INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2010, VOL. 56, NO. 2, PP. 137-144
Manuscript received May 26, 2010; revised June, 2010. 10.2478/v10177-010-0018-z

Mapping and Recognition of Radio Frequency Clutter in Various Environments in Australia

Johnson Agbinya, Vivian Lee, Khalid Aboura, and Zenon Chaczko

***Abstract*—Radio frequency spectrum mapping allows determining the radio frequency signatures prevalent within an environment. We address the primary frequency bands used for cellular, wireless Local Area Network (LAN), Universal Mobile Telecommunications System (UMTS) and Ultra-wideband (UWB) communications. The purpose of the experiment presented in this paper is to map the detected radio frequencies within an environment and display the collated data on a graphical user interface. A program identifies the presence of the aforementioned radio frequency signatures and recognizes signal levels which exceed the exposure standards enforced by the Australian Communication and Media Authority. The results assist in the understanding of the ramifications of long-term exposure to radio frequency radiation associated with the continued proliferation of wireless devices.**

***Keywords*—Electromagnetic pollution, environmental monitoring, software engineering.**

I. INTRODUCTION

THERE is an increasing dependence in every country on limited radio frequency (RF) spectrum and a thickening soup of radio frequency radiations world wide. This dual increasing pervasiveness of radio frequencies and signals in most surroundings provides a strong motivation for understanding the effects of radio frequencies in living spaces. Health and regulatory concerns are paramount within the radio communication industry. Radio frequency spectrum mapping allows determining the radio frequency signatures prevalent within an environment. This also allows stakeholders to discern the related power level of each signal and visualize any potential causes of concern. To address this problem, the primary frequency bands in focus in this paper are the ones used for cellular, wireless LAN, UMTS and UWB communications. Providing safe radio frequency power levels and penetration are regulatory demands and are integral to the design and location of wireless technologies. Continual exposure to devices can potentially lead to detrimental effects on human tissue. Due to the difficulties of controlled experimentation on human exposure to high levels of non-ionizing radiation, theoretical and experimental procedures are inconclusive in regards to the causal effects between exposure and adverse health effects. The purpose of the methodology presented in this paper is to map the detected radio frequencies within an environment and display the collated data on a graphical user interface. The program identifies the presence of the aforementioned radio frequency signatures and recognizes signal levels which exceed the exposure standards enforced by the Australian Communication and Media Authority (ACMA). Data reinforce the theoretical understanding of radio frequency propagation and detect the primary uses of the spectrum within an arbitrary location. The results in our methodology can be used in the understanding of the effects of long-term exposure to radio frequency radiation associated with the continued proliferation of wireless devices [6].

A. Radio Frequency Soup in Any Location

Due to the high densities of radio frequency signals from various communication sources such wireless LAN, cellular communication base stations, radio and TV stations, satellite and other terrestrial communication systems, presence of large RF power at a location is of interest. This is to ensure that the location is exposed to acceptable power levels as regulated by government agencies in various countries. The measurement of radio frequency field exposure predominantly focuses upon the exposure levels in the near field region. The area surrounding a radio frequency source can be partitioned into two separate regions: the near-field zone, and the far-field zone. The near-field zone is also composed of the inductive and radiative zones. In the inductive zones, antennas couple energy to each other via the process of mutual induction and in the radiative near-field, energy transfer is through normal RF propagation obeying Maxwells equations. An electric dipole produces two fields, an electric field and a magnetic field. Electric and magnetic fields behave differently in the near field and far fields and hence require different equations to model them in free space and in practical situations. Two sets of equations describing these fields at angular directions and radial directions need to be given. We first provide the angular behaviors of the fields. The induced voltage (per meter) in a dipole antenna excited by a current source at angular frequency ω along an angular direction θ is given by the expression:

$$E_\theta = \frac{I\ l\ \beta^3}{4\pi\omega\epsilon_0}[\frac{j}{\beta r} + \frac{1}{(\beta r)^2} - \frac{j}{(\beta r)^3}]\sin(\theta)e^{-j\beta r}\ V/m \quad (1)$$

In this expression I is the physical length of the dipole antenna in meters. $\beta = \omega/c = 2\pi/\lambda$ s its electrical length per meter of wavelength of the antenna. $\omega = 2\pi f$ is the angular frequency in radians per second, f is the frequency of the radiation in Hertz, λ is the wavelength in meters, c the speed of light

---

This work was supported by the Centre for Real-Time Information Networks (CRIN) of the University of Technology Sydney, Australia.

J. Agbinya, V. Lee, and Z. Chaczko are with the School of Computing and Communications, University of Technology Sydney, 15 Broadway, Ultimo, NSW 2007, Australia (e-mail: Johnson.Agbinya@uts.edu.au; Zenon.Chaczko@uts.edu.au).

K. Aboura is with the School of Civil and Environmental Engineering, University of Technology Sydney, 15 Broadway, Ultimo, NSW 2007, Australia (e-mail: Khalid.Aboura@uts.edu.au).

