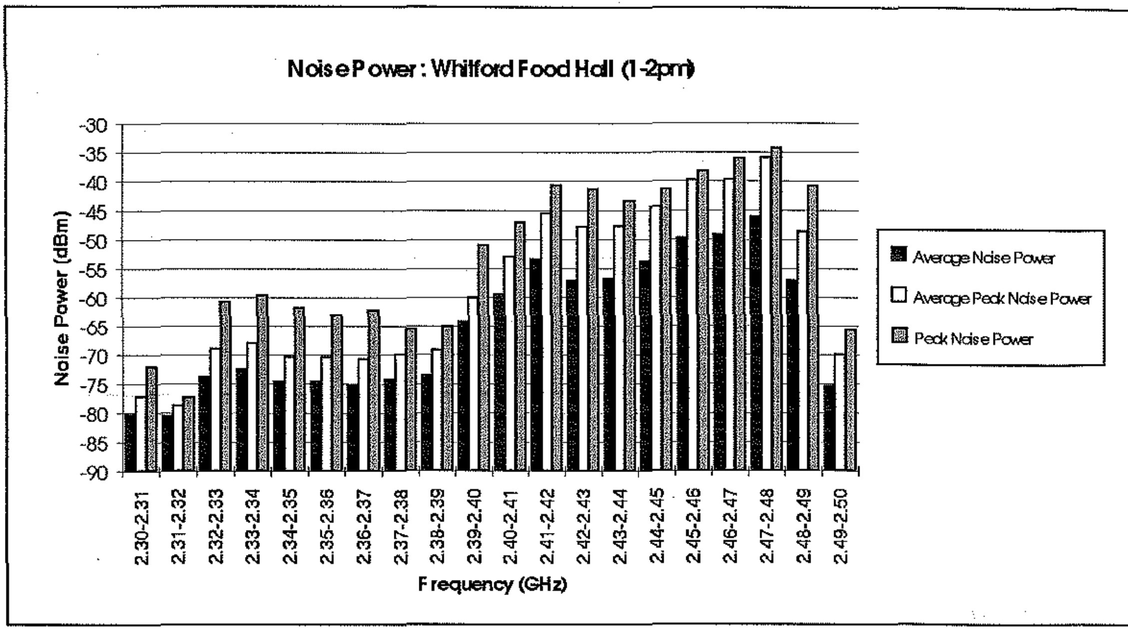

Figure 31 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (1-2pm)

6.3.1.6 Time (2-3pm)

Average Peak Noise Power :

Table 30 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	7.81E-06	-81.07567254	4.29E-05	-73.68042467	0.207004014	-36.84021233
2.31-2.32	7.42E-06	-81.2953328	4.95E-05	-73.05161448	0.222545735	-36.52580724
2.32-2.33	1.71E-05	-77.66539514	9.10E-04	-60.40899502	0.954004117	-30.20449751
2.33-2.34	1.91E-05	-77.19420667	1.59E-03	-57.99512278	1.259632511	-28.99756139
2.34-2.35	1.26E-05	-79.01084726	1.04E-03	-59.84761615	1.017698636	-29.92380808
2.35-2.36	1.34E-05	-78.73291596	6.17E-04	-62.09941787	0.785288263	-31.04970894
2.36-2.37	9.97E-06	-80.0114855	1.00E-03	-59.99877669	1.000140849	-29.99938834
2.37-2.38	1.12E-05	-79.52693147	3.36E-04	-64.74004944	0.579425399	-32.37002472
2.38-2.39	1.39E-05	-78.58193144	2.35E-04	-66.2929188	0.484567252	-33.1464594
2.39-2.40	7.84E-05	-71.05570055	1.37E-03	-58.62298232	1.171792958	-29.31149116
2.40-2.41	0.000244766	-66.11249424	3.97E-04	-64.01398001	0.62994263	-32.00699
2.41-2.42	0.000489576	-63.10180298	2.99E-04	-65.24640788	0.546612559	-32.62320394
2.42-2.43	0.000256288	-65.91271918	9.26E-04	-60.33533876	0.962128462	-30.16766938
2.43-2.44	0.000259704	-65.85521031	4.73E-04	-63.252429	0.68766758	-31.6262145
2.44-2.45	0.000511761	-62.90933083	1.08E-04	-69.67228252	0.328386938	-34.83614126
2.45-2.46	0.001265626	-58.9769452	5.43E-05	-72.65234102	0.233014501	-36.32617051
2.46-2.47	0.001427383	-58.45459533	4.36E-04	-63.60349778	0.660427442	-31.80174889
2.47-2.48	0.003194322	-54.95621283	6.74E-05	-71.71630881	0.259528203	-35.8581544
2.48-2.49	0.000254712	-65.93949774	1.90E-03	-57.20982569	1.378823623	-28.60491285
2.49-2.50	9.26E-06	-80.33262381	4.15E-04	-63.81636507	0.644438898	-31.90818254

Average Peak Hold Noise Power (2 minute) :

Table 31 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.07E-05	-79.69235129	3.90E-05	-74.08856362	0.197502146	-37.04428181
2.31-2.32	1.09E-05	-79.63288562	3.73E-05	-74.28649432	0.193052435	-37.14324716
2.32-2.33	3.47E-05	-74.59057262	9.84E-04	-60.06912238	0.992073574	-30.03456119
2.33-2.34	4.30E-05	-73.66706168	1.49E-03	-58.26248856	1.221449657	-29.13124428
2.34-2.35	2.91E-05	-75.36804257	9.20E-04	-60.36021622	0.959376749	-30.18010811
2.35-2.36	3.46E-05	-74.61268636	6.12E-04	-62.13268668	0.782286195	-31.06634334
2.36-2.37	2.49E-05	-76.03344426	1.01E-03	-59.96382315	1.0041737	-29.98191157
2.37-2.38	2.70E-05	-75.69087829	3.17E-04	-64.98900836	0.563053396	-32.49450418
2.38-2.39	3.90E-05	-74.08724138	2.15E-04	-66.68179722	0.463351037	-33.34089861
2.39-2.40	0.000179772	-67.45278581	1.33E-03	-58.77080487	1.152019304	-29.38540243
2.40-2.41	0.001002112	-59.99083918	5.03E-04	-62.98483617	0.709182796	-31.49241808
2.41-2.42	0.003326517	-54.7801029	2.78E-04	-65.56384429	0.526996566	-32.78192214
2.42-2.43	0.001635282	-57.86407402	9.01E-04	-60.45074163	0.94942993	-30.22537082
2.43-2.44	0.001832235	-57.37018747	4.07E-04	-63.89959872	0.638292974	-31.94979936
2.44-2.45	0.003762256	-54.24551698	1.17E-04	-69.31732664	0.342084714	-34.65866332
2.45-2.46	0.014929105	-48.25966229	7.74E-05	-71.1105369	0.278274336	-35.55526845
2.46-2.47	0.013006971	-48.85823836	3.65E-04	-64.37629019	0.604206636	-32.18814509
2.47-2.48	0.026276706	-45.80429079	5.91E-05	-72.28725281	0.243017394	-36.1436264
2.48-2.49	0.002322829	-56.3398267	1.72E-03	-57.65217835	1.310361373	-28.82608918
2.49-2.50	3.30E-05	-74.81226914	4.08E-04	-63.89517749	0.638617956	-31.94758874

Peak Hold Noise Power (2 minute) :

Table 32 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.56E-05	-78.07
2.31-2.32	1.46E-05	-78.37
2.32-2.33	0.000234	-66.3
2.33-2.34	0.00032	-64.95
2.34-2.35	0.000186	-67.31
2.35-2.36	0.00018	-67.44
2.36-2.37	0.000156	-68.07
2.37-2.38	7.53E-05	-71.23
2.38-2.39	0.000104	-69.81
2.39-2.40	0.001442	-58.41
2.40-2.41	0.003681	-54.34
2.41-2.42	0.00869	-50.61
2.42-2.43	0.007586	-51.2
2.43-2.44	0.004529	-53.44
2.44-2.45	0.007727	-51.12
2.45-2.46	0.026424	-45.78
2.46-2.47	0.029174	-45.35
2.47-2.48	0.036898	-44.33
2.48-2.49	0.013366	-48.74
2.49-2.50	8.93E-05	-70.49

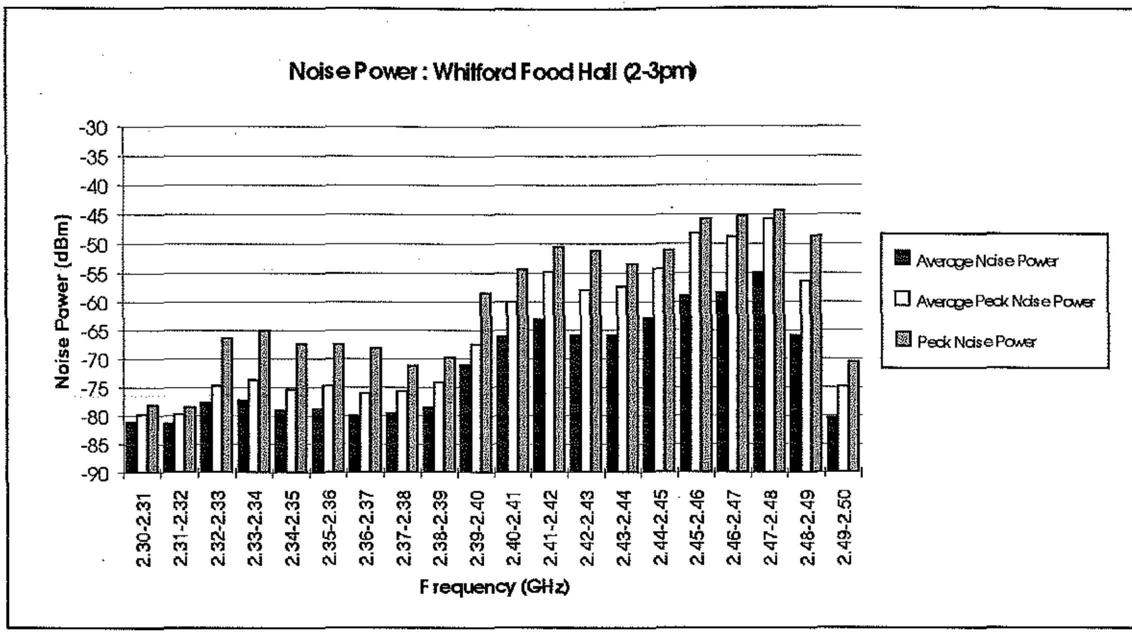

Figure 32 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (2-3pm)

6.3.1.7 Time (3-4pm)

Average Peak Noise Power :

Table 33 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	7.05E-06	-81.51994699	4.45E-05	-73.51401972	0.211008045	-36.75700986
2.31-2.32	6.40E-06	-81.93595142	4.76E-05	-73.22255954	0.21820868	-36.61127977
2.32-2.33	1.44E-05	-78.41207349	9.28E-04	-60.32642031	0.963116857	-30.16321016
2.33-2.34	1.62E-05	-77.91473718	1.54E-03	-58.12176183	1.241400479	-29.06088092
2.34-2.35	1.09E-05	-79.63713778	1.15E-03	-59.41099267	1.070164072	-29.70549633
2.35-2.36	1.23E-05	-79.10544709	6.26E-04	-62.03370669	0.791251717	-31.01685335
2.36-2.37	9.50E-06	-80.22287813	1.02E-03	-59.90109627	1.011451788	-29.95054813
2.37-2.38	1.05E-05	-79.79372752	3.36E-04	-64.7336934	0.579849558	-32.3668467
2.38-2.39	1.12E-05	-79.51562671	1.99E-04	-67.00477596	0.44643805	-33.50238798
2.39-2.40	6.66E-05	-71.76711862	1.53E-03	-58.14812081	1.237638924	-29.07406041
2.40-2.41	0.000203437	-66.91570342	3.82E-04	-64.17531297	0.618349981	-32.08765649
2.41-2.42	0.000427853	-63.68705078	3.12E-04	-65.05358569	0.558882763	-32.52679285
2.42-2.43	0.000213937	-66.69715029	8.06E-04	-60.93640056	0.897800766	-30.46820028
2.43-2.44	0.000226649	-66.44645782	4.90E-04	-63.09432294	0.700299559	-31.54716147
2.44-2.45	0.000451554	-63.45290612	1.33E-04	-68.75088067	0.365137104	-34.37544034
2.45-2.46	0.001100967	-59.58225503	7.31E-05	-71.36059979	0.270377165	-35.6802999
2.46-2.47	0.001132251	-59.46057389	4.06E-04	-63.91617796	0.637075791	-31.95808898
2.47-2.48	0.002839138	-55.46813524	8.42E-05	-70.74623196	0.290193982	-35.37311598
2.48-2.49	0.000223865	-66.50013753	1.86E-03	-57.30210374	1.364252672	-28.65105187
2.49-2.50	8.76E-06	-80.57430607	4.15E-04	-63.82256215	0.643979278	-31.91128107

