Remote Electromagnetic Energy (EME) Power Logging

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The African proverb says it takes a village to raise a child & I've been fortunate to be supported by an amazing tribe of people in all areas of my life.

STATEMENT OF CANDIDATE

I, Isobel Fraser, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering (Honours) in the Department of Telecommunications Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment an any academic institution.

Student's Name: Isobel Fraser

Student's Signature: Isobel Fraser (Digital Signature)

Date: 02/09/2017

ABSTRACT

Today we take connectivity for granted, particularly in first world countries like ours. When using devices to connect to a vast network for every day communication, we are generally unaware of the policies and procedures that are required for implementation.

Electromagnetic Energy (EME) Exposure is something that is an underlying necessity for wireless connectivity. This has become increasingly important in the telecommunications industry when assessing exclusion zones for public health as new technologies (3G, 4G, 5G) will make it considerably harder to comply with regulatory standards. Currently, regulatory standards are based on precautionary methodology, which is restrictive as it relies on theory. The precautionary methodology is limiting to resources, productivity and efficiency.

This project aims to show that by using readily available devices, a real-world problem can be solved by collecting accurate data from mobile base stations to find out the real exposure values. This will be achieved by accurately measuring the EME Levels produced on site over a period of time.

This data will enable us to detect the worst case scenario and provide vital information for more effective designs that meet the regulatory requirements. As the standards allow the six-minute sliding average to be taken, this can then be correlated to traffic from the site so that we in the future will be able to map more accurately model the exclusion zones.

The profile will provide a complete picture of exposure and traffic that defines the category of a site as either high or normal. Currently, exclusion zones don't account for actual beam tilts using a broad range of 0 to 10 degrees for implementing boundary zones. Therefore, the current methodology is a one size fits all approach for all sites, as opposed to the tailored approach proposed by this research. By measuring using real-time logging, Optus will be able to see if this is viable and set an example for change in the industry once proven and verified by National Association of Testing Authorities (NATA).

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Introduction

Telecommunications is an exchange of communication by voice, video or data linking people all over the world. Prior to 1996, telecommunication services were limited due to their fixed nature.

In 1996, the Telecommunications Act was approved which incited the deregulation of the telecommunications market and possibilities of offering a universal service [1]. In turn, this lead to rapid advancement and change to the dynamics of the industry as infrastructures such as base stations and optics were put in place. This growth continues exponentially due to the increase in demand with an average person owning 3.64 devices [2]. This industrial change to using the spectrum for communicating wirelessly has generated a need for monitoring the radiation emitted.

The Telecommunications industry is a core contributor to producing Electromagnetic Energy (EME), with Australia complying with industry standards developed by Australian Radiation Protection, Nuclear Safety Agency (ARPANA) RF standards, and Australian Communications and Media Authority (ACMA). These standards educate companies on how to achieve and produce documentation for public health requirements, for exposure to EME levels, aligning with the International Commission on Non-Ionizing Radiation Protection (ICNRP) standards.

The current approach implemented looks at Electromagnetic Energy (EME) exclusions zones modeled using a precautionary approach. This method only looks at the worst-case scenario with all transmitters running at full throttle and antenna tilts using a wider than reality envelope pattern, neither of which may ever reach its full capacity nor taking into account the traffic profile that affects the power of the base stations. This is dependent on usage as all technologies have some form of dynamic power control that reduces transmitted power, depending on traffic.

Therefore, Optus currently must factor in very large EME exclusion zones when designing base stations and for the production of safety documentation that is made available to the public via Australian Mobile Telecommunications Association (AMTA) [5] and Radio Frequency National Site Archive (RFNSA) [6].