(3×10^8 m/sec), r is the distance from the source of radiation to the point of observation and $\epsilon_0 = 1/(36\pi 10^{-9})\ F/m$ is the permittivity of free space. Apart from a dipole antenna, a magnetic loop antenna can be used for near field inductive communications. When a magnetic loop antenna is excited with a current I at angular frequency ω, the electric field at direction θ is:

$$E_\theta = -j\ \frac{\omega\mu_0 m\beta^2}{4\pi}[\frac{-1}{j\beta r} + \frac{1}{(\beta r)^2}]\sin(\theta)e^{-j\beta r}\ V/m \quad (2)$$

Power levels can be very high in the near field region in most locations. Equations (1) and (2) depend on a range in the form of $1/r$, $1/r^2$ and $1/r^3$. Close to the antenna (near field), when r is small the term $1/r^3$ dominates. Farther away from the antenna the terms $1/r^2$ and $1/r^3$ attenuate very fast and are close to zero and the term inversely proportional to range is the most important. This is the far field region. Hence the boundary between the near and far field can be estimated. An accepted near field boundary is where the range is determined by the expression $r = \lambda/2\pi$. Radio frequency identification (RFID) and some short range communication systems operate in the near-field region. In the far-field region where most terrestrial communication systems operate, the power loss as a function of distance and frequency is given by the expression:

$$P(r,f) = \frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{(4\pi)^2 r^2} = \frac{G_T G_R}{4}\frac{1}{(\beta r)^2} \quad (3)$$

In (3), r is the distance between the transmitter and receiver, G_T and G_R are the gains of the transmitting and receiving antennas, $\beta = 2\pi/\lambda$ and λ is the wavelength of transmission in meters. This expression shows that far field free space power loss is proportional to the inverse power of distance squared. Due to the prevalence of radio communication systems at a location, the total amount of power absorbed by an object originates from many sources. Although each source contributes a little bit of power, the object itself is in a soup of many power sources with each contributing to the overall power absorbed by the object.

B. Radio Frequency Exposure

The current Australian standards in reference to radio frequency exposure are set by ACMA, while the Commonwealth regulations are governed by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Both agencies have sets of regulations based on limits set by the International Commission for Non-Ionizing Radiation Protection (ICNIRP) [14]. The limitations set by the ICNIRP are based on the documentation proposed by the World Health Organisation. In 2002, ARPANSA published the standard *Radiation Protection Standard - Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz* [10]. The ARPANSA standard sets limits for human exposure to RF fields in the frequency range 3 kHz to 300 GHz. The standard includes:

- mandatory basic restrictions for both occupational and general public exposure involving all or part of the human body,
- indicative reference levels for measurable quantities derived from the basic restrictions,
- approaches for verification of compliance with the Standard and
- requirements for management of risk in occupational exposure and measures for protection of the general public.

At the different frequency ranges, the standard basic restrictions are designed to prevent adverse reactions related to radio frequency field exposure:

- electrostimulation of excitable tissue (3 kHz - 100 kHz),
- adverse effects arising from localised and/or whole body heating (100 kHz - 6 GHz),
- excess heating of skin or cornea for frequencies in the range (6 GHz - 300 GHz),
- nuisance auditory effects (300 MHz - 6 GHz),
- adverse effects associated with extremely high pulsed fields (3 kHz - 300 GHz).

Basic restrictions from 10MHz - 10GHz, averaged over a 6 minute interval in 10 gram tissue, is shown in Table I. All values are based in SAR (W/Kg) (see Section II-B).

From these standards, some reference levels for a variety of units of measurement for a range of 2-300GHz are shown in Table II.

TABLE I
RADIOFREQUENCY SAR LIMITS

	Occupational	**General Public**
Whole body	0.4	0.08
Localized - head and torso	10	2
Localized - limbs	20	4

TABLE II
RADIO FREQUENCY LIMITS IN VARIOUS MEASUREMENTS

	Occupational	**General Public**
Electric field (V/m)	137	61
Magnetic field (A/m)	0.36	0.16
Magnetic induction (μT)	0.45	0.20
Power Density (W/m^2)	50	10

II. RADIO FREQUENCY MEASUREMENTS

A major reason for the determination of radio frequency strength at a location relates to the interaction between the field and biological tissues such as the human body. Difficulties in the measurement of radio frequency fields can be attributed to the variation in field strength as a result of a range of characteristics associated with electromagnetic fields. These characteristics include ground reflection and scattering. To circumvent this known issue, numerous calculations involve spatial averaging.

A. Spatial Averaging

The use of spatial averaging reduces the uncertainty related to the measurement of and analysis of the effects of radio frequency exposure over the human body. It is commonly employed in situations where the point measurements of radio frequency field levels approach the exposure limits. As the calculations approach the defined limits, the need for a more accurate measurement approach is required. Two common environments where spatial averaging is optimal to reduce measurement uncertainty are the regions surrounding:

- Wireless systems antennas
- Radio and television broadcast antennas

The need for consistency in the above situations results from the type of antenna applied. In wireless systems, it is common for antennas to be co-linear dipole arrays. Such an antenna can be identified by lobes which coincide with peak field strength powers. On average, these lobes are spaced one wavelength apart and will result in a variation of approximately 6 dB between the peaks and the troughs of the electromagnetic wave. As such, this variation will cause large differences in field strength over a common vertical axis. In essence, the process of spatial averaging involves the calculation and subsequent averaging of a series of measurements which denote the human form. The most practical method of measurement involves the use of survey equipment due to the large number of data points per second required. This increases the accuracy due to the large number of measurements obtained.