Average Peak Hold Noise Power (2 minute) :

Table 34 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	9.75E-06	-80.11192975	5.12E-05	-72.90710655	0.22627922	-36.45355327
2.31-2.32	1.02E-05	-79.89754729	4.77E-05	-73.21297176	0.21844968	-36.60648588
2.32-2.33	2.50E-05	-76.02516606	9.63E-04	-60.16212741	0.981507516	-30.0810637
2.33-2.34	3.15E-05	-75.0118743	1.44E-03	-58.41344745	1.200404536	-29.20672372
2.34-2.35	2.21E-05	-76.55645839	9.74E-04	-60.11619903	0.986711179	-30.05809952
2.35-2.36	2.57E-05	-75.8972618	7.68E-04	-61.14770978	0.876222722	-30.57385489
2.36-2.37	1.82E-05	-77.39416649	8.61E-04	-60.65222273	0.92766007	-30.32611137
2.37-2.38	1.99E-05	-77.01712486	3.34E-04	-64.76145628	0.577999131	-32.38072814
2.38-2.39	2.62E-05	-75.81257541	2.22E-04	-66.53949262	0.471004839	-33.26974631
2.39-2.40	0.000127584	-68.94204337	1.38E-03	-58.60316522	1.174469489	-29.30158261
2.40-2.41	0.000711368	-61.47905719	5.52E-04	-62.58314617	0.742750053	-31.29157308
2.41-2.42	0.001873234	-57.2740796	2.34E-04	-66.30357796	0.483972964	-33.15178898
2.42-2.43	0.001091468	-59.61989064	1.03E-03	-59.89016662	1.012725321	-29.94508331
2.43-2.44	0.001238765	-59.07011036	4.43E-04	-63.54022569	0.66525587	-31.77011285
2.44-2.45	0.002650308	-55.76703621	1.50E-04	-68.24671002	0.386958596	-34.12335501
2.45-2.46	0.010475177	-49.79838645	9.45E-05	-70.24485157	0.307437912	-35.12242578
2.46-2.47	0.009308238	-50.31132544	4.41E-04	-63.55739454	0.6639422	-31.77869727
2.47-2.48	0.018045691	-47.43626487	6.59E-05	-71.81229883	0.256675879	-35.90614942
2.48-2.49	0.001334577	-58.74656499	1.75E-03	-57.57055083	1.322733822	-28.78527541
2.49-2.50	2.15E-05	-76.68114767	3.39E-04	-64.69438442	0.582479679	-32.34719221

Peak Hold Noise Power (2 minute) :

Table 35 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.52E-05	-78.18
2.31-2.32	1.43E-05	-78.45
2.32-2.33	0.000166	-67.79
2.33-2.34	0.000231	-66.36
2.34-2.35	0.000145	-68.4
2.35-2.36	0.000148	-68.3
2.36-2.37	0.000106	-69.73
2.37-2.38	5.68E-05	-72.46
2.38-2.39	7.11E-05	-71.48
2.39-2.40	0.00104	-59.83
2.40-2.41	0.002698	-55.69
2.41-2.42	0.004989	-53.02
2.42-2.43	0.005321	-52.74
2.43-2.44	0.003148	-55.02
2.44-2.45	0.005662	-52.47
2.45-2.46	0.018967	-47.22
2.46-2.47	0.022182	-46.54
2.47-2.48	0.026303	-45.8
2.48-2.49	0.009036	-50.44
2.49-2.50	5.36E-05	-72.71

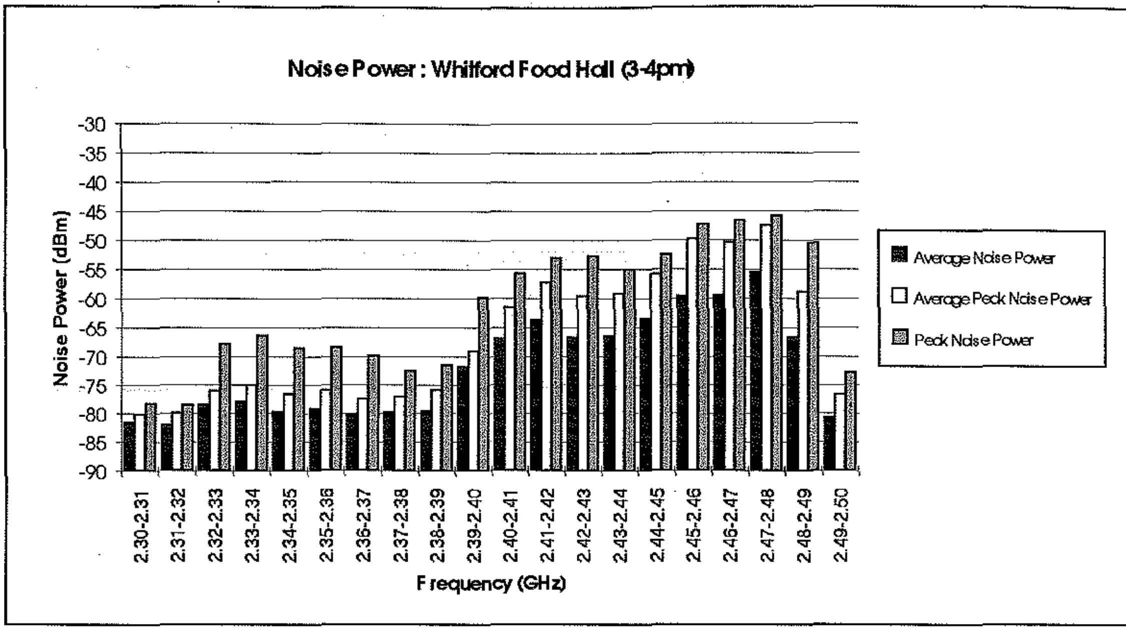

Figure 33 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (3-4pm)

6.3.1.8 Time (4-5pm)

Average Peak Noise Power :

Table 36 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	8.32E-06	-80.80081949	4.60E-05	-73.37077589	0.214516749	-36.68538794
2.31-2.32	7.89E-06	-81.02771196	4.62E-05	-73.35711185	0.214854477	-36.67855593
2.32-2.33	1.79E-05	-77.47866993	9.06E-04	-60.42786524	0.951933779	-30.21393262
2.33-2.34	1.88E-05	-77.24907346	1.54E-03	-58.11468422	1.242412433	-29.05734211
2.34-2.35	1.29E-05	-78.88405334	1.04E-03	-59.81871575	1.021090446	-29.90935787
2.35-2.36	1.33E-05	-78.76602178	6.00E-04	-62.21771947	0.774665164	-31.10885974
2.36-2.37	9.99E-06	-80.00264807	9.72E-04	-60.12352788	0.985878977	-30.06176394
2.37-2.38	1.18E-05	-79.27754386	3.18E-04	-64.97675112	0.563848519	-32.48837556
2.38-2.39	1.42E-05	-78.4649998	1.95E-04	-67.08951613	0.442103744	-33.54475807
2.39-2.40	8.33E-05	-70.79559429	1.38E-03	-58.58640243	1.176738272	-29.29320122
2.40-2.41	0.000255402	-65.92775414	3.98E-04	-63.9969697	0.631177509	-31.99848485
2.41-2.42	0.000522177	-62.82181991	3.14E-04	-65.0337142	0.560162833	-32.5168571
2.42-2.43	0.000262174	-65.81410749	8.81E-04	-60.5502819	0.938611574	-30.27514095
2.43-2.44	0.000275691	-65.59578189	4.24E-04	-63.72502714	0.65125136	-31.86251357
2.44-2.45	0.000533337	-62.72998298	1.20E-04	-69.21670445	0.346070657	-34.60835223
2.45-2.46	0.001366545	-58.64375982	4.74E-05	-73.24333678	0.217687334	-36.62166839
2.46-2.47	0.001486407	-58.27862217	5.00E-04	-63.01344093	0.706851125	-31.50672047
2.47-2.48	0.003252496	-54.87783276	7.08E-05	-71.50054438	0.266055831	-35.75027219
2.48-2.49	0.000254745	-65.93893498	1.83E-03	-57.36495403	1.354416695	-28.68247702
2.49-2.50	9.48E-06	-80.23001553	4.08E-04	-63.88886714	0.639082084	-31.94443357

Average Peak Hold Noise Power (2 minute) :

Table 37 :

Frequency (GHz)	Mean (uW)	Mean(dBm)	Variance	Variance (dB)	Stdev	Stdev (dB)
2.30-2.31	1.12E-05	-79.51081474	4.58E-05	-73.39281284	0.213973188	-36.69640642
2.31-2.32	1.09E-05	-79.61939634	3.71E-05	-74.31037985	0.192522285	-37.15518992
2.32-2.33	3.91E-05	-74.08143285	8.57E-04	-60.67124263	0.925630952	-30.33562132
2.33-2.34	4.97E-05	-73.04056541	1.43E-03	-58.43384389	1.19758902	-29.21692195
2.34-2.35	3.07E-05	-75.13393601	8.81E-04	-60.54918268	0.938730365	-30.27459134
2.35-2.36	3.71E-05	-74.30710954	6.05E-04	-62.18116071	0.777932588	-31.09058036
2.36-2.37	2.71E-05	-75.66531708	8.60E-04	-60.65555139	0.927304635	-30.32777569
2.37-2.38	2.75E-05	-75.61219544	3.07E-04	-65.12815323	0.554105344	-32.56407661
2.38-2.39	5.17E-05	-72.86259053	1.35E-04	-68.68203492	0.368042739	-34.34101746
2.39-2.40	0.000211977	-66.7371089	1.42E-03	-58.47951667	1.191308298	-29.23975833
2.40-2.41	0.001147753	-59.40151465	4.99E-04	-63.01807485	0.70647412	-31.50903743
2.41-2.42	0.003587509	-54.45206975	2.86E-04	-65.43742332	0.534722962	-32.71871166
2.42-2.43	0.001753375	-57.561252	8.43E-04	-60.74121397	0.918204256	-30.37060698
2.43-2.44	0.001957513	-57.08295346	3.59E-04	-64.4432257	0.599568372	-32.22161285
2.44-2.45	0.004380197	-53.5850636	1.06E-04	-69.7307265	0.326184767	-34.86536325
2.45-2.46	0.017088456	-47.67297175	6.08E-05	-72.16115709	0.246571085	-36.08057855
2.46-2.47	0.015042041	-48.22693243	3.67E-04	-64.349327	0.606085159	-32.1746635
2.47-2.48	0.02814732	-45.50562951	4.57E-05	-73.3967171	0.21387703	-36.69835855
2.48-2.49	0.002609119	-55.83506113	1.79E-03	-57.46718471	1.338569004	-28.73359236
2.49-2.50	3.44E-05	-74.63386978	3.80E-04	-64.20597489	0.616171002	-32.10298744

Peak Hold Noise Power (2 minute) :

Table 38 :

Frequency (GHz)	Level (uW)	Level (dBm)
2.30-2.31	1.58E-05	-78.02
2.31-2.32	1.46E-05	-78.36
2.32-2.33	0.000244	-66.13
2.33-2.34	0.000364	-64.39
2.34-2.35	0.000192	-67.16
2.35-2.36	0.000193	-67.15
2.36-2.37	0.000159	-67.99
2.37-2.38	7.55E-05	-71.22
2.38-2.39	0.000124	-69.05
2.39-2.40	0.001762	-57.54
2.40-2.41	0.004188	-53.78
2.41-2.42	0.009638	-50.16
2.42-2.43	0.007943	-51
2.43-2.44	0.004688	-53.29
2.44-2.45	0.008414	-50.75
2.45-2.46	0.028973	-45.38
2.46-2.47	0.033963	-44.69
2.47-2.48	0.038371	-44.16
2.48-2.49	0.016069	-47.94
2.49-2.50	8.99E-05	-70.46