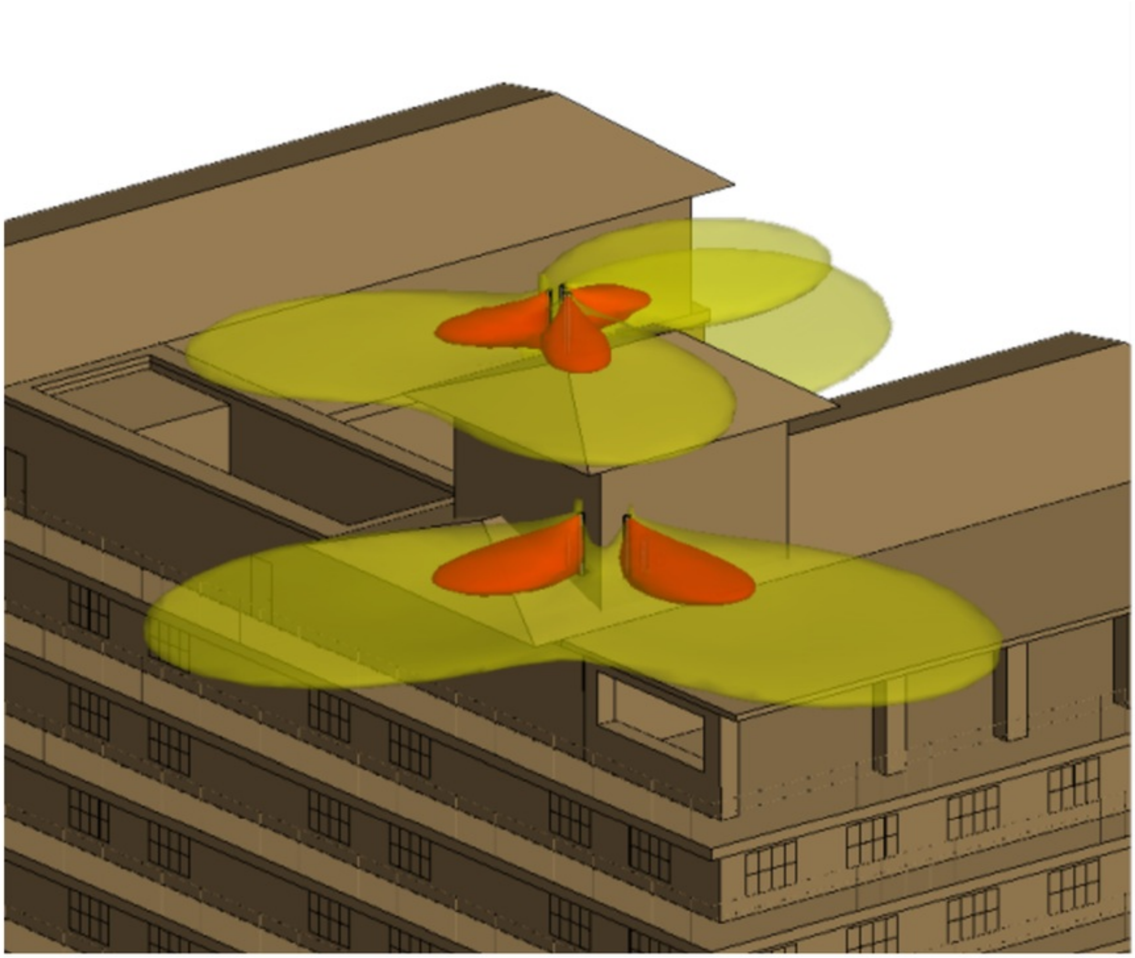

Figure 1. 3D Diagram simulating EME exclusion zones, occupational (red), non-occupational or general public (yellow) zones of an actual base station site [3]

The theory in place doesn't take into account the fact that the zones in practice are based on actual power input and tilts (the beam angle). The actual zone is smaller, as full power is generally not required unless it is a highly busy site. From the data collected, the correlation of the site traffic will be providing much-needed information for accurate compliance documentation, with safety factors built into the designs relating directly to the site. Once completed the next step is to get the results verified by an outside body for example Total Radiation Solutions (TRS) that is accredited by a National Association of Testing Authorities (NATA).

The research question proposed is whether it is possible to provide a more accurate model of cumulative EME levels by correlating logged measured EME Levels to traffic profiles at Mobile Phone Base

Stations.

This project aims to develop a low-cost solution that is practical for implementation on mobile base station sites by use of EME RF personal monitoring devices and logging actual cumulative EME levels over long periods. The information that will be logged can be used to evaluate the actual worst case of EME levels and implemented to more accurately model the EME exclusion zones. Having accurate data is essential in understanding the EME levels that are actually present at Optus sites, to accurately and effectively provide an economical design that meets the EME compliance requirements.

As technology continues to advance there is an increasing demand on the mobile network to support emerging technologies. This will mean that new applications are necessary, as the sites will continue to expand and grow, not only within the Optus network but also within telecommunications as a whole. This means that the problem the industry is facing is that EME exclusion zones are growing and continuing to expand making it increasingly difficult to remain compliant with both regulations and technology, and provide high-quality products to consumers. The effect of this is that it will limit the quality of the mobile networks due to the increasing costs and the reduction in viable sites.