B. Radio Frequency Exposure Calculations

The chief indicator for radio frequency exposure is the specific absorption rate (SAR). SAR measures the amount of radiation absorbed into the body and is closely related to the rise in body temperature, as a result of RF field absorption into tissue. It is expressed in watts per kilogram. The use of SAR is particularly prominent in the analysis of health effects for radio frequencies that exceed 100KHz. The SAR is calculated as the time domain derivative of the specific absorption (SA). Numerically,

$$\text{SAR} = \frac{\delta}{\delta t}(SA) = \frac{\delta}{\delta t}(\frac{\delta W}{\delta m}) = \frac{\delta}{\delta t}(\frac{\delta W}{\phi \delta V}) \tag{4}$$

The calculation of the SAR in (4) is dependent upon the incremental energy δW that is absorbed by the incremental mass δm that is contained in a volume δV of a given density ϕ. However, due to the intrusive nature of the ideology surrounding the measurement of SAR, the procedure is difficult to implement practically. Hence the reliance on theoretical processes based on computational and experimental models can vary. The computational techniques employed are analytical and numerical. One method focuses on calculating the distribution of absorbed energy in simplified tissue geometries. Such geometries involve cylinders and spheroids. Another process involves the utilization of finite difference time domain (FDTD) which led to software for modeling and calculations of local and regional SARs.

Experimental means to determine SAR involve animals or models composed of tissue-equivalent synthetic material, referred to as phantoms. These phantoms have limitations due to the homogenous nature of the material. There are two methods of measurement employing phantoms [18], [19]. One technique focuses on temperature changes within the phantom, which result from the heat produced from exposure to radio frequency energy. Such a calculation employs temperature probes and is only conclusive if the change in temperature is linear with time. Such a technique is only valid when exposure levels are concentrated enough so the temperature changes are not considerably influenced by heat transfer in and out of the body. Mathematically, SAR $= \gamma \Delta T / \Delta t$. According to this equation, SAR is based on temperature rise ΔT (^{0}C); Δt = time interval (seconds); γ = phantom material specific heat capacity (J/kg^{0}C). The second technique to measure SAR is based on electric fields utilizing electric field probes. This method can only be applied to localized regions of measurement and for low values of SAR, such that any absorbed temperature does not induce a detectable change in temperature. Mathematically, SAR is based on σ = tissue conductivity (S/m); E = rms electric field strength induced in the tissue (V/m); ρ = mass density (kg/m^3), SAR $= \sigma |E|^2 / \rho$. Hyperthermic effects on human tissue as a result of radio frequency exposure also relate to the frequency. This factor contributes to the depth of energy penetration into human tissue [5]. It is seen that there are two levels of thermoreceptors within mammals which respond to changes in temperature. The surface receptors are seen to focus on generation of thermal sensations and reactions. These receptors are stimulated by conventional thermal stimuli present in the surrounding environment and high frequency radio frequency radiation which is superficially absorbed within the tissue. The receptors located deeper within the body are present within the brain, spinal cord and internal organs. Such receptors are stimulated through alterations in deep body temperature. Deeply penetrating radio frequencies can affect these receptors and bypass the surface receptors, resulting in abnormal changes in temperature within the body.

C. Exposure Levels Monitoring

It is important to note that the guidelines set by the respective governing bodies to limit exposure to radio frequencies provide protection against the known adverse health effects. However, biological effects associated with radio frequency exposure may not necessarily result in adverse health effects to humans [20]. Therefore, such related monitoring and ensuring that exposure levels are met is not definitive. Within Australia, the Australian Communications and Media Authority mandates the compliance of all mobile and communications devices prior to public distribution or installation. In particular, ACMA's Radiocommunication Standard *Electromagnetic Radiation - Human Exposure* [9] details the limits for electromagnetic radiation exposure based on the restrictions set by ARPANSA. This standard also identifies the methods of testing deemed suitable for various transmission devices. This creates a uniform and consistent measurement across various radiocommunication devices. The measurement methods are characterised according to the distance between the device and the human body. Schedule 2 of the ACMA Radiocommunication Standard denotes the method to measure devices designed to be used against the human head. However, devices used more than 20 cm from the human body are measured using the techniques outlined in the *Radiocommunications (Electromagnetic Radiation Human Exposure) Amendment Standard 2007 (No. 1)* [8]. All telecommunication devices must be approved and be granted a licence by ACMA proving that such devices fulfil all standards enforced by various telecommunications agencies. The radiocommunications licence conditions *Apparatus Licence - Determination Act 2003* [7] notes that the licensee of the transmission device must demonstrate to ACMA that the radio frequency field of the equipment complies with the standard. ACMA must be provided all documentation regarding compliance within 20 days of an observance request and the licensee must keep records as proof. Consequently, all recommendations to exposure limits can be categorized into two types:

- Basic restrictions which must always be followed, since such limits are based upon quantities which are internal to the human body and are not measurable. The units include SAR.
- Reference levels which can potentially be exceeded, as long as basic restrictions are met, since these are stated in quantities that do not involve the presence of a human body. An example is electric field strength.