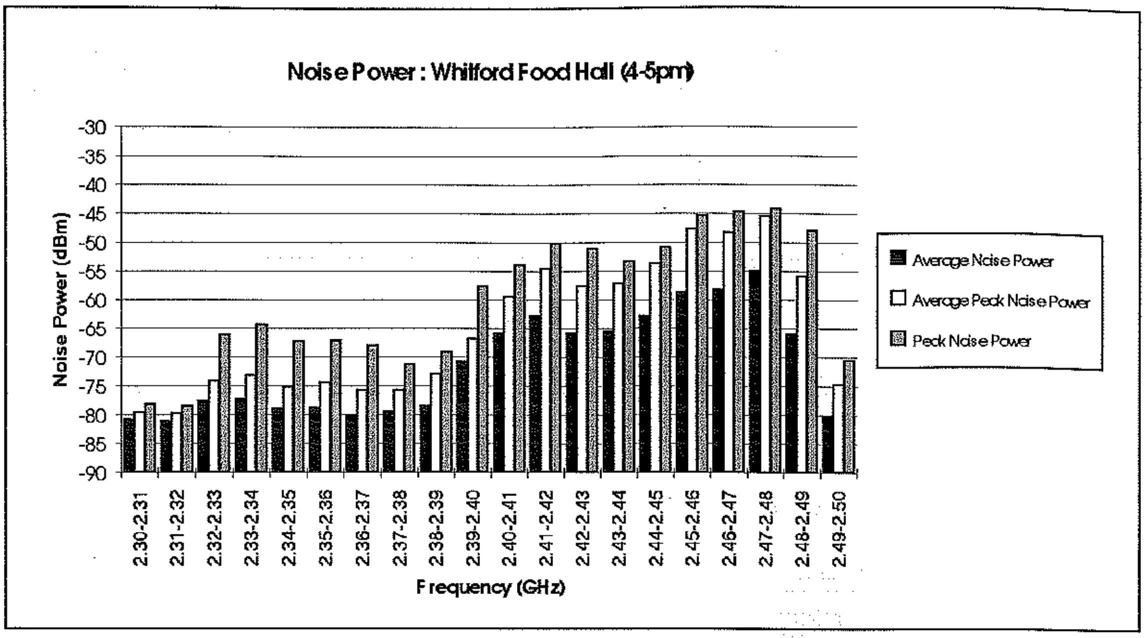

Figure 34 Conglomerate Noise Power For Whitford City Shopping Centre Food Hall (4-5pm)

Figures 27 through 34 illustrate the dependence of noise power at Whitford City Shopping Centre Food Hall with respect to time of day. At this stage, a comparison between the various plots is not appurtenant, and will be presented accordingly in the following Section 6.3.2.

More appropriately at this stage, we should consider the graphs for conformity to expectations. Firstly, the peak hold (2 min) noise level classifications for each time frame exhibit the highest level; period. This is as to be expected because this is a maximum figure. Correspondingly, the lowest noise level is represented by the average peak noise level, and all graphs comply with this fact.

If we consider the graphs now in more detail, it is possible to see that each plot is similar in spectral nature to Figure 26, the spectrum analyser trace. This is so with respect to spectrum occupancy and intensity. The variation that actually occurs in the graphs is in direct conjunction with the time of day, such that at

peak operation times, (ie : lunchtime), the measured and subsequently calculated intensities reach a maximum.

An interesting feature that can be noticed on these graphs, is that the variation in relative noise powers between adjacent classifications (ie : average peak - average peak hold noise power; average peak hold - peak hold noise power) is somewhat related to spectrum occupation, and thus intensity. Clarifying this statement, the highest variation between average peak and average peak hold noise power (thus lowest variation between average peak hold and peak hold noise power), generally occurs where the noise intensity is at its highest; from 2.41-2.49 GHz. This can be attributed to the fact that the noise spectrum more evenly occupies (broad peaks) the sub-bands corresponding to high noise levels, and sporadically occupy (narrow peaks) the sub-bands corresponding to lower noise levels. This can be easily verified by examining once more, Figure 26.

Finally, the highest level of noise encountered within the 200 MHz band, is found within the 2.45-2.48 GHz frequency range. This is in accordance once more, with the sample trace presented in Figure 26.

6.3.2 Diurnal Variation

Now that all the statistical analyses have been completed for the multiple operation environment, it is time to consider more closely the dependence between noise levels and the time of day, for the typical operating environment (Whitford City Shopping Centre Food Hall) in question. The graphs presented in this section, are done so in two forms. The first provides a histogram representation over a refined frequency band (2.39-2.46 GHz), while the second is a line chart plot over the entire 200 MHz measurement span. The

chart formats were chosen in accordance with the representation that best facilitated easy but thorough interpretation and analysis.

Average Peak Noise Power :

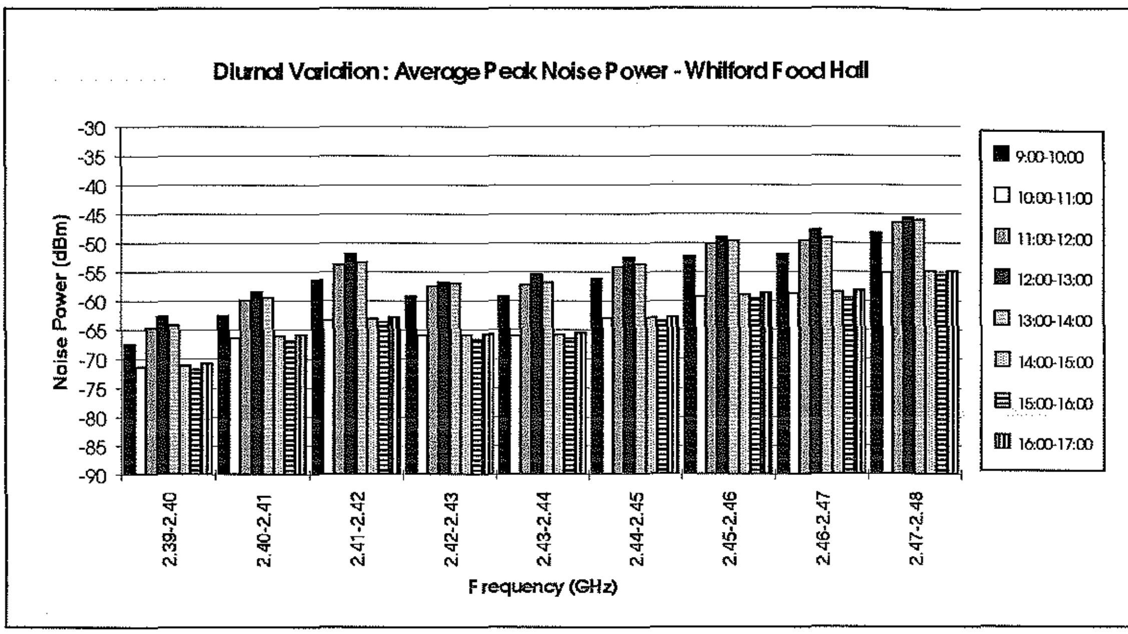

Figure 35 Diurnal Variation In Average Peak Noise Power For Whitford City Shopping Centre Food Hall

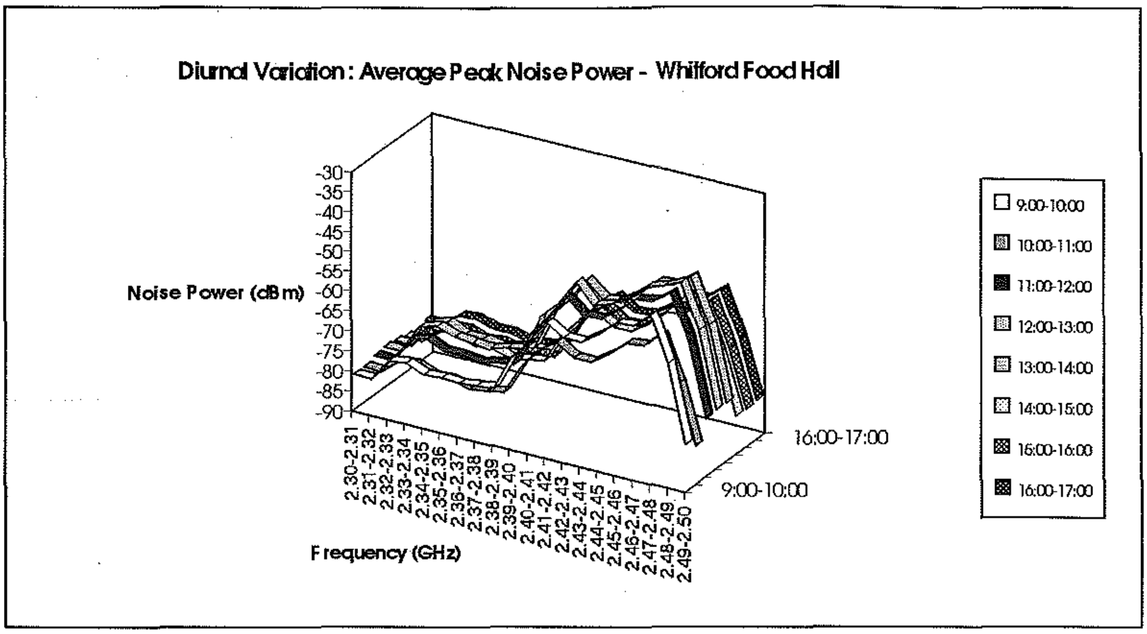

Figure 36 Diurnal Variation In Average Peak Noise Power For Whitford City Shopping Centre Food Hall

Average Peak Hold Noise Power (2 minute) :

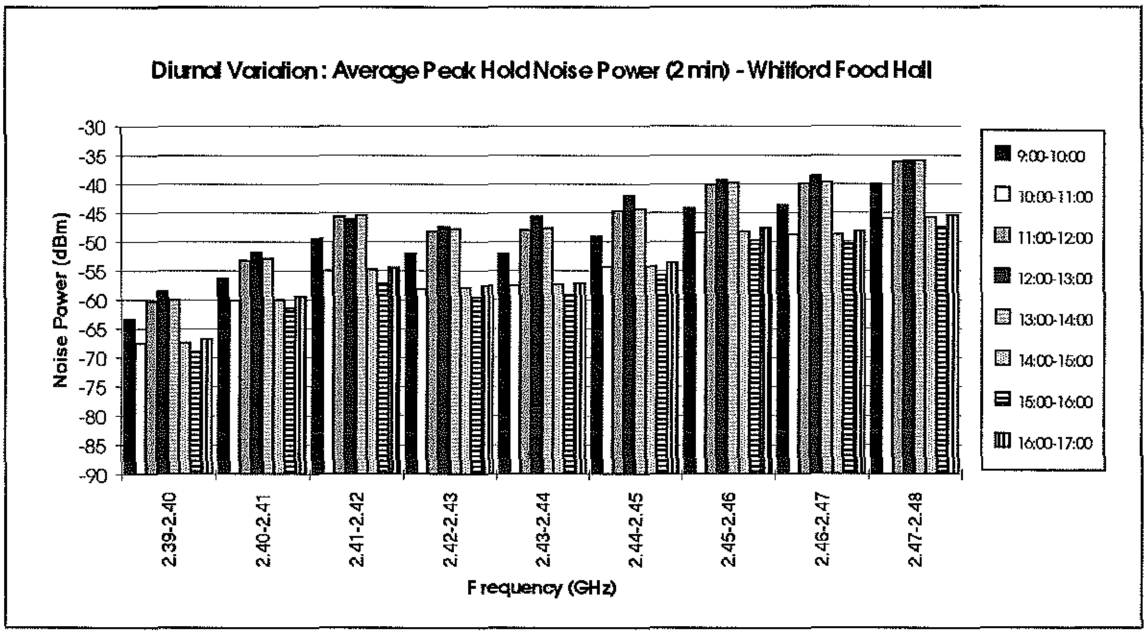

Figure 37 Diurnal Variation In Average Peak Hold Noise Power (2 min) For Whitford City Shopping Centre Food Hall