1.1 Project Goals

The aim of the project is to develop a cost-effective solution using off –the-shelf-components to construct a remote EME monitoring system that will have the ability to collect cumulative EME measurements from a base station over sustained periods of time. This project will enable the correlation between traffic carried from the site and total radiated EME levels to be assessed. This will be achieved by making use of a low-cost personal monitor that measures all the technologies (for example 3G, 4G…) radiation produced on sites. While there are existing commercial products on the market that can provide remote logging, there are none that can provide cumulative measuring that meets the requirements by covering the full range of frequencies and are cost-effective to install and deploy an engineering solution fit for industry use.

The goals can be broken down into the following requirements. The short-term goals are firstly the modification of a Personal RF monitor with the ability to log at least one week of data entries from a mobile base station. Once the data is collected it will be correlated between traffic and total cumulative EME levels by using analytic tools such as excel in post-processing.

This is expanded upon in the long-term goals when the first short-term goal of logging for a period is achieved. It will then be enhanced by uploading remotely to a server, with the addition of automation. Another long-term objective is that an alarm system could be added and adapted to a monitoring system triggered as a result of EME levels above RPS3 standard occupational limits (red zone), either warning the RF workers and staff in these areas or automatically limiting the power when required for access. RF workers would no longer need to confirm power reduction or transmitter shutdown, saving time and creating easy and safer access to these mobile base station sites.

Depending on the results, the aim is to first achieve short-term goals and determine the actual case for individual sites, in turn proving that EME zones will decrease based on carried traffic, providing an accurate depiction of the site while still meeting the regulatory requirements.

The breakdown of the primary objectives:

i. To develop a cost-effective system with off the shelf-components
ii. To generate data logs over time periods
iii. To use the logs to correlate between traffic and total cumulative EME levels

And Secondary objectives:

iv. Addition of a solar system (as not all sites will have access to power)
v. To store logs to a remote server
vi. Addition of an alarm system for alerting levels to staff members
vii. Integration of automation of limiting output power when required
viii. Then use the logs to correlate between traffic and total cumulative EME levels

The stakeholders for this project consist of industry supervisors, and technical specialists in RF EME Rob Myles and Rob Werner from Optus, who have continuously been consulted throughout the project to ensure that the desired results of the system are practical for implementation and can be achieved and replicated for future use. Total Radiations Solutions (TRS) have been able to provide subject matter experts Dr. Phill Knipe and Max Birch from EMSS for assistance. Non-technical support was received from both Bruce Pike (for resource acquisition and the overall requirement for corporate governance aspects) and Professor Rein Vesilo; Macquarie university supervisor at university milestones (providing valuable feedback, based on the university requirements from an academic perspective).

The original contribution of this project that differs from current work in the radiofrequency fields is that we are looking at the measurement from the dynamic range perspective, which is used to convert to a percentage of the standard for RPS 3. As the software renders as a jpeg image, a workaround was therefore implemented to prevent errors via the use of code to enable the much needed functionality of the FieldSense monitor software for extended time periods. The work around was required because the software hasn't been extensively tested for this purpose, as the device is generally used by RF workers when on site to confirm the location of the EME exclusion zones.

1.2 Project Plan

The industry project was conducted over semester 2 2017. The following outline helped to achieve the goals of the project.

Project Timeline

The Gantt chart (figure.2) shows the time management put in place to achieve the project objectives in a timely manner.