D. Effects of Radio Frequency Exposure on Human Tissue

Radio frequency energy is classified as non-ionizing radiation since the associated energy levels are not strong enough to produce any ionization of atoms and molecules [6]. As a result, biological molecular damage like effects on genetic material and tissue are not prevalent. The electromagnetic energy emitted from a source is partially reflected by human body and partially absorbed and transformed within the body [20]. The ratio between reflection and absorption is dependent on various factors such as characteristics of the medium traveled and the body. However, the interaction between radio frequencies and cell tissue can stem from the following methods [20]:

- Penetration by electromagnetic waves and the propagation into living organisms
- Primary interaction with waves and cell tissue
- Potential secondary effects of the primary interaction

Biological effects of radio frequency exposure are therefore focused on human tissue and in particular the internal electromagnetic field. The SAR levels widely employed measures the power absorbed within the absorbing mass. Extensively analyzed thermal effects of radio frequency exposure depend on this SAR spatial distribution. Hence, the consequent value of SAR influences the absorption effects of exposure on the human body [20].

In general, the chief biological effects caused by radio frequency energy are the related hyperthermic effects. Exposure to high intensity RF energy can result in the heating of biological tissue and the subsequent increase in body temperature. Such an increase can cause tissue damage, especially in vulnerable areas of the human body like the eyes, due to the body's inability to successfully dissipate any excessive heat generated within the said localized area. These hyperthermic effects result from the transfer of energy between the propagating radiation and the matter that is absorbing. The transfer of energy varies according to frequency, based on dielectric loss due to the movement of the atoms and molecules in an alternating electric field. This loss is proportional to radiation intensity. It is evident that pulsed exposure to radiation has a higher likelihood to result in biological effects, than continuous waves [20].

However, any associated harmful biological effects associated with exposure to low levels of radio frequency radiation are presently ambiguous and inconclusive. Current epidemiological evidence is not definitive in demonstrating any causal effects between radio frequency exposure and adverse health effects. However, current evidence also does not rule out the absence of any associated hazards. Elwood (1999) [12] concluded that any health affects that result may be quite small and are therefore undetected by humans as a source of concern. The main source of concern by numerous members of the public, in terms of radio frequency exposure surrounds the increased use of mobile phone. The close proximity to the head and neck region results in higher exposure [17]. There is currently inconsistent evidence demonstrating clear health ramifications of high mobile phone usage. Current experimentation demonstrates little or no evidence of abnormal cellular or carcinogenic effects. However, it must be noted that the possibility biological and psychological effects are possible, albeit unclear in any conclusions. Any potential effects cannot be successfully dismissed and experimental proceedings are still underway to determine solid conclusions in such a hypothesis. Recently, an important research article was released by the INTERPHONE project group. INTERPHONE is a multi-national project testing whether using mobile phones increases the risk of various cancers of the head and neck. The project comprises national epidemiological studies from 13 countries, which are coordinated by the International Agency for Research on Cancer (IARC), an agency of the World Health Organization [13]. The International Journal of Epidemiology published a combined data analysis from a multi national population-based case-control study of glioma and meningioma, the most common types of brain tumour [15]. This is the first in a series of combined data analyses of head and neck tumours published as part of the internationally coordinated INTERPHONE project. The key message of the article is "INTERPHONE is the largest case-control study of mobile phone use and brain tumours yet and includes the largest numbers of users with at least 10 years of exposure. A reduced OR for glioma and meningioma related to ever having been a regular mobile phone user possibly reflects participation bias or other methodological limitations. No elevated OR for glioma or meningioma was observed $\geq$ 10 years after first phone use. There were suggestions of an increased risk of glioma, and much less so meningioma, in the highest decile of cumulative call time, in subjects who reported usual phone use on the same side of the head as their tumour and, for glioma, for tumours in the temporal lobe. Biases and errors limit the strength of the conclusions that can be drawn from these analyses and prevent a causal interpretation" [15]. The news of the report was received with different perceptions. Phone and electronic companies saw the news in support of the safety of the technology, while some media reported it as a warning and a need to investigate further [4].

Fears related to links between cancer and exposures to radio frequencies are widespread. However, the epidemiological connection is not highly conclusive due to the difficulties associated with determining a single, definitive cause for cancer. Current belief is the fact that there are no direct carcinogenic effects associated, but there is a possibility of indirect damage [20]. The conflicting evidence results in a need for further experimentation in all aspects of radio frequency exposure. This methodology described in this paper attempts to only measure the presence and power levels of radio frequency signals within a university campus in the middle of the Australian city of Sydney.