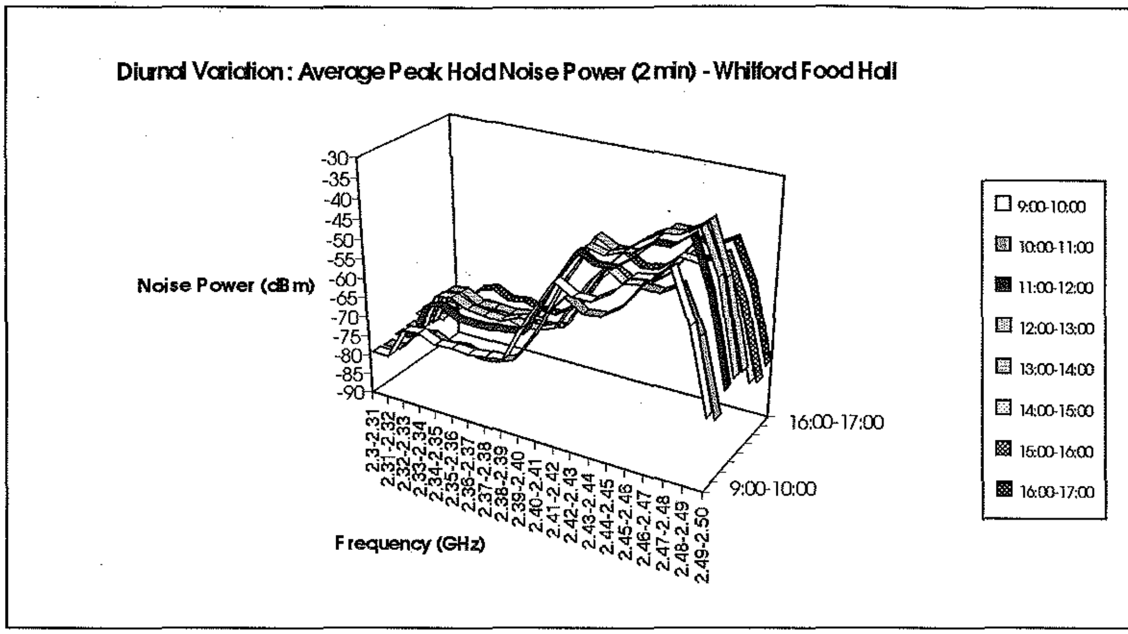

Figure 38 Diurnal Variation In Average Peak Hold Noise Power (2 min) For Whitford City Shopping Centre Food Hall

Peak Hold Noise Power (2 minute) :

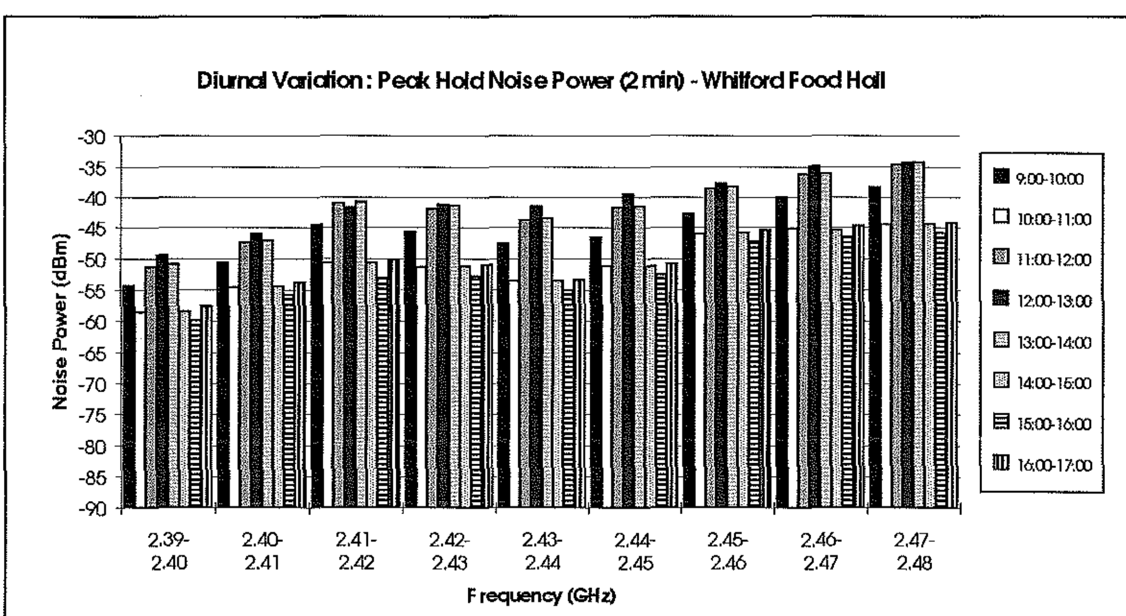

Figure 39 Diurnal Variation In Peak Hold Noise Power (2 min) For Whitford City Shopping Centre Food Hall

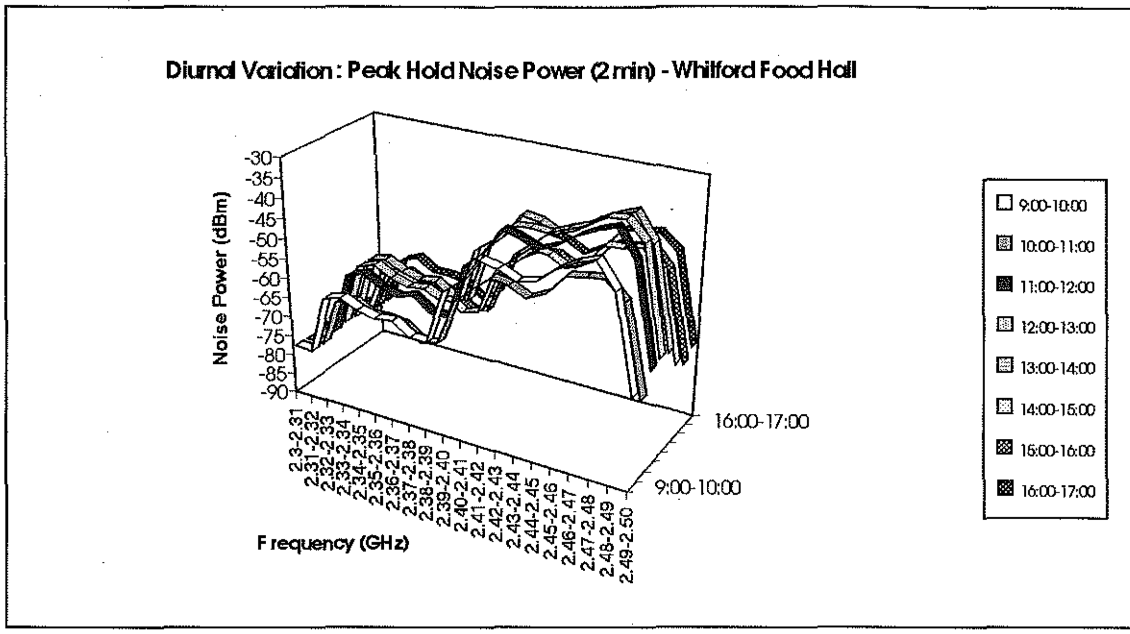

Figure 40 Diurnal Variation In Peak Hold Noise Power (2 min) For Whitford City Shopping Centre Food Hall

Considering Figures 35 through 40, it is possible to see that during the business day, two peak regions occurred. The first peak region encountered, occurred between 9 and 10am, which coincided with breakfast time. Although this may seem like a late breakfast, in terms of the clients of the food hall (both staff and customers), from my observations, breakfast comprised the majority of meals eaten. Another contributing factor to this first peak region, was that this time of the day also was used as preparation (pre-cooking) for the lunchtime period.

The second peak region that occurred, which was both higher in intensity, and longer in duration, was between 11am and 2pm. This time interval represented lunch time. The number of people present in the food hall at this time was far in excess of that encountered at other times of the day, which meant that one would expect all cooking activities (including microwave ovens) to be at their peak. This expectation was supported by the findings of the measurements.

Over the three hour period, the highest noise levels measured were generally found in the time slot from 12-1pm, which one would expect to coincide with the commonly accepted traditional lunch period.

People traffic density was at its highest during this three hour lunch period time, and as a result we would expect that this would coincide with the highest level of absorption (attenuation) of spurious output from the microwave ovens, by human tissues. Therefore, it would be reasonable to assume that the actual composite emission from the various sources could in fact be higher than was actually measured. However, if we consider that this study was to focus on typical operating environments and topologies, it would be unreasonable to state that figures presented in the diurnal analysis were inaccurate because no consideration was given to relative absorption levels. Rather, the measurements typified the operating environment, in terms of what the LAN's would actually encounter, and it would be unrealistic to allow for these absorptive losses.

In accordance with the peak regions illustrated in the above points, a lull or reduction in measured noise power was found to exist at times between the peaks (10-11am, 2-5pm). This is as to be expected, as few people would actually require the services of the food hall at these times, although some may argue that the time from 4-5pm could represent dinner time, and hence we should see some increase in microwave oven activity during this time. However, this was not the case, as observations yielded that few people used this time to acquire dinner, probably due to the fact that it was a little early, and most people were keen to go home at the conclusion of the day.

6.3.3 CONGLOMERATE AVERAGE DIURNAL VARIATION

This section deals with slightly different quantities to the preceding material, in that it considers an average noise power across the frequency band of interest (2.39-2.48 GHz) for each of the noise classifications, with respect to time of day.

The procedure for calculation of this data, involved obtaining the statistical average (sum noise powers [μW] and divide by sample size) for each of the noise classifications over the frequency range of interest, for each hourly time period. The data was then collated for the time span from 9am-5pm to produce a graphical output, indicating the dependence of noise power upon the time of day. The three curves for each noise classification were then depicted on the one graph, to allow simple comparison of the data. Once again, the graphs are illustrated in more than one form, to best aid the readers understanding.

The aim of this methodology is to provide a broad guide as to what noise levels (average peak, average peak hold and peak hold) can be expected within the operating band overall, in relation to the time of day. This analysis is important for the material to follow in Section 7, as it allows us to consider the significance of such an operating environment, with respect to the effect that the noise distribution may have upon a typical wireless LAN configuration.

Once again, the analysis presented is for the Whitford City Shopping Centre Food Hall, which is meant to typify a multiple microwave oven operating environment.

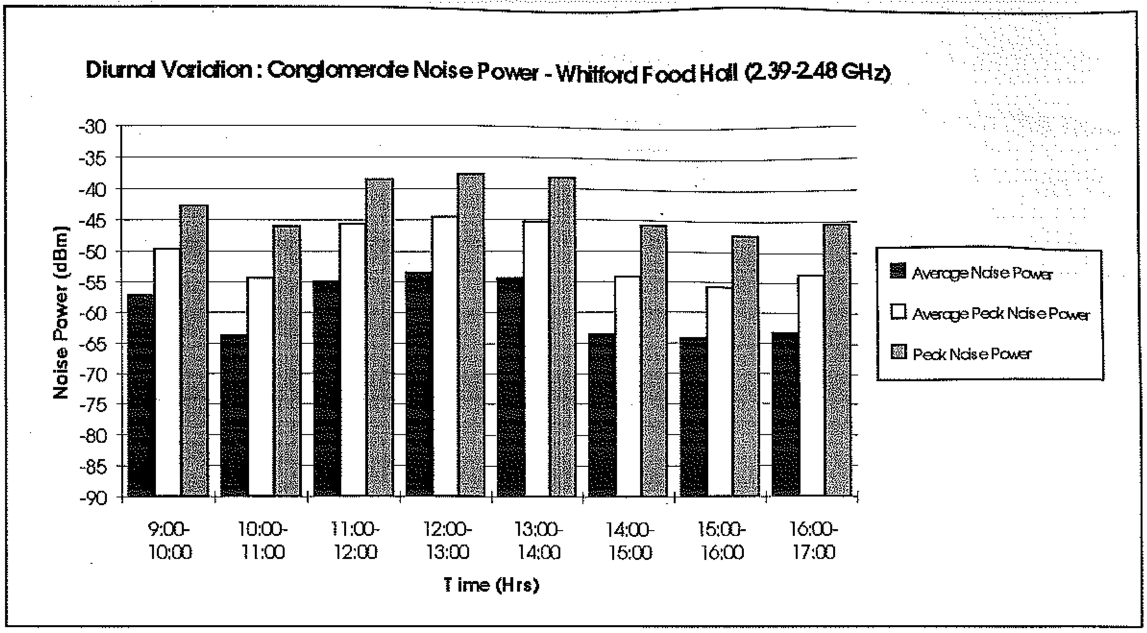

Figure 41 Diurnal Variation In Conglomerate Noise Power Over Frequency Band Of Interest For Whitford City Shopping Centre Food Hall