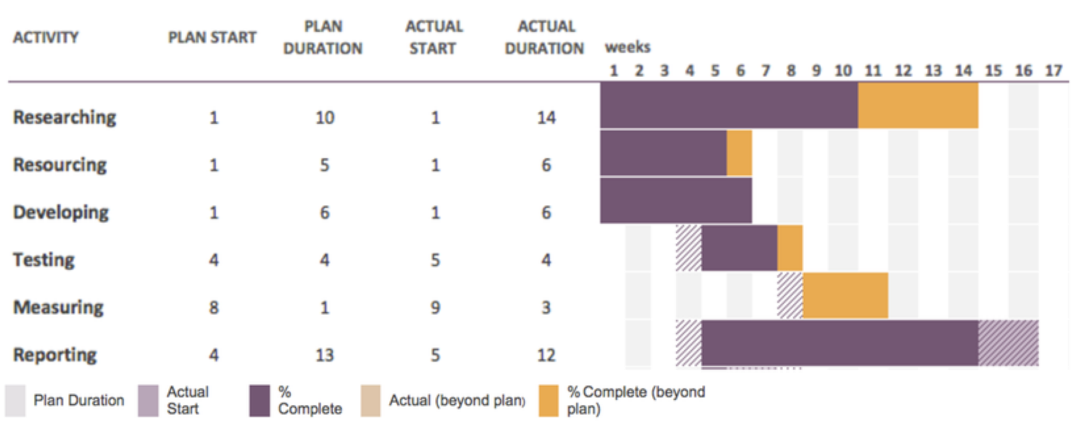

Figure 2. Gantt Chart

Date	Week	Milestone	Tasks
31-Jul	1		Resourcing
7-Aug	2		Resourcing
14-Aug	3		Testing, developing and resourcing
21-Aug	4		Testing, developing and resourcing
28-Aug	5		Testing, developing and resourcing
4-Sep	6		Testing, developing and resourcing
11-Sep	7	Progress Report (11/09),	Testing
18-Sep	8		Mid Semester break
25-Sep	9	Deployed on 25/9	Mid Semester break, Measuring
2-Oct	10		Measuring
9-Oct	11	Removed on the 11/10.	Measuring
16-Oct	12		Analysing, Acquiring traffic data
23-Oct	13		Analysing both EME & traffic data
30-Oct	14		Analysing both EME & traffic data, Reporting
6-Nov	15	Final Report (6/11)	
13-Nov	16	Poster/seminar abstract / logbook (16/11)	
27-Nov	17	Presentation (27/11)	

Figure 3. Scheduled break down

Deliverables

The deliverables are functional components, for example hardware and software working together, prototyping the collection of data for analysis. The outcomes of the project are achievable through functional prototype deployed over generous time intervals due to the element and scope.

The core deliverables:

1. Pilot – testing viability
2. Prototype - remote monitoring system
3. Solar system – power source

Outcomes

The overall outcome of the project is the development of a functional prototype that was implemented on a mobile base station over a long-time interval. It was also required to function as a self-powering system available when required, as power won't always be accessible on site. The conclusion is that Optus will be able to use an external industry accredited body to verify the results.

Project Costing

The Budget of this project came to an estimated $2,000 not including labour and already available recourses and infrastructure. The final cost came in at $1,655.35, which is a large reduction as there are commercial products that cost well above $20,000 depending on the brand. Consequently, the project was achieved at roughly 10% of the cost that is ideal for deploying, as the cost will exponentially increase with the number of sites otherwise.

Project Work Health and Safety (WHS)

This industry project required learning gaps to be completed that consisted of RF EME awareness training, working at height awareness and site induction white card for the ability to visit sites thus certifying compliance competency. The creation of a risk register and safe work method statements (SWMS) were also required to understand the risk for the specific site and tasks at hand, for example using the hierarchy of controls promoting safe work practices which includes Personal Protective Equipment PPE is essential when on site.

1.3 Overview

In chapter one we look at the core objectives of the project. Chapter two explains the background to understand more about EME what it is and the reasoning behind it. Chapter three unpacks the design and methodology of measuring EME. Chapter four shows the experimental procedure detailing set up for both pilot and prototype stages. Chapter five present the results & discussion. Chapter six concludes by wrapping up the project and chapter seven examines future work and what could have been done if there were no time and resource constraints.

Chapter 2
Background

2.1 *What is Electromagnetic Energy (EME)?*

Electromagnetic energy (EME) is the energy produced from the electromagnetic spectrum and is comprised of both ionising and non-ionising energy travelling through free space, i.e. air (figure 4).