III. FREQUENCY DETECTION AND CAPTURE

Spectrum analysis is important for monitoring, allowing government regulatory agencies to allocate various frequencies to radio communication services. Out-of-band and spurious emissions may cause interference to the broadcasted signal. Such interference can distort the message, ensuring that the original information cannot be successfully demodulated. Radio frequency signatures can be monitored through the use of spectrum estimators. Such a device assists users by identifying the frequencies within a range and plots it against the respective amplitude. It can be designed to display a power spectrum. It is essentially a wideband receiver. There are numerous types of spectrum analyzers including swept-tuned, heterodyne, Fourier, vector and hybrid analyzers. A Fourier analyzer employs digital signal processing methods by applying fast Fourier transform (FFT) to the time-domain signal samples, acquired at least at the Nyquist rate. The FFT provides for speed and flexibility in the analysis. The output from the FFT is a set of spectral lines in the frequency domain. An advantage of digital analyzers is the ability to preserve information pertaining to the phase and amplitude of the original input signal. Such information is beneficial to the subsequent analysis of modulation schemes applied to encode the data. However, a main limitation to this type of analyzer is the limited frequency range it can monitor. A vector signal analyzer is similar to a Fourier analyzer. The spectrum analyzer digitises the time-domain input signal as well. However, it includes down-converters before the analog-to-digital converter (ADC), allowing a wider frequency range.

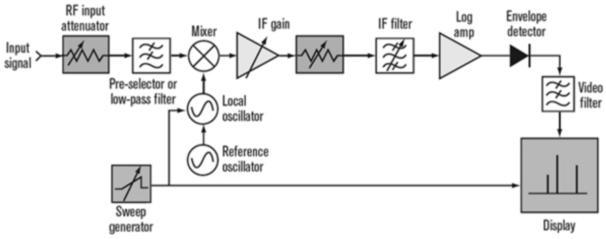

Fig. 1. Spectrum analyzer Circuit Diagram [3].

A swept-tuned heterodyne analyzer converts higher frequency signals to measurable quantities. It particularly employs a swept-frequency local signal to down-convert the input signal and feeds it to a narrowband filter. By sweeping the local signal across a range of frequencies results in an output from the filter which denotes a similar sweep across the radio frequency spectrum of the input signal [3]. A diagram of this spectrum analyzer is shown in Figure 1. A hybrid analyzer employs both digital and analog spectrum analysis techniques. The use of the signal down-conversion from analog spectrum analyzers allows the input signal to be translated to a lower frequency that can be analyzed. The resultant signal is consequently sampled and FFT is applied. Such a hybrid technique allows a higher frequency range to be analyzed whilst maintaining the advantages of digital analyzers to preserve signal information.

A. Spectran Spectrum Analyser

To explore the radio frequency signatures prevalent in the environment it was decided to use off the shelf components. A Spectran Spectrum analyzer (Figure 2) was employed to detect radiation and their respective signal strengths. The analyzer is manufactured by Aaronia AG. It uses digital signal processing to extract and filter the characteristics of the radio frequencies. It is designed to identify a frequency range of 10MHz to 6GHz.

Fig. 2. Spectran HyperLOG Antenna [1].

B. *Spectran HyperLOG Antenna*

The Spectran Spectrum analyzer employs the directional HyperLOG antenna which is logarithmic-periodic [2]. It has a frequency range of 400MHz-6GHz. The nominal impedance of this antenna is 50 ohms with a gain of 5dBi. It has 561 calibration points in 10MHz steps and an antenna factor of 20-40dB/m. Such a log-periodic antenna is unidirectional, broadband and narrow-beam. It is particularly employed for wide bandwidths. The HyperLOG antenna is an example of a log-periodic dipole array (LPDA), as demonstrated by the shape of the antenna [11]. An LPDA consists of a number of parallel dipole elements which decrease in size from the back to the front of the antenna. As evident in the diagram, the direction of the beam is from the narrow-most section of the antenna. The dipoles are sized such that the largest dipole at the back of the antenna is half the wavelength of the lowest frequency of the antenna and the shortest dipole element is approximately half the wavelength of the highest frequency. The spacing between each dipole also decreases as the dipoles become shorter. The primary feature of the LPDA antenna is the logarithmic variation of the electrical properties of the antenna with the frequency. This variation of the electrical attributes of the antenna is determined by the shortening parameter τ and the relative separation factor ρ. Mathematically, they are determined by (5) and (6) [11]:

$$\tau = \frac{D_{n+1}}{D_n} = \frac{L_{n+1}}{L_n} \tag{5}$$

$$\rho = \frac{1-\tau}{4\tan\frac{\alpha}{2}} = \frac{D_n}{2L_n} \tag{6}$$

C. *Spectran Spectrum Analyzer Output*

The output of the Spectran Spectrum analyzer is able to be viewed on the in-built LCD display or the bundled software. The user is able to specify the frequency range to be swept and send this information to the handheld device. The analyzer is designed to output a graph highlighting the top three frequencies in MHz and the respective power levels in dBm on a graph.