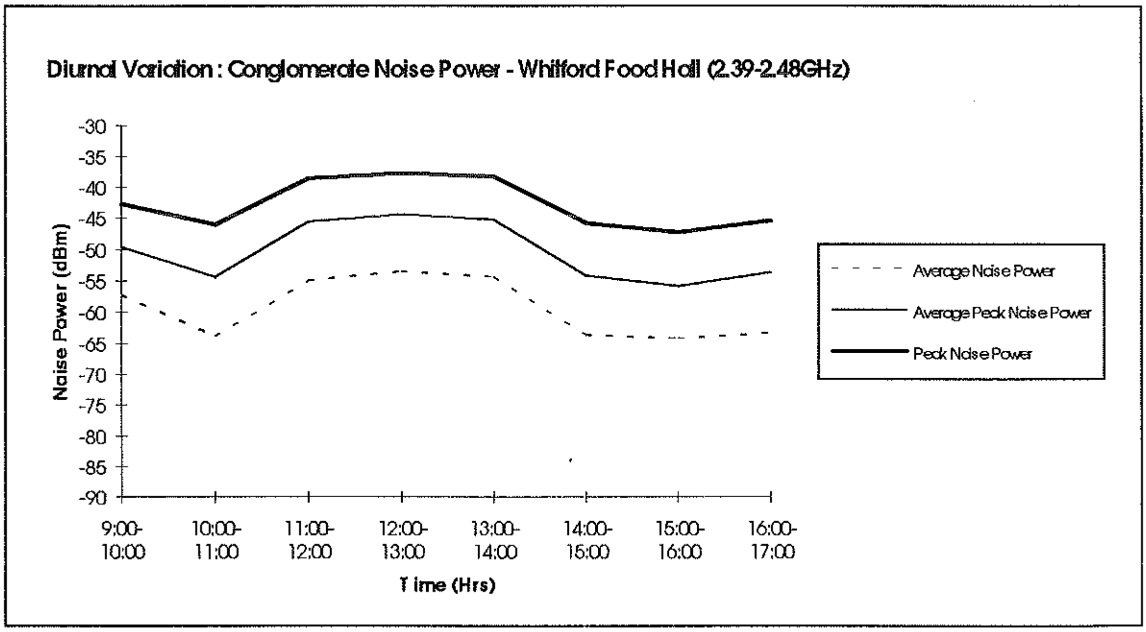

Figure 42 Diurnal Variation In Conglomerate Noise Power Over Frequency Band Of Interest For Whitford City Shopping Centre Food Hall

Figures 41 and 42 are two different representations of the same information. Both figures clearly demonstrate the dependence that exists between the noise power level for microwave ovens in Whitford City Shopping Centre Food Hall (and hopefully other similar environs), and the time of day. The diurnal variation is seen to clearly reach a maximum between 11am and 2pm (lunchtime), coinciding with the greatest frequency of use of microwave ovens.

In examining the shape of these graphs, and in particular the curves presented in Figure 42, there is a distinct variation to the shape proposed in Figure 8, which is representative of typical radio noise power. Figure 8 shows a connection between typical radio noise power and time of day, with respect that it is attune to the level of business activity (peak activity results in peak noise levels) and meteorological changes. From this study however, Figure 42 reveals that this dependence is non-existent for microwave ovens, and in fact can almost be considered to be the reverse. In this case, the highest levels of noise power are related to times of minimal business activity, which refers to meal times, primarily lunchtime for the commercial analysis presented. This finding supports the expectation proposed in Section 5.4.2.2 (Multiple Instances Of Microwave Ovens).

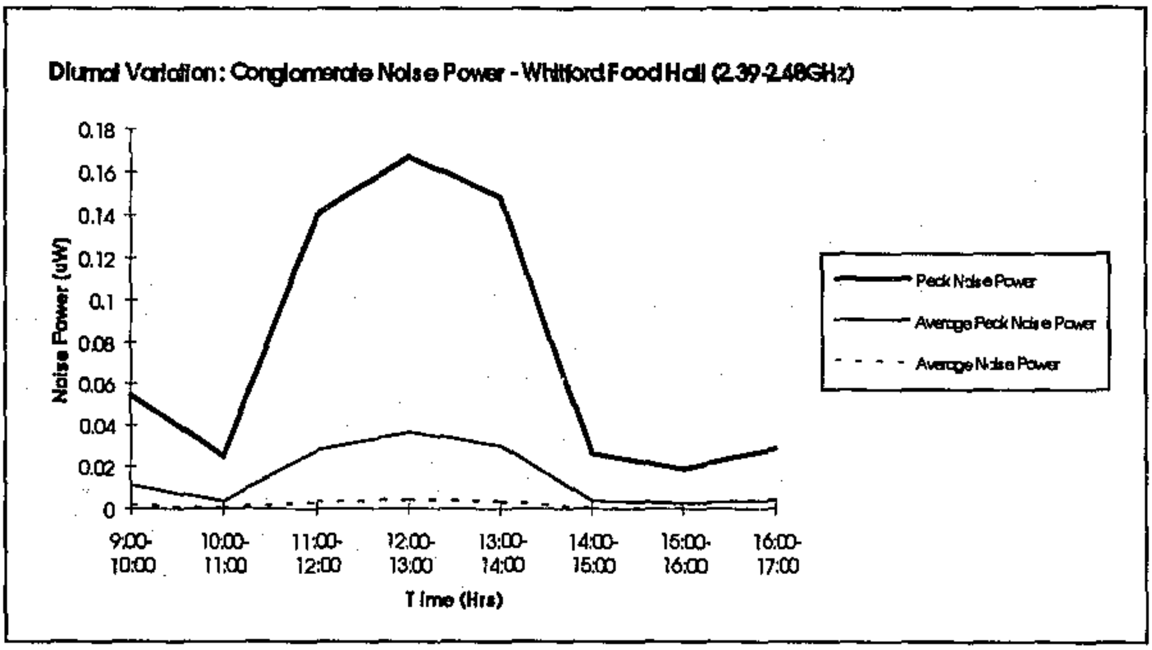

Figure 43 Diurnal Variation In Conglomerate Noise Power (expressed in µW) Over Frequency Band Of Interest For Whitford City Shopping Centre Food Hall

Finally, Figure 43 is an illustration of the same information of Figures 41 and 42, but the noise power is represented on a linear scale, namely µW. This scale will prove useful in the analysis presented in Section 7.

As in the previous cases, Figure 43 clearly demonstrates the diurnal dependence of the noise power from microwave ovens.

6.4 MISCELLANEOUS NOISE SOURCES

6.4.1 BUILDING ALARMS

Building alarms as those used typically in businesses, although only discovered in two cases from the various measurement sites, were found to output a discrete frequency of moderate to low levels.

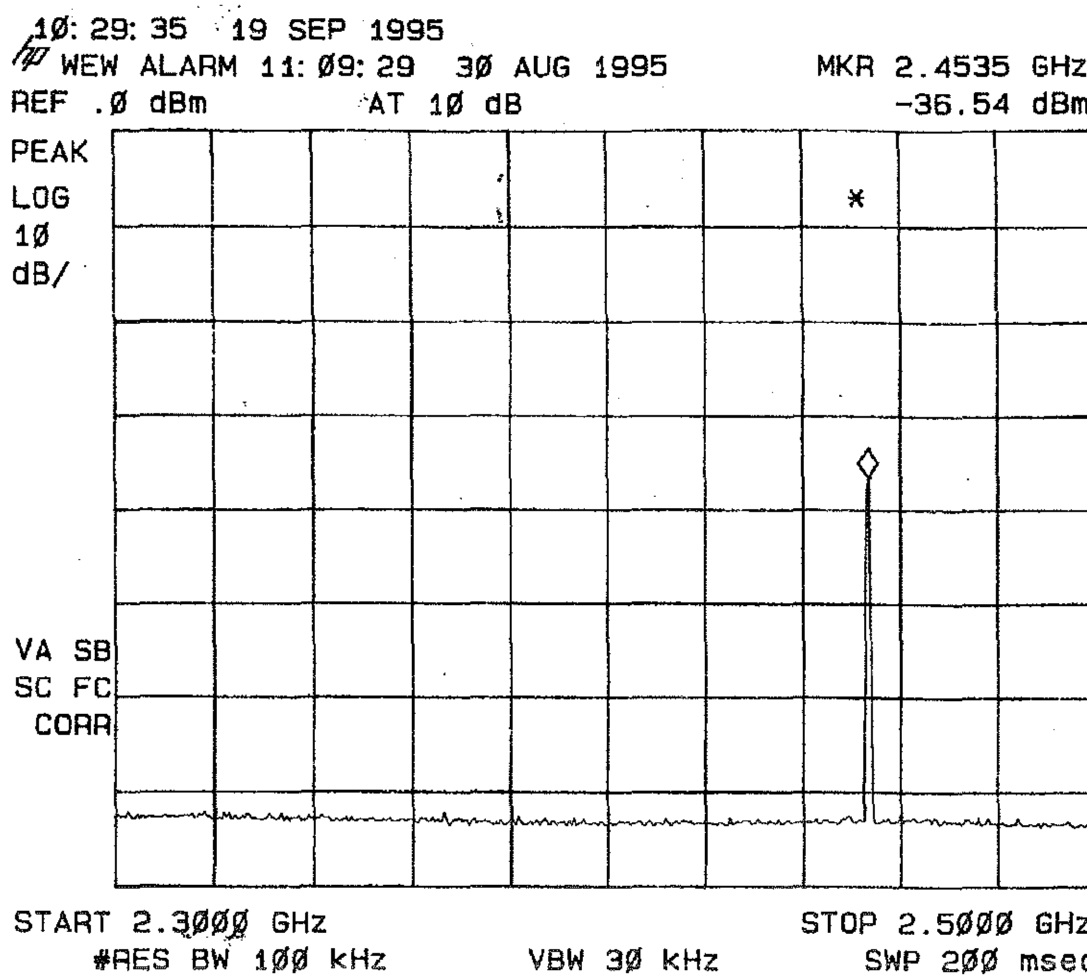

Figure 44 Sample Spectrum Analyser Output For Alarm System At Wilson's Engraving Works At A Distance Of 1m Using Directional Corner Reflector Antenna

The first finding was at Wilson's Engraving Works, as shown in Figure 44. This reading was taken at a distance of 1m from the alarm unit, with the directional corner reflector antenna, for the purpose of determining the exact origin of the noise source. The level of this output, allowing for antenna gain and feeder loss was -50.34 dBm, at a frequency of 2.4535 GHz. The output comes from the alarm unit itself (oscillator circuit), and not the sensors, as they operate at infra-red frequencies, much higher than we are concerned with.

The second instance of this classification was found at Whitford City Shopping Centre Food Hall, during a brief time when no microwaves were operating (let me assure, this did not occur very often, or for long periods of time; generally less than 10 seconds). I must stress that I am assuming that this particular noise source is of the same origin as that found at Wilson's Engraving Works (alarm system), as it was impossible to track the signal down. The level of this output was -72.58 dBm, at a frequency of 2.4505 GHz.

Both instances of this signal occupy the frequency spectrum in accordance with the band of interest (2.4-2.48 GHz). However, due to the fact that the signals are relatively low power (-50.34 dBm or 0.009 μW at 1m) which decreases by 6 dB for every doubling in distance, and they occur at one small partition within the frequency spectrum, they are unlikely to be of great concern to wireless LAN systems.

6.4.2 PAY TV

Pay TV is a recent commercial development in Western Australia, whereby a multiple channel television service is supplied to subscribing customers. Numerous channels requires multiple frequencies, as each separate channel must have its own allocated frequency slot. An output of the spectrum analyser, shown in Figure 45, illustrates the various channels used. The maximum power of the received frequencies was -61.36 dBm, taking into account antenna gain and feeder loss.