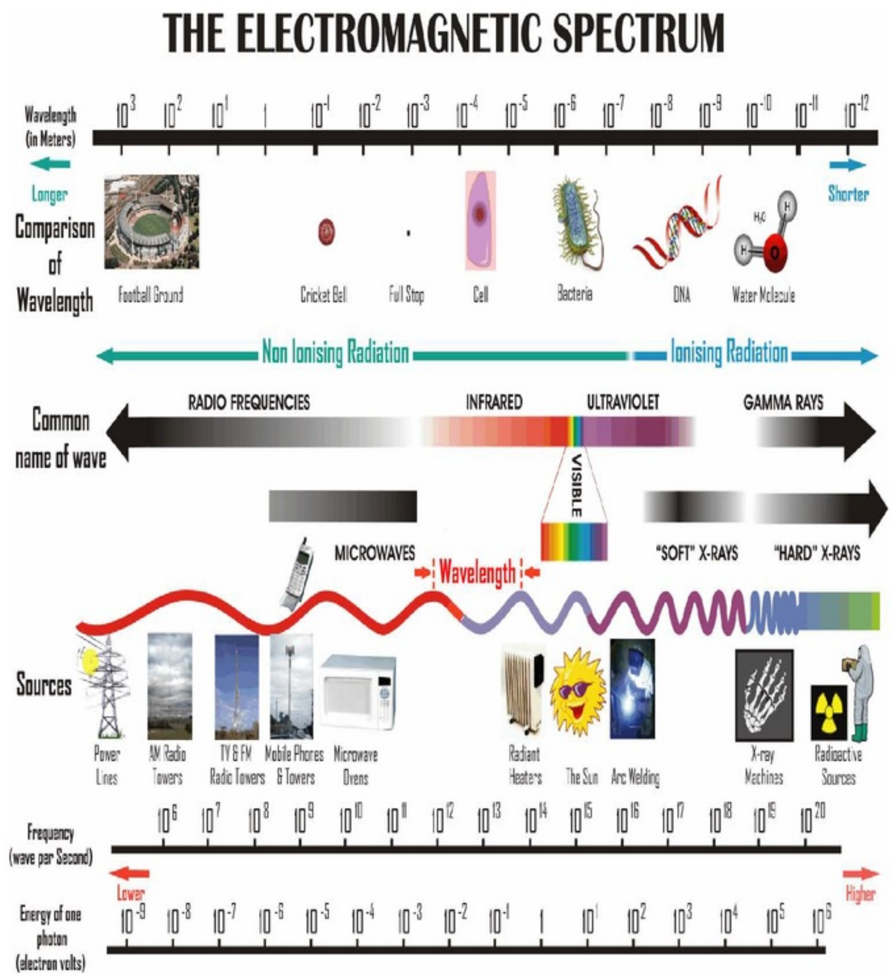

Figure 4. The Electromagnetic Spectrum [46]

The entire EME is quite broad but from a telecommunications industry perspective we are only interested in the EME exposure that occurs within the range of 3KHz to 300GHz (non-Ionising), which includes the invisible signals (to the human eye) emitted by wireless devices. From industry perspective, this can also be referred to as Radiofrequency Electromagnetic Field (RF EMF) of the same frequencies range but will be referred to as EME in this paper.

All Transmitting Antennas produce EME. Non-ionising radiation doesn't carry enough energy to ionize atoms or damage molecules at a cellular level however it will cause heating.

EME occupies this section of the spectrum as seen in figure 4 and contains Radiofrequency radiation of High Frequency (HF)/ Very High Frequency (VHF)/ Ultra High Frequency (UHF) [48] all of which are used for communication purposes. This is useful because different technologies use different bands for example 4G uses 700MHz for transmitting data.

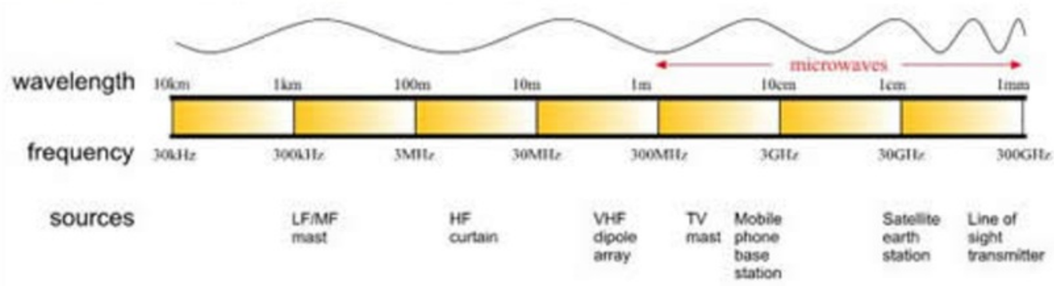

Figure 5. The Radiofrequency (RF) section of the electromagnetic spectrum [47]

EME Exposure is comprised of waves for mobile communications and these waves make up both the Electric (E) and the Magnetic Field (H) of the waveform (Figure 6).

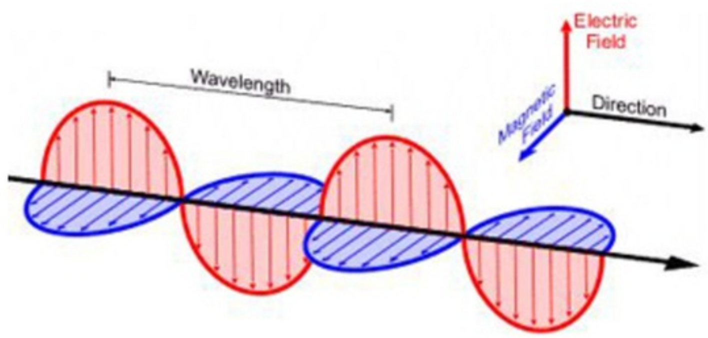

Figure 6. How E & H fields are propagating [9]

As the source is directional - and in order to be able to collect the field strengths - the device measuring must be isotropic to pick up accurate readings for reliable data and to confirm the reality of the EME produced.