IV. RADIO FREQUENCY POLLUTION MAPPING

A computer program was designed with the purpose of creating a graphical user interface (GUI) to display the prevalent frequencies and respective powers [16]. It is to be used in conjunction with the program bundled with the Spectran Spectrum analyzer. The radio frequency readings are obtained from the spectrum analyzer, resulting in a *.ldt file which can be used as an input to the computer program. The user is able to select one of the three sweeps available in the file or a combination of the three. The information is plotted on graphs. The program aims to identify the frequencies which exceed the mandatory maximum exposure levels for non-ionizing radiation. This is integral to recognizing the radio frequency pollution. The associated power levels are detailed. The user is able to zoom into areas of the computer graph to gain a clearer view of the power and frequency of a particular peak on the power spectrum. This allows users to analyze a dominant cluster of prevalent frequencies or manually select the frequency range they wish to examine.

To determine the power density of the particular frequency detected, (7) can be used:

$$s = \frac{10^{\frac{P-G}{10}}}{1000} \times \frac{4\pi}{\lambda^2} \quad (\mathrm{W\ m^{-2}}) \tag{7}$$

The HyperLOG 4060 antenna, used with the spectrum analyzer is seen to have a gain of 5dBi. The program is designed to calculate the power density of the three frequencies of highest signal strength. This allows users to determine if the frequencies prevalent within the environment exceed the maximum permissible signal strength. If the signal is seen to exceed the ICNIRP recommended limitations, the output box communicates this information to the user. The use of the top three frequencies is based on the idea that if these frequencies do not exceed maximum permissible power levels, all other detected frequencies will also be below the maximum power density.

The input data files must contain measurements from 400MHz to 6GHz, with a sample value every 3MHz. The theoretical maximum permissible power density levels are determined through the values associated with general public exposure of the radio frequency spectrum. These values are seen to be lower than those specified for occupational exposure. Due to the desire of allowing the measurement of the radio frequency spectrum at any arbitrary location, it was decided that the general public exposure levels are most relevant. This will enable a broader and most relevant analysis of the probability of experiencing the biological effects of exposure to non-ionizing radiation.

V. RESULTS AND ANALYSIS

A series of measurements were conducted at the University of Technology Sydney (UTS). Engineering labs were chosen as a location of possible high exposure and the university foyer as a general public area.

A. *University Engineering Lab*

Figure 3 indicates the power density levels of all available radio frequencies prevalent between 400MHz and 6GHz, extracted on a day of October 2008 and measured in a University Engineering laboratory. All three sweeps are displayed in the graph and the resultant plot indicates that the measured data between all three sweeps are similar. The graph indicates that there are two main clusters of dominant frequencies. However, there are 5 regions within this given bandwidth that are detected by the spectrum analyzer. The chief cluster is situated between 2.7GHz and 3GHz. According to the ACMA radio frequency Spectrum Plan 2005, this frequency range is associated with aeronautical radio navigation, radiolocation and radio navigation. It is used predominantly by ground-based radars and is not associated with the aforementioned wireless technologies investigated here. The secondary cluster is evident in the bandwidth of 540 MHz and 580 MHz. In accordance with the ACMA radio frequency Spectrum Plan 2005, this region of the radio frequency spectrum is allocated

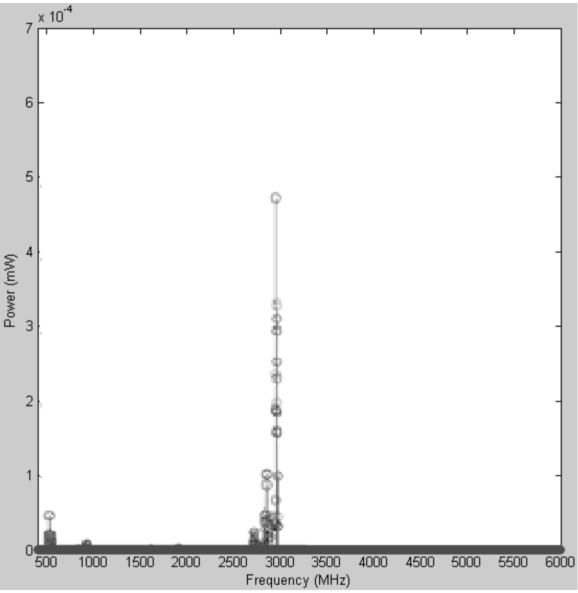

Fig. 3. MATLAB GUI results – UTS Lab.

to broadcasting and fixed mobile. As denoted in the Benelec Wireless Products Cellular Frequency Chart, the correlated Australian television channels for this frequency bandwidth are channels 30-35. This is located within the ultra-high frequency (UHF) band IV. There is also evidence of frequencies within the 860-960MHz range. This indicates the presence of the cellular mobile frequency networks. That is GSM/GPRS and 3G. Due to the restricted access in the engineering lab, the low levels of this bandwidth do not result in a large impact on the services available for end users there. The presence of 1870MHz-1930MHz [16] is associated with frequencies related to Digital Enhanced Cordless Telecommunications (DECT) devices. The devices are particularly employed for cordless telephony and even Voice-over-IP (VoIP). This region can also indicate the existence of GSM signals. Another prevalent frequency cluster detected in the lab is between 1630MHz and 1720MHz [16]. This region of the radio frequency spectrum, in accordance with to the ACMA radio frequency Spectrum Plan 2005, is associated with mobile satellite (earth-to-space), radio astronomy, space research, radio astronomy and meteorological aids and satellites. It can also be noted from the resultant GUI information that the frequencies detected do not exceed maximum permissible power density. These limits are set by the ICNIRP and adopted by APANSA within Australia. The maximum power detected within the frequency range is at 2974MHz. Its EIRP is 33.17dBm (0.0004819mW). This is well below the maximum EIRP of approximately 36dBm.