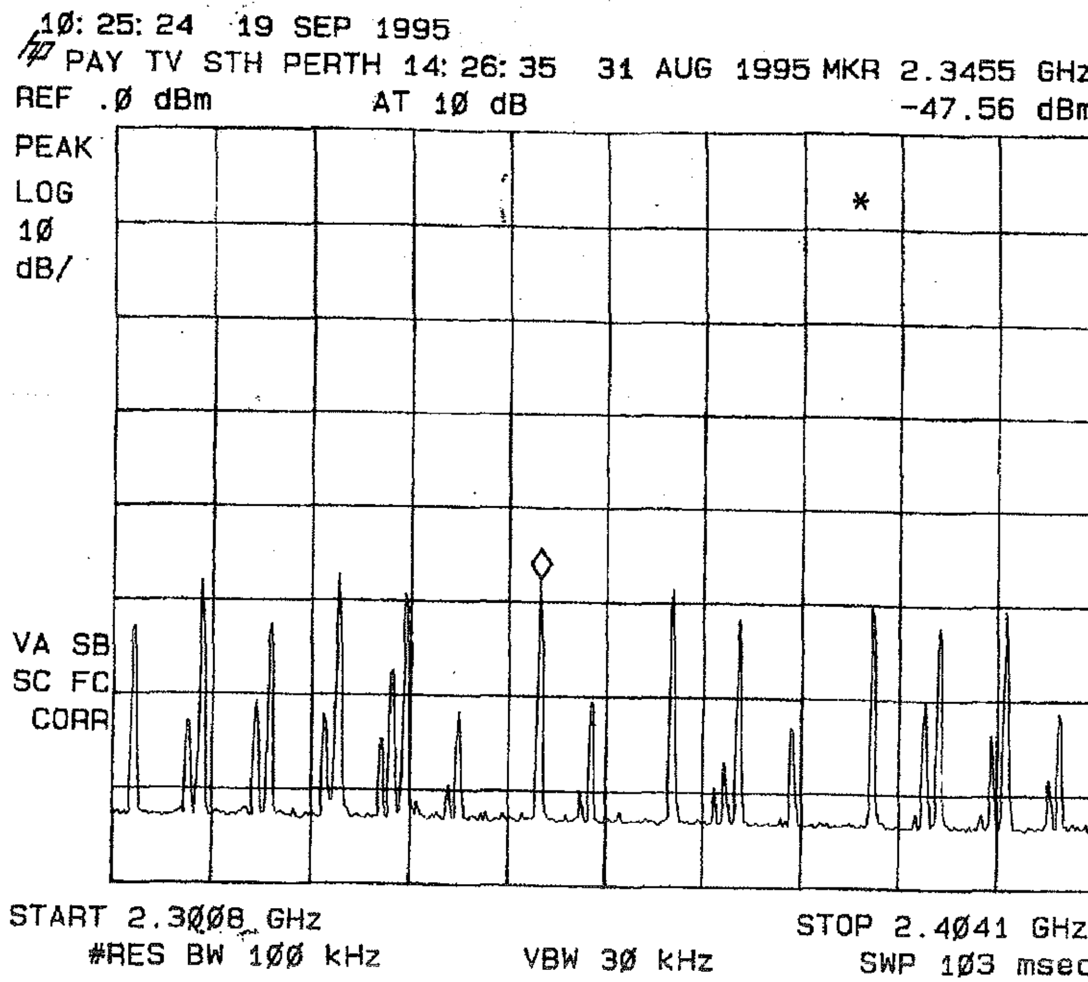

Figure 45 Sample Spectrum Analyser Output For Pay TV From South Perth Foreshore Using Directional Corner Reflector Antenna

This measurement trace was obtained on the South Perth foreshore, which provided a direct line of sight path across the Swan River between the transmitting station (Perth Centre Point Tower), and our receiving antenna (directional corner reflector). The approximate transmission path length was 1.5 km. It is worth stating that some of these frequencies were detected with no line of sight transmission path. For example, on Wanneroo Road, approximately 8 km from the transmitting station, at least 10 separate frequencies were received, the highest being -72.61 dBm, once again correcting for system losses and gains.

The significance of this finding however is minimal, as this portion of the spectrum is licensed by the SMA (Spectrum Management Authority), so no other users are able to operate within the allocated frequency band. As a result, the channels are *out of band* with respect to our wireless LAN frequency allocation, and the effect upon a microwave LAN system can be deemed irrelevant.

7. SIGNIFICANCE OF RESULTS

Given the substantial amount of measurement and analysis data presented in Section 6, we now have the task of ratiocinating the relevance and significance of the findings, with respect to the application of wireless LAN's. Although system specifics have not been finalised, certain criteria (though broad in nature) can be utilised to consider the consequence of the background noise sources determined in this study.

7.1 CHARACTERISATION

As mentioned previous in Section 6.2.1, the ability to characterise both a single microwave oven, and multitude in a typical environment, is an important criterion of the analysis. Knowing the *signature* of a microwave oven, enabled me ascertain the offending noise source that was measured in the Edith Cowan Library Photocopier Section. If it were not for this knowledge of a typical spectrum for a microwave oven, one of two things could have happened. The worse scenario would be that the source of noise was wrongly assumed to be the photocopiers, and the second situation could have been that a great deal of effort would have been required to determine exactly what had caused the noise burst. Fortunately, our prior knowledge of the leakage spectrum for microwave ovens, enabled us to quickly ascertain that the photocopiers were not responsible for the measured signal, but rather a microwave oven operating within proximity of the receivers range was the culprit, and appropriate measures could be duly undertaken to ensure that it was not operational while conducting measurements.

Resulting from the analysis presented in Section 6, we now have a good understanding of the spectrum allocation and intensity of microwave ovens,

operating in unity or multiplicity. This knowledge will prove useful in future measurement applications, to determine if a measured signal is likely to be produced by a microwave oven, or whether a different electronic device is the source.

Given this characterisation, it is possible to see that the majority of leakage noise power (in terms of greatest intensity) emitted from microwave ovens, coincides directly with the frequency band that has been allocated for the operation of wireless microwave LAN's. This is not particularly good news, given that there is a ***possibility*** that the two channels (2.4-2.485 and 5.5-5.585 GHz) may actually be utilised in the system; one for up-link and one for down-link. Even if the lower frequency band were not to be used, operating at a higher frequency has certain disadvantages, such as higher levels of signal attenuation by obstacles, and increased cost of componentry, to name a few. However, we must not jump to conclusions, until we consider the characteristics of a typical system (Section 7.2), to determine the significance of the noise levels.

7.2 IMPACT ON A TYPICAL SYSTEM

It is envisaged that the wireless LAN's to be developed, will operate with output power levels from 10-100 mW, at distances of up to 50m. With this in mind, lets consider the free space loss (FSL) over typical operating distances, to compare the received signal level to various noise levels, as calculated in Section 6. This analysis is based upon a line of sight transmission path, meaning that absorption effects are not taken into account. In addition, other system degradation effects such as multipath have not been considered, for the sake of simplicity. To give statistical consideration to this phenomenon is well beyond the scope of this project, and would require a detailed analysis alone.

Utilising equation (2) :

$$FSL = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 dB \qquad \textbf{(2..)}$$

Theoretical path losses over typical distances using equation (2..) are shown in Table 39 :

Table 39 : Free Space Loss Figures Over Various Distances

Distance (m)	Path Loss (dB)
2	46.16
5	54.12
10	60.14
20	66.16
50	74.12

An empirical estimation of these figures was conducted utilising a Hewlett Packard Vector Analyser, as illustrated in Figure 46.

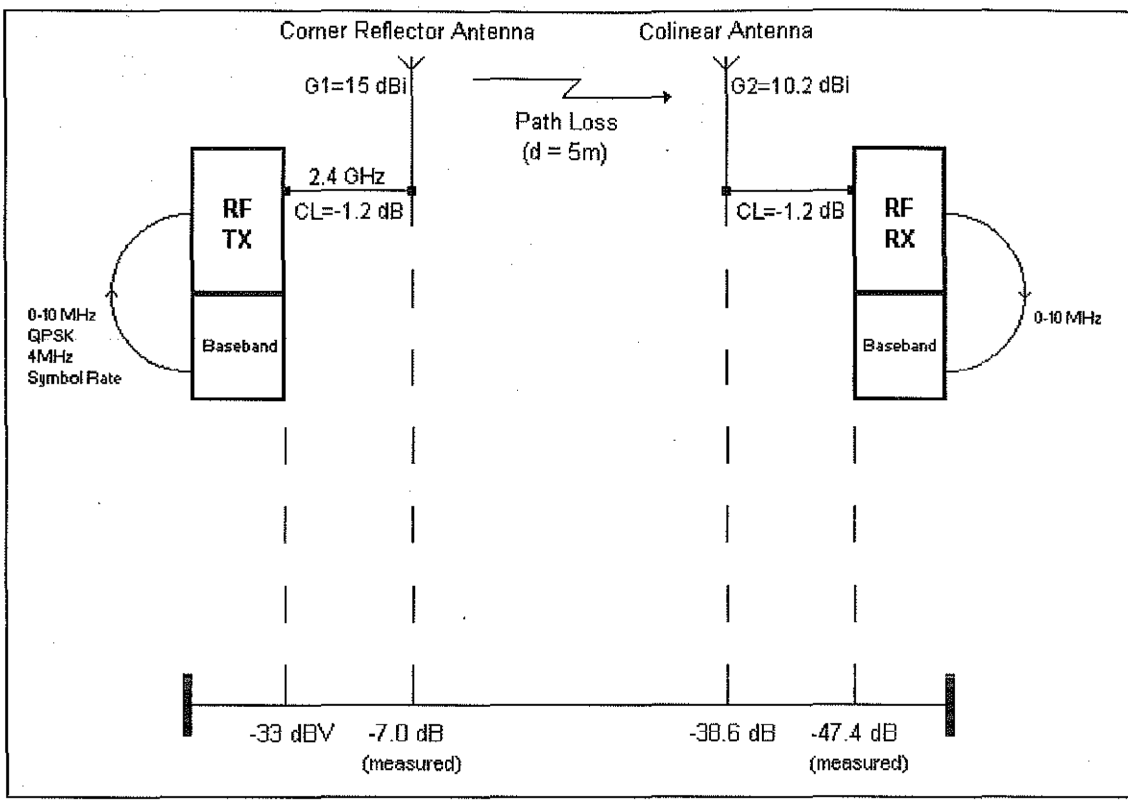

Figure 46 Empirical Calculation Of Path Loss Over 5m At 2.425 GHz

In this case, the free space loss over a distance of 5m is calculated by determining the difference between the measured transmitted signal (-7 dB) at the input to the transmitting antenna, and the measured received signal (-47.4 dB) as displayed on the analyser, with respect to appropriate gains and losses. Therefore,

$$FSL = (G1+G2-7)-47.4$$

$$= 56.5 \text{ dB}$$

Over a distance of 5m, the empirical and theoretical values were only 2.38 dB in arrears, which is a reasonable result.

Now that we have calculated the path loss over various distances, lets consider some typical operational scenarios to determine the possible effects that the measured noise levels may have upon the proposed system.

It must be pointed out at this stage, that any conclusions drawn on the basis of this information are only tentative, as the exact system specifications at this point in time are unknown. Rather, the analysis of noise effects over certain operating specifications are to be used as a guide as to what performance degradation one could expect, given the results presented in Section 6.

Scenario One :

- Transmission Distance = 2m.

a)

- Output Power = 10 mW = 10 dBm.

Link Analysis :

- Received Signal Level = Transmitted Power - FSL

= 10 - 46.16

= -36.16 dBm.

= 0.242 μW.

b)

- Output Power = 50 mW = 16.99 dBm.

Link Analysis :

- Received Signal Level = Transmitted Power - FSL

= 16.99 - 46.16

= -29.17 dBm.

= 1.211 μW.

c)

- Output Power = 100 mW = 20 dBm.

Link Analysis :

- Received Signal Level = Transmitted Power - FSL

= 20 - 46.16

= -26.16 dBm.

= 2.421 μW.

This procedure was repeated for four other typical operating scenarios, and by considering the path loss over the indicated distances, the results are shown in the following table, Table 40.