There are inherent risks that can be mitigated to prevent any biological effects. According to section 5 of the RPS 3[8] Occupation Zones - which are the safety precautions put in place by ARPANSA - at high frequency RF radiation, the thermal effects could potentially heat up the internal organs affecting health, including symptoms that affect the immune system and sleeping patterns. Compliance is an essential part of being a regulator for the telecommunication organisations and current precautionary methodologies overestimate the reality of the values by approximately 4-8 times when looking at the zones for the protection of public health

2.2 Antenna theory

The principal is that any wire with an input of electrons will radiate electromagnetic waves, as in the case of antennas that produce Radio Frequency (RF) fields. These Electromagnetic fields produced are complex as not all radiate into free space. For example, near field reactive [49] stay in the vicinity of the antenna, whereas near radiating field regions have a strong inductive effect and do not behave like far field regions as the relationship of E & H uniformed aren't perpendicular to each other, whereas far fields have this relationship and provide accuracy for measuring.

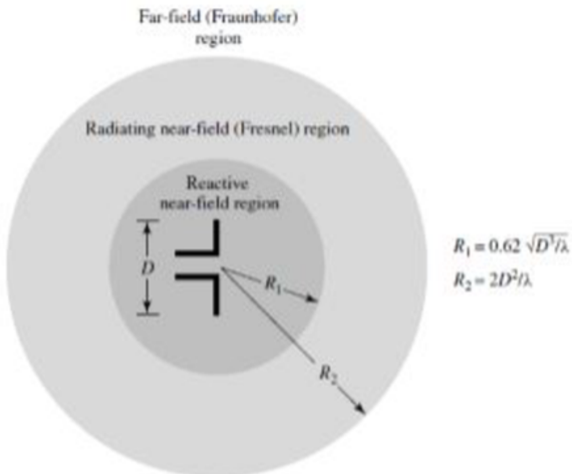

Figure 7. Field Regions [37]

When calculating EME zoning in the industry it is necessary to make sure the specifications meet compliance, as radiation patterns are based on the antenna gains. [3] The theory shows the link between power density (S), input power (P), gain (G), and distance to the center on the Antenna (R)[4].

$$S = \frac{P*G}{A*\pi*R^2} \text{ ...... (1)}$$

Power density equation [4]

This is used along with the manufactured gain to create exclusion zones that are theoretical and larger than meet the standards. The other method is to use the product of the E & H values and the 377 Ω Ohms for free space to find S [8].

$$|S| = \frac{|E|^2}{377} = 377|E|^2 \text{ ...... (2)}$$

Power density practical equation [8]

When measuring the results, we take what is considered far field measurements as the standard, which must be above 2m. It is important to choose an isotopic probe with the ability to measure both H & E fields. This is needed for accuracy [39] as near field E & H don't correspond in the same relationship as far field as they alter rapidly. A wide dynamic range is ideal as this corresponds to sensitivity of the device.

2.3 Antennas

Directional Antennas come in various types. In the case of roof top base stations, panels are used because they enable to reach a specified coverage needed for a sector, where a sector is a region of an antennas placement. Generally, these antennas look like a part of the building and all antennas produce radiation patterns that vary based on the technologies used. These patterns include front, side and back lobes based on the beams produced to provide a comprehensive pattern envelop which surrounds the outline of the beams produced and will account for some areas that can't be reached. This is caused by the downwards tilt and can be altered by either a mechanical tilt (the physical angle of the antenna) or the more practical approach as it is easier to alter the electrical tilt, which will change the beam direction by altering the phase of the source to produce an angle from 0-10 degrees, indicated in figure 8.

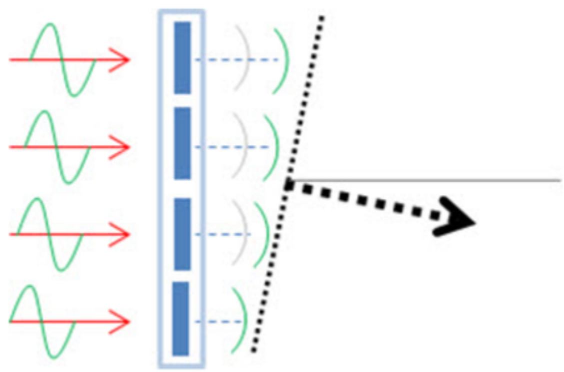

Figure 8. How electrical tilt works [42]

The radiation from the Antenna produces an antenna pattern, which is then interpreted in to EME restriction zones for public safety.