B. University Foyer

At the university foyer, the cellular network is dominant due to the high levels of associated frequencies at 880MHz to 940MHz. This represents GSM, 3G and ISM devices transmitting in this location. The power levels of this associated range emphasizes the fact that this region is heavily populated by the general public, most of whom carry mobile phones which are transmitting regularly to associated towers. There is also a detected frequency signals at 1800-1810MHz, which also emphasizes the presence of cellular networks. The detected 2680MHz-2700MHz range demonstrates the existence of fixed mobile satellites and earth exploration satellites. Citizen band radio service is also situated in the latter section of frequency range. The frequency band of 2790MHz and 2800MHz identified within this sweep is chiefly employed for meteorological aids and aeronautical navigation. This is similar to the detection of 2910MHz-2940MHz. Therefore, the primary existence of cellular technology associated frequencies within this location emphasizes the dependency of user-oriented devices in the area. Due to the high traffic flows on a constant basis, this is integral to assist in supporting end users. It is also noted that all frequencies detected within this test area are within the maximum permissible power limitations set for radio frequency exposure for the general public.

C. Building 1, Level 3 Concourse

An adjacent area, Building 1, Level 3 Concourse, is also a heavily populated area and a main thoroughfare. In studying this area, it is also palpable that numerous clusters of frequencies are detected during testing. The most dominant frequency identified lies in the 2660MHz-2710MHz range. This indicates the presence of signals associated with fixed and mobile satellites, earth exploration satellites and radio astronomy. The presence of signals in the 460MHz-660MHz range is dedicated for broadcasting in the UHF band. These broadcast frequencies are primarily employed for various television stations. Space-to-earth meteorological satellite transmissions are also utilized in this region. Since this is a main thoroughfare, it is understandable for cellular frequencies to exist at this location. therefore, the radio frequency clusters of 800MHz-950MHz, 1840MHz-1940MHz and 2000MHz-2140MHz indicate the presence of 3G, GSM and UMTS devices transmitting and receiving signals. This can emphasize the rampant use of cellular telephone devices, especially in a highly populated environment. Frequencies between 1100MHz and 1329MHz are used for aeronautical radio-navigation and active earth exploration and space research. Such frequencies also indicate the presence of signals from radio-navigation satellites, for both space-to-earth and space-to-space purposes. The frequencies detected in this range are also well within the maximum exposure limits for the general public, in respect to radio frequency signal strength.

D. Alumni Green

The Alumni Green is situated in the middle of the UTS Broadway campus, surrounded by three buildings. Since the Alumni Green is an enclosed open space, signal attenuation will be evident as radio frequency signals will be reflected, refracted and absorbed objects in the environment. Such objects include buildings and trees. The principle frequency detected in this region is between 2970MHz-2985MHz. It is used for radio-navigation and radio-location. This is the most dominant frequency range within the swept area. Aeronautical navigation is also prevalent in the range of 2740MHz to 2750MHz. Cellular network devices are also identified in this location. In particular, UMTS, GSM, 3G and PCS services are prevalent. The associated frequency bandwidths these are evident in are: 860MHz-960MHz, 2110MHz-2170MHz and 1895MHz-1925MHz. These frequency ranges are associated with both the transmission and reception of cellular signals between devices. The presence of such signals can also emphasis the location of cellular base stations, which can be easily detected when the radio frequency spectrum is analyzed in an outside environment. The strong presence of frequencies from 1990MHz-2020MHz, 2200MHz-2380MHz and 2530MHz-2540MHz highlights the presence of signals from satellites. Associated technologies involve: mobile earth-to-space satellites, fixed space-to-earth satellites, earth exploration satellites and space operations and research satellites. These satellites are administered by the government and are allocated strict universal areas of the radio frequency spectrum which no other signals can deviate to reduce interference. Once again the detected frequencies located in the scanned range of 400MHz-6000MHz are within permissible maximum exposure limitations.

E. Evident Trends

In spite of the varied environments tested and the differing results, it is evident that there are some trends within the results. One primary observation is that there are no detected frequencies greater than 3GHz with all test results. The region of the radio frequency spectrum between 3GHz and 6GHz is situated in the super-high frequency (SHF) range. The waves are also less than 10cm in length. Another common characteristic of the collated data is the strong presence of frequency clusters in the 2.7GHz to 3GHz range. This region of the spectrum is associated with ground-based radars, and in particular, radiolocation and radio navigation. The given frequency range of 400MHz-6GHz spans across two ITU bands: ultra-high frequency (UHF) and super-high frequency (SHF). These two said bands are highly populated and therefore placing a limitation upon the analysis of the entire given portion of the spectrum to identify signature allocations.