Table 40 : Summary Of Typical System Operation Scenarios

Scenario	Distance (m)	Output Power (mW)	Received Signal Power (dBm)	Received Signal Power (μW)
One	2	10	-36.16	0.242
	2	50	-29.17	1.211
	2	100	-26.16	2.421
Two	5	10	-44.12	0.039
	5	50	-37.13	0.194
	5	100	-34.12	0.387
Three	10	10	-50.14	0.010
	10	50	-43.15	0.048
	10	100	-40.14	0.097
Four	20	10	-56.16	0.002
	20	50	-49.17	0.012
	20	100	-46.16	0.024
Five	50	10	-64.12	3.87×10^{-4}
	50	50	-57.13	1.94×10^{-3}
	50	100	-54.12	3.87×10^{-3}

7.2.1 Single Microwave Oven Environment

7.2.1.1 Noise Power Considerations (2m Directional)

Considering Figures 17-19, which represent the calculated noise powers for the various classifications across the 200 MHz spectrum, we can evaluate the possible effect of the measured noise levels upon a typical system. The

directional measurements were chosen in this case, as they produced higher mean values than the corresponding omnidirectional case, as mentioned previously.

With respect to the frequency band of interest (2.39-2.48 GHz), and referring to the Summary Table 40 presented in Section 7.2, the average peak noise power from a single microwave oven located ≤ 2m from either the transmitter, becomes significant at transmission distances ≥ 10m, with output power equal to 10 mW. At these points, the received signal can actually be completely enveloped in the noise spectrum, if its specific frequency is in the 2.45-2.46 GHz band. Anywhere else within the band of interest, the significance of microwave ovens should be minimal (but still feasible), as their radiation levels do not reach high enough average noise levels at those frequencies.

For the average peak hold noise power (2 min) levels (practical worst case), when the system transmission path is ≥ 5m, the noise spectrum can begin to cause problems because at system operating power levels of 10 mW, it is possible for the signal to be below the noise level. As the transmission path distance increases, the system will become more susceptible to noise corruption, even at higher output levels. For example, even over a transmission path of 10m, if a microwave oven is within 2m of the system, the received signal could be complete buried within the noise.

As expected the scenario is worse in the case of peak hold noise power (2 min), with the noise power being greater than the received signal level in all instances, no matter what operating power of transmission distance. Therefore, in certain random instances, it is possible that the system will experience an outage(s), even if the transmit power is at a maximum.

7.2.1.2 Average Power Considerations (2m Directional)

Now we shall consider the average noise powers across the 2.39-2.48 GHz band for each noise classification, which are shown in the Table 41. Utilising this data, we can consider in general terms, the effect of a single microwave oven upon a typical system.

Table 41 : Average Noise Power - 2m Directional

Noise Classification	Average Noise Power (μW)	Average Noise Power (dBm)
Average Peak Noise Power	1.058×10^{-3}	-59.76
Average Peak Hold Noise Power (2 min)	1.850×10^{-2}	-47.33
Peak Hold Noise Power (2 min)	1.356	-28.68

Referring once more to Summary Table 40 presented in Section 7.2, a microwave oven ≤ 2m from a typical wireless LAN system, when considering average peak noise power levels, would be unlikely to have an effect upon the system. This is because only at transmission distances of 50m, is the received signal level at a transmit power of 10 mW lower than the noise level, by 4.36 dBm, and this scenario is likely to be uncommon because it is an extreme case. However, we must remember that this is only a guide, and because the noise power does exceed the received signal power in certain instances, the possibility for signal disruption is still feasible.

Considering the average peak hold noise power (2 min) levels (average worst case), system outages could possibly start to occur at transmission distances ≥ 10m, if the transmit power is as low as 10 mW. Indeed, if the transmission distance is up to 20m, problems could occur at transmit powers of 10 and 50 mW, as the noise power is greater than the received signal power. Even at transmit powers of 100 mW, the noise power is only 1.17 dBm shy of the received signal power, and because of the nature of the average measurements across the band, it is possible that real applications may indeed experience problems. Furthermore, at transmit distances of 50m, the received signal level is lower than the noise level, for all transmitting powers.

Finally, examining the peak hold noise power (2 min) levels (absolute worst case), by considering the average of these values across the band of interest, outages could occur in any one of the operating scenarios presented, with the noise power exceeding the received signal power (by as much as 27.48 dBm) in all but the case of the system transmitting at 100 mW over a distance of 2m. Although worst case situations traditionally occur infrequently, their existence is a reality. Therefore, a microwave oven located within 2m of either the receiver or transmitter of a wireless LAN system, has the potential to disrupt system operation.

7.2.1.3 Noise Power Considerations (10m Omnidirectional)

Similar to the previous case, the omnidirectional measurements were chosen as they yielded the highest noise levels over the band of interest. For the following analysis, Figures 20-22 are to be referred to.

With respect to the operating frequency band (2.39-2.48 GHz), when considering the average peak noise power levels (Figure 20), of the five

scenarios presented, only with transmission distances of 50m is a microwave oven likely to cause problems. In the 2.45-2.46 GHz sub-band, the noise power exceeds the received signal power by 4.85 dBm, only when the transmit power is 10 mW. In the case of 50 or 100 mW transmit powers, the received signal level is higher than the noise level. Therefore, it is unlikely that a microwave oven ≥ 10m from the transmitter or receiver of a typical LAN will cause significant problems in all but one of the operating circumstances presented in Section 7.2. This is because the average peak noise power within this frequency does not exceed the received signal powers for the various scenarios, except in the extreme case presented.

Considering the average peak hold noise power (2 min) levels (Figure 21), a microwave oven could start to affect system performance when the transmission distance begins to exceed 10m. At transmit powers of 10 mW over 10m, the calculated noise power in the 2.45-2.46 GHz sub-band exceeds the received signal power by 2.2 dBm. Once the transmission distance reaches 20m, the noise power exceeds the received signal power at transmit powers of 10 and 50 mW, and is almost equal at 100 mW. In addition, the noise power in this sub-band exceeds the received signal power for all transmit powers over 50m, and in the 10 mW case for the 2.43-2.44 GHz sub-band. Consequently, for the average worst case scenario, there is significant potential for a microwave oven within a 10m radius of the system to cause considerable disruption, it no preventative measures are taken.

Examining the absolute worst case scenario, (peak hold noise power [2 min] : Figure 22), a microwave oven could effect the system in any one of the operating scenarios presented, because in all but three instances, the 2.45-2.46 GHz sub-band noise level exceeds the received signal level. Furthermore, anywhere from 2.43-2.46 GHz, the peak hold noise power (2 min) begins to

exceed the received signal power level in various instances of the four operating scenarios. Therefore, when considering the peak hold noise power (2 min) levels, there is significant potential for a microwave oven to cause considerable disruptions to the system.

7.2.1.4 Average Power Considerations (10m Omnidirectional)

By examining Table 42, we are able to consider what possible effect a microwave oven located at 10m from a typical system may have, by examining the average noise powers for the 2.39-2.48 GHz band, for each of the three noise classifications.

Table 42 : Average Noise Power - 10m Omnidirectional

Noise Classification	Average Noise Power (μW)	Average Noise Power (dBm)
Average Peak Noise Power	1.992×10^{-4}	-67.01
Average Peak Hold Noise Power (2 min)	2.492×10^{-3}	-56.04
Peak Hold Noise Power (2 min)	5.080×10^{-2}	-42.941

First considering the average peak noise power, it is possible to deduce that the expected received signal level given theoretical path loss calculations, exceeds the noise power level by a minimum of 2.89 dBm. Therefore, although the potential for system disruption is minimal, because the difference between received signal power and noise power level is only 2.89 dBm, it cannot be

ignored, as it is a very real possibility that outages could occur as a result of these fine tolerances.

Examining the average peak hold noise power (2 min), there are only three instances whereby the received signal power is lower than the calculated noise power, and this is under scenario four, when the transmission distance is 20m, and the transmit power is at a minimum of 10 mW, and in scenario five, when the transmission distance is 50m and the transmit power 10 and 50 mW respectively. Therefore, although the potential for signal disruption is minimal when considering the average peak hold noise power (2 min) over the band of interest, the fact that situations exist whereby the system could experience outages, means it cannot be ignored.

Finally, considering the worst case scenario (peak hold noise power [2 min]), the average value calculated over the band of interest does exceed the received signal power in numerous instances. Over transmission distances as short as 5m, at a transmit power of 10 mW, the noise power is 1.18 dBm greater than the projected received signal power. As the transmission distance increases, this trend continues, with transmit powers ≤ 50 mW over 10m, and complete dominance over 20 and 50m. Therefore, in the worst case scenario, there is significant potential for a microwave oven situated 10m from a typical system to cause disruption.

7.2.2 Multiple Microwave Oven Environment

7.2.2.1 Average Power Considerations

For the purpose of this examination, Figures 41 through 43, which represent the average noise powers over the frequency band 2.39-2.48 GHz, for the three measurement classifications, are utilised.

Considering the average peak noise power, it is possible to see that for the three hour period between 11am and 2pm, there exists the greatest potential for the multiple microwave oven operational environment presented to influence a typical system. This is so, because at a transmit distance of 20m, the received signal power is lower than the noise power by up to 3 dBm, at an output power of 10 mW. Over transmission distances of 50m, the noise power level exceeds the received signal power level at output powers of 10 and 50 mW respectively. Closer examination reveals that in the case of 50m transmission, the received signal power is lower than the noise power, even between 9-10am, when the transmit power is 10 or 50 mW. Although the noise power only exceeds the received signal power in a few cases, the fact that we are dealing with an average peak noise power level which is very common, means that the potential threat is certainly real.

For all other instances of the operating scenarios presented, the average peak noise power never exceeds the received signal power, according to this analysis.

Moving onto average peak hold noise power (2 min) variations with respect to time of day, it is possible to ascertain that from the data presented, there is potential for system disruption, because the noise power levels exceed the received power levels in various instances of the four scenarios presented, over the entire measurement period (9am-5pm). Even during the quietest measurement period (3-4pm), the noise power is at least equal to the received signal power when the transmission distance is 20m and the transmit power 10

mW, and greater when operating at 10 and 50 mW over 50m. As we move further towards the peak time periods for noise levels (12-1pm is the highest), the potential for disruption increases. For example, at this peak period, the noise level begins to exceed the received signal level, over transmit distances as short as 5m (transmit power = 10 mW). As this distance increases, the adverse effects increase, whereby at a transmit distance of 20m the noise power exceeds the received signal power even at maximum output power of 100 mW. The maximum value by which the noise exceeds the signal power is approximately 19.6 dBm. This figure corresponds to the scenario of the transmit distance being 50m with an output power of 10 mW.

Finally, as expected, the potential for disruption when considering peak hold noise powers (2 min) is noticeably higher than for the previous two cases. Over the entire time frame considered (9am-5pm), the noise power level exceeds the received signal power level in a minimum of six of the fifteen operational instances presented (3-4pm), and a maximum of twelve times for the 12-1pm time frame. The only occasions in which the received signal is higher than the noise power, are at a transmit distance of 2m and output power of 50 and 100 mW respectively, and a 100 mW output power over 5m. However, because these parameters are conducive to high system performance (high power, short transmit distance), and are probably less likely to be found in practical systems, the potential for system degradation in the worst case is proven to be valid.

7.3 PROPAGATION IN FREE SPACE

As indicated in Section 5.4.2.1, basic transmission loss is described by an inverse square law with distance, such that received power decreases by 6 dB for every doubling in distance. In an effort to evaluate the measurement data for validity to this relationship, the analysis was based upon comparing the

omnidirectional measurements (single microwave oven instance) for the 2 and 10m measurements, and the same for the directional measurements. This was achieved by averaging the data over a frequency band which corresponded to the measured levels being at least 8 dB above the noise floor for the 2m cases, so that at 10m significant drops in received noise power could be registered. This helped to eliminate the instances whereby a level that was not substantially clear of the noise floor at 2m, would be of similar level at 10m, thus resulting in erroneous calculations.

From 2m to 10m, the expected reduction in received signal level is ≅ 16 dBm.

Omnidirectional Measurements :

Table 43 : Average Noise Levels For Various Classifications

Distance (m)	Classification	Frequency Range (GHz)	Average Level (dBm)
2	Average Peak Noise Power	2.41-2.47	-60.37
2	Average Peak Hold Noise Power (2 min)	2.41-2.47	-52.96
2	Peak Hold Noise Power (2 min)	2.39-2.48	-36.64
10	Average Peak Noise Power	2.41-2.47	-57.71
10	Average Peak Hold Noise Power (2 min)	2.41-2.47	-51.87
10	Peak Hold Noise Power (2 min)	2.39-2.48	-40.66

Reduction :

- Average Peak Noise Power = -2.66 dBm.
- Average Peak Hold Noise Power (2 min) = -1.09 dBm.
- Peak Hold Noise Power (2 min) = 4.02 dBm.