2.4 RF personal monitor

RF personal monitors play an important role in the industry as they determine non-visible boundaries when changes occur in the field strength and provide a visual signal of the current levels. When selecting a device with a wide frequency range it is desirable that it is fit for use. Desirable features are the ability to simultaneously measure E & H and isotropic sensors.

Figure 9. FieldSense 2.0 [55]

Taking into account the above, the FieldSense RF personal monitor was selected as the system has a wide range of 50 MHz to 6 GHz. Then outputs the levels as a percentage of the standards to show the time-averaged RMS power density results. The monitor specifications are up to ICIRP international standards and is fit for use in Australia as it follows the RPS 3 standard with + or - 3 dB uncertainty [14], which is the same for even the highest quality system on the market. Three orthogonal E field probes and another three H field probes to create isotropic nature receives the ideal placement and is face on for measuring as stated in the calibration documentation on how the faces respond, following national physical laboratory and IP64 weatherproof rating. As the monitor powers itself from a micro USB cable, which simultaneously is used to send data, the battery connection did not require future modification for an additional power source. This works in the temperature range of -20 °C to 50 °C, on average the lowest temperature in Sydney is 16 °C and highest is 45.8 °C [54], including the ability of data logging capabilities while being cost effective ($800 Au).

2.5 *Standards*

The RPS 3 [8] provides the industry standards that Telecommunications operators need to comply with. The limits of the corresponding frequencies are displayed in the fig.6. The internal working of the monitor will project this as a percentage between 2% and 200% as part of the dynamic range to convey the exposure of how the zones are established. This takes into account all technologies present on a site and the frequencies used for the services.

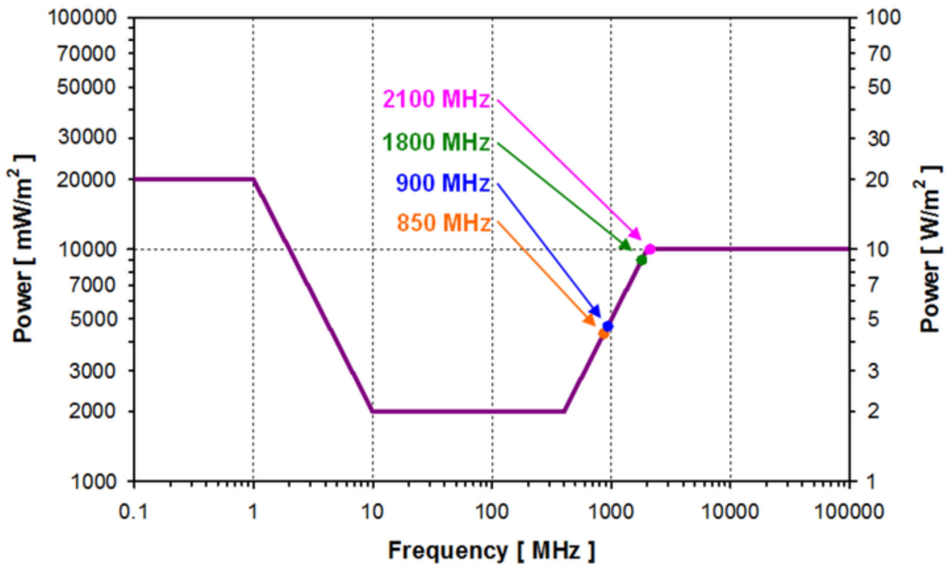

Figure 10. Showing the limits [10]

These levels establish the exclusion zones and are a safety barrier to determine the set exposure levels within the area emitted by an antenna, and to set up the limits of the non-occupational, occupational and the general public limits [8] detailed in the table 7 (figure 11). This relates to both the E & H fields as this is important and although considered far field it can vary on source and could be near field radiating, which means there is no link between E & H fields, and highlights the need for probes that can measure both.

TABLE 7

REFERENCE LEVELS FOR TIME AVERAGED EXPOSURE TO RMS ELECTRIC AND MAGNETIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m²)
Occupational	100 kHz – 1 MHz	614	$1.63/f$	–
	1 MHz – 10 MHz	$614/f$	$1.63/f$	$1000/f^2$ (see note 5)
	10 MHz – 400 MHz	61.4	0.163	10 (see note 5)
	400 MHz – 2 GHz	$3.07 \times f^{0.5}$	$0.00814 \times f^{0.5}$	$f/40$
	2 GHz – 300 GHz	137	0.364	50
General public	100 kHz – 150 kHz	86.8	4.86	–
	150 kHz – 1 MHz	86.8	$0.729/f$	–
	1 MHz – 10 MHz	$86.8/f^{0.5}$	$0.729/f$	–
	10 MHz – 400 MHz	27.4	0.0729	2 (see note 6)
	400 MHz – 2 GHz	$1.37 \times f^{0.5}$	$0.00364 \times f^{0.5}$	$f/200$
	2 GHz – 300 GHz	61.4	0.163	10