VI. CONCLUSION

The past decades have witnessed an increase in the study of the effects of electromagnetic fields on human health. There are still no definitive conclusions on many parts of the spectrum. A common problem is that data were estimated more often than observed. We report on a study for the detection and mapping of radio frequencies within an environment. The message of the study is important. If the described experiments are conducted on a large scale, a database to ensure access to EMF pollution data could be built. The use of the data could assist in the understanding of the ramifications of long-term exposure to radio frequency radiation associated with the continued proliferation of wireless devices.

ACKNOWLEDGMENT

Vivian Lee conducted many of the experiments described in this paper and acknowledges the support of the Centre for Real-Time Information Networks.

REFERENCES

[1] HyperLOG 4000 LogPer broadband LogPer EMC EMI antenna span 400MHz to 6GHz. [Online]. Available: http://www.spectran.com/HyperLOG4000_en.shtml

[2] Log Periodic Antenna. [Online]. Available: http://www.radio-electronics.com/info/antennas/log_p/log_periodic.php

[3] "Refresh! Spectrum Analyzers," EEPN Magazine, April 2007. [Online]. Available: http://electronicdesign.com/article/test-and-measurement/refresh-spectrum-analyzers34666.aspx

[4] ABC – Australian Broadcasting Corporation, "Study probes link between cancer and phones," Reporter: Ticky Fullerton, 2010, broadcast: 17/05/2010. [Online]. Available: http://www.abc.net.au/lateline/content/2010/s2902097.htm

[5] E. R. Adair, "Thermoregulation: It's role in microwave exposure," in *Radio frequency radiation dosimetry*, B. J. Klauenberg and D. Miklavcic, Eds. Netherlands: Kluwer Academic Publishers, 2000, pp. 345–356.

[6] J. Agbinya, Z. Chaczko, and K. Aboura, "Radio frequency pollution mapping," in *Proc. of the Fourth International Conference on Broadband Communication Information Technology and Biomedical Applications*, Wroclaw, Poland, 2009.

[7] "Radiocommunications licence conditions (apparatus licence) determination act 2003," Australian Communications and Media Authority, 2003. [Online]. Available: http://www.acma.gov.au/WEB/STANDARD/1001/pc=PC_318

[8] *Radiocommunications (Electromagnetic Radiation Human Exposure) Amendment Standard 2007 (No. 1)*, Australian Communications and Media Authority Std., March 22, 2007. [Online]. Available: http://www.acma.gov.au/WEB/STANDARD/1001/pc=PC_310474

[9] *Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 2001*, Australian Communications Authority Std., 2001. [Online]. Available: http://www.latrobe.edu.au/eemanage/Lectures/OHS-RadioRadiation.pdf

[10] *Radiation Protection Standard - Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz*, Australian Radiation Protection and Nuclear Safety Agency Std., 2002. [Online]. Available: http://www.arpansa.gov.au/Publications/codes/rps3.cfm

[11] Y. Chung and R. Haupt, "Log-period dipole array optimisation," in *Aerospace Conference Proceedings, IEEE*, vol. 4, 2000, pp. 449–455.

[12] J. M. Elwood, "A critical review of epidemiological studies of radiofrequency exposure and human cancers," *Environmental Health Perspectives*, vol. 107, no. 1, pp. 155–168, 1999.

[13] GSMA, "INTERPHONE Project Overview," 2009. [Online]. Available: http://www.gmsworld.com/documents/health/research/GSMA_INTERPHONE_Overview.pdf

[14] International Commission on Non-Ionizing Radiation Protection, "ICNIRP guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 ghz)," *Health Physics*, vol. 74, no. 4, pp. 494–522, April 1998.

[15] INTERPHONE Study Group, "Brain tumour risk in relation to mobile telephone use: results of the interphone international case-control study," *International Journal of Epidemiology*, pp. 1–20, May 17, 2010, doi:10.1093/ije/dyq079, advance access.

[16] V. Lee, "Monitoring and recognition of radio frequency signatures," Capstone Project Report, Faculty of Engineering and Information Technology, University of Technology Sydney, Australia, 2008.

[17] J. C. Lin, "Safety standards for human exposure to radio frequency radiation and their biological rationale," *IEEE Microwave Magazine*, pp. 22–26, Dec. 2003.

[18] M. A. Stuchly and S. S. Stuchly, "Measurements of electromagnetic fields in biomedical applications," *Critical Reviews in Biomedical Engineering*, vol. 14, no. 3, pp. 241–288, 1987.

[19] ——, "Experimental radio and microwave dosimetry," in *Handbook of biological effects of electromagnetic fields*, 2nd ed., C. Polk and E. Postow, Eds. Boca Raton: CRC Press, 1996, pp. 295–336.

[20] A. V. Vorst, A. Rosen, and Y. Kotsuka, *RF/Microwave Interaction with Biological Tissues*. Hoboken, New Jersey: John Wiley & Sons, 2006.