These results are far from expected, with only the peak hold noise power measurements experiencing a small reduction in received level. The other two classifications actually saw an increase in the received signal over the distance increase, which is entirely the opposite to what is theoretically expected. This however can be accounted for, by a similar explanation to what was provided in Section 6.2.1.2 for the variation in measured levels at 2m between the two antennae. Clarifying, because the omnidirectional antenna was not entirely effective at 2m as a result of its height above the microwave oven, one would expect that the improved efficiency at 10m would render the measured values higher relative to the 2m measurements. As a result, this improved efficiency would tend to offset the reduction in received signal level over the increased distance.

- Classification Average = -2.17 dBm.

As this average shows, in general there was a 2.17 dB increase in signal level in measuring from 10m with respect to measuring from 2m. This highlights the fact that the omnidirectional measurements at 2m were inappropriate.

Directional Measurements :

Table 44 : Average Noise Measurements For Various Classifications

Distance (m)	Classification	Frequency Range (GHz)	Average Level (dBm)
2	Average Peak Noise Power	2.41-2.47	-47.09
2	Average Peak Hold Noise Power (2 min)	2.41-2.47	-45.33
2	Peak Hold Noise Power (2 min)	2.39-2.48	-27.34
10	Average Peak Noise Power	2.41-2.47	-65.25
10	Average Peak Hold Noise Power (2 min)	2.41-2.47	-56.87
10	Peak Hold Noise Power (2 min)	2.39-2.48	-40.77

Reduction :

- Average Peak Noise Power = 18.16 dBm.
- Average Peak Hold Noise Power (2 min) = 11.54 dBm.
- Peak Hold Noise Power (2 min) = 13.38 dBm.

Directional measurements taken over the two distances, did not suffer from the same anomaly as the omnidirectional measurements, and the figures calculated above support this fact. In order to obtain the most accurate

representation, lets consider the average of the three measurement classifications.

- Classification Average = 15.29 dBm.

The empirical classification average is approximately equal to the theoretical reduction in received signal level of 16 dBm over the increased distance from 2m to 10m. Therefore, it is reasonable to assume that the measurement procedure (allowing for the anomaly with the omnidirectional antenna at 2m), was indeed practical and theoretically sound.

8. CONCLUSION

The aim of this project, was to measure and study the factors of background noise evident on wireless microwave LAN channels, and to develop the statistical models representative of the noise figures for the various application environments. This objective has been achieved, with the presentation and analyses presented in Sections 6 and 7 respectively.

One of the most important phases of this project, was to develop a robust foundation on which to begin accumulating measurement data. Knowing what phenomena exist, or at least what to expect, and understanding how one should go about the task of accumulating results, and what analysis is to be carried out on those results, is an obvious but often overlooked prerequisite.

The literature search revealed that although a substantial amount of work had been conducted on wireless LAN characteristics as a whole, very few authors demonstrated results pertinent to the study of the background noise evident on the allocated wireless LAN channels. As a result, I feel that the material presented in this report substantiates the presence of noise sources within the bands of interest, with respect to typical operational environments, and provides an indication of how one can expect a typical system to behave in the environment characterised.

The three major potential system disruptors found as a result of this study, were Pay TV, microwave alarm systems, and microwave ovens. The first two categories were ascertained to be of minimal concern, due to the spectral occupation falling on the borders of the band utilised for wireless LAN operation. Microwave ovens however, were deemed to of major concern to the effective operation of the proposed system, as a result of the coincidence of

spectral position and the relatively high power levels. The term relative, refers to the typical output powers proposed for the intended system, with respect to received signal levels subsequent to free space loss considerations.

Section 7 considered the significance of the results obtained for the various microwave oven measurements, which included an analysis of both single and multiple instances of the ovens. As a result of these considerations, it was deemed that microwave ovens operating either on a stand alone basis, or in multiplicity, have significant potential to disrupt transmission. Furthermore, this analysis was based on simple line of sight transmission (no obstacles), as well as ignoring other adverse effects such as multipath, which contribute significantly to signal degradation. Therefore, it is highly possible that the impact of microwave ovens on system performance could indeed be worse than was tentatively suggested.

The statistical analyses presented provide accurate information regarding the respective noise power levels for the various configurations of measurement procedures, as well as supplying information regarding sample variance and standard deviations, with respect to the mean values as a result of the normalisation process. In addition, the attainment of data was carefully planned in accordance with requirements for statistical accuracy (sample size), and pertinent analysis procedures. These facets, coupled with measurements being conducted in various applicable application environments, render the statistical analyses and significance considerations germane to the requirements of the project.

As a result of this investigation, microwave ovens can be considered to be of significant importance, to be catered for in system design. Although removed from the scope of this report, I will conclude with suggestion as to what may be

done in an effort to counter the potential problems that may occur as a result of my findings.

Characteristically speaking, the spectrum output from microwave ovens has a definitive shape, with respect to intensity and spectral location. The characterisation of this shape, may allow system designers to overcome (or at least minimise) the potential problems that may arise as a result of the noise sources present, by using preventative measures such pre-emphasis and de-emphasis. Basically, this technique provides a means of improving the signal to noise ratio at the output of the receiver, by boosting areas of the modulation at the transmitter that need to overcome the higher power noise levels, and attenuating the output of the receiver in a manner which helps to overcome the noise problems. Because we now have a characteristic shape for the noise spectrum, this technique of improving the signal to noise ration is a realistic proposition.

Other techniques, such as *smart* power control, may be able to help combat the diurnal variation in the noise power. Because wireless LAN's are typically battery driven, one does not want to operate at full power indefinitely, as battery drain is too high. Rather, knowing that the noise power level is highest in an environment such as the Whitford City Shopping Centre Food Hall, in the vicinity of lunch time, it may be appropriate to utilise higher average transmit powers at this time, and reduce these powers during times of less microwave oven activity (mid morning / afternoon). As I stated, these are only suggestions, as it is beyond the scope to consider them in greater detail, and to determine their relative merit, or worth.

In conclusion, the analyses presented provide accurate information with respect to the background noise evident on microwave wireless LAN channels,

which should prove useful, specifically speaking for channel characterisation considerations, while in more general terms, aid various facets of system design and construction.

9. REFERENCES

Note : The referencing format is as per Edith Cowan University Guidelines, as stipulated by :

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10. APPENDIX

A.1 STATISTICAL FORMULAE

The following formulae represent the means utilised to calculate the statistical parameters of mean, variance and standard deviation, for Sections 6.2-6.3.

Note : The multiplication by the factor 10^3 in each case, is in addition to the generic formulae for these statistical parameters. The multiplicative factor was incorporated solely to convert the calculated figure from mW to μW.

A.1.1 MEAN

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n} \times 10^3 \qquad (8)$$

where :

x_i = sample value.

n = sample size.

A.1.2 VARIANCE

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1} \times 10^3 \qquad (9)$$

A.1.3 STANDARD DEVIATION

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1} \times 10^3} \qquad (10)$$

A.2 LETTERS REQUESTING MEASUREMENT APPROVAL

A.2.1 EDITH COWAN UNIVERSITY JOONDALUP CAMPUS

May 16, 1995

Jason Hislop
[redacted]

Joondalup Campus Manager
Edith Cowan University
Joondalup Drive
Joondalup, WA. 6027

RE : PERMISSION TO TAKE MICROWAVE NOISE MEASUREMENTS ON JOONDALUP CAMPUS.

To Campus Manager,

Thank you for taking the time to read this short note, from which I take the opportunity to introduce myself. I am currently completing my final year as a Bachelor of Engineering student at Edith Cowan University, and as part of my course requirement, I am to undertake and complete a final year engineering project.

My project involves an analysis of background noise prevalent on frequency channels allocated for the emerging technology of wireless LAN's. As part of this project, I am required to complete a set of field measurements of noise levels in various applicable operating environments.

Permission granted, I would intend to take a series of such measurements on **JOONDALUP CAMPUS (Library, Computing Centre)**. The measurements would involve the use of two portable aerials, and a compact electronic device (spectrum analyser). The measurement process will be passive in nature, with no radiated power emitted. I will only be detecting noise, not emitting it. Therefore, the mechanism is completely safe for all concerned.

I can be contacted at the above address, or by phone, and look forward to hearing from you soon. Thank you for your anticipated cooperation, and assisting me in my work and future aspirations.

Sincerely,

Jason Hislop

A.2.2 WHITFORD CITY SHOPPING CENTRE

May 16, 1995

Jason Hislop
[redacted]

Centre Management
Whitford City Shopping Centre
Whitfords Avenue
Hillarys, WA. 6025

RE : PERMISSION TO TAKE MICROWAVE NOISE MEASUREMENTS ON PREMISES.

To Centre Management,

Thank you for taking the time to read this short note, from which I take the opportunity to introduce myself. I am currently completing my final year as a Bachelor of Engineering student at Edith Cowan University, and as part of my course requirement, I am to undertake and complete a final year engineering project.

My project involves an analysis of background noise prevalent on frequency channels allocated for the emerging technology of wireless LAN's. As part of this project, I am required to complete a set of field measurements of noise levels in various applicable operating environments.

Permission granted, I would intend to take a series of such measurements at **WHITFORD CITY SHOPPING CENTRE**. The measurements would involve the use of two portable aerials, and a compact electronic device (spectrum analyser). The measurement process will be passive in nature, with no radiated power emitted. I will only be detecting noise, not emitting it. Therefore, the mechanism is completely safe for all concerned.

I can be contacted at the above address, or by phone, and look forward to hearing from you soon. Thank you for your anticipated cooperation, and assisting me in my work and future aspirations.

Sincerely,

Jason Hislop

A.2.3 WILSON'S ENGRAVING WORKS

May 16, 1995

Jason Hislop
[redacted]

Mr Clayton Wilson
Wilson's Engraving Works
30 Westchester Road
Malaga, WA. 6062

RE : PERMISSION TO TAKE MICROWAVE NOISE MEASUREMENTS ON PREMISES.

Dr Mr Wilson,

Thank you for taking the time to read this short note, from which I take the opportunity to introduce myself. I am currently completing my final year as a Bachelor of Engineering student at Edith Cowan University, and as part of my course requirement, I am to undertake and complete a final year engineering project.

My project involves an analysis of background noise prevalent on frequency channels allocated for the emerging technology of wireless LAN's. As part of this project, I am required to complete a set of field measurements of noise levels in various applicable operating environments.

Permission granted, I would intend to take a series of such measurements at **WILSON'S ENGRAVING WORKS**. The measurements would involve the use of two portable aerials, and a compact electronic device (spectrum analyser). The measurement process will be passive in nature, with no radiated power emitted. I will only be detecting noise, not emitting it. Therefore, the mechanism is completely safe for all concerned.

I can be contacted at the above address, or by phone, and look forward to hearing from you soon. Thank you for your anticipated cooperation, and assisting me in my work and future aspirations.

Sincerely,

Jason Hislop

A.2.4 EDGEWATER TRAIN STATION

May 16, 1995

Jason Hislop
[redacted]

Mr Robert Campbell
Director of Public Transport Coordination
Deloitte Touche Tomatsu Building
Level 5 19 Pier St
Perth, WA. 6000

RE : PERMISSION TO TAKE MICROWAVE NOISE MEASUREMENTS AT EDGEWATER TRAIN STATION.

Dear Mr Campbell,

Thank you for taking the time to read this short note, from which I take the opportunity to introduce myself. I am currently completing my final year as a Bachelor of Engineering student at Edith Cowan University, and as part of my course requirement, I am to undertake and complete a final year engineering project.

My project involves an analysis of background noise prevalent on frequency channels allocated for the emerging technology of wireless LAN's. As part of this project, I am required to complete a set of field measurements of noise levels in various applicable operating environments.

Permission granted, I would intend to take a series of such measurements at **EDGEWATER TRAIN STATION**. The measurements would involve the use of two portable aerials, and a compact electronic device (spectrum analyser). The measurement process will be passive in nature, with no radiated power emitted. I will only be detecting noise, not emitting it. Therefore, the mechanism is completely safe for all concerned.

I can be contacted at the above address, or by phone, and look forward to hearing from you soon. Thank you for your anticipated cooperation, and assisting me in my work and future aspirations.

Sincerely,

Jason Hislop