Figure 11. RPS 3 Standards insert [8]

These zones are normally referred to as the red zones for an area and are both the working standard for RF workers and Yellow zones, where only RF workers are permitted to enter but are not accessible to the public unless an RF worker is present. Reading an RF monitor, this is interpreted by the dynamic range where any reading above 20% is the non-occupational exclusion zone (yellow zone) and any reading greater than or equal to 100% is the occupational exclusion zone (red zone) that is five times the occupational boundary, which requires a shutdown period of the antenna for entry. The radiation exposure is taken as the highest level of the E & H field strengths that are present.

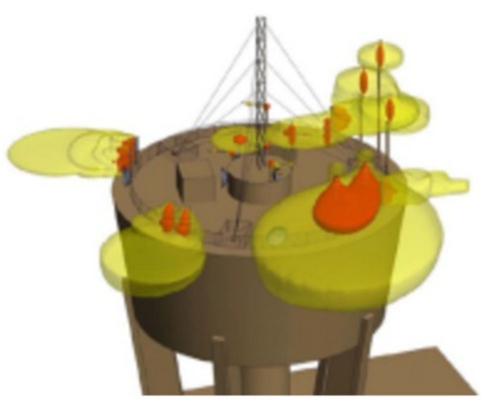

Figure 12. Model of a base station site simulation on three-dimensional plane simulating RF EME exclusion zones that occur, included: occupational (red), non-occupational (yellow) and public (white) zones [51]

The related studies of the topic generally only look at public exposure, however, it has been established that the occupational exposure [44] is perhaps more important. There is a direct link to public exposure although the rate that waves reduce is due to the inverse squared law. Due to the nature of the inverse squared law ([45] double the distance ¼ of the exposure), the levels that the public is actually exposed to is negligible due to the distance away from the Antenna and establishes the need to look at the occupation zone for RF workers. In the papers, they used a board band device to look at each technology and plot the power density to give a contour plot from various points but didn't take into consideration the traffic profile or the ability of using one point of reference. As this point relates to all the others there is no need for the relationship of the RF fields, when plotting for the EME designs.

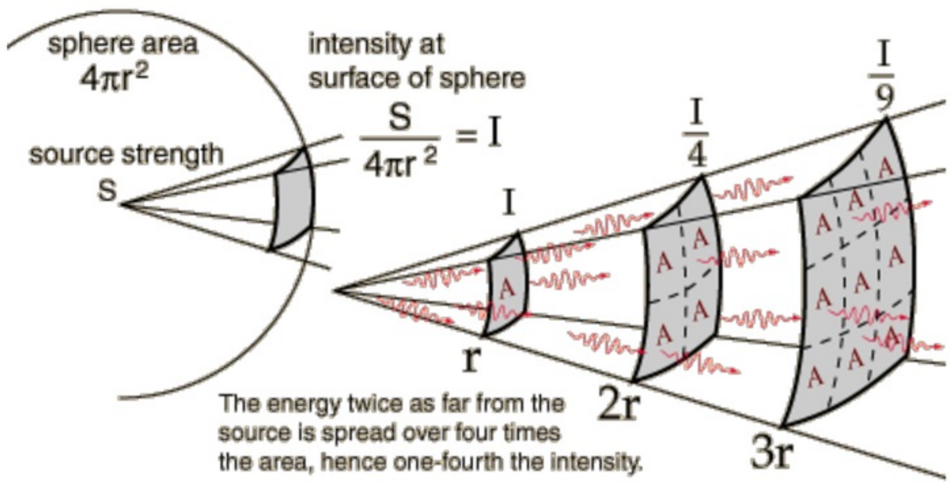

Figure 13. Inverse square law [53]

These standards are put in place to prevent health hazards of thermal heating, electrostimulation and microwave hearing effect and the zoning is important for work health and safety. If the fields are very high the human body can absorb enough energy to increase the internal core temperature, which can lead to cataracts, angle currents, and sterility all due to excessive heating. RF shocks have the same effects as touching an electric fence with earthing causing arcing [8]

2.6 Traffic profile

To develop a holistic picture of network traffic, traffic profiling is formed from the Down Link Physical Resource Block (DL PRB) utilisation, as counters can be set to gather the information.

Although it only provides LTE (4G technologies) it gives the best indication. It defines a site as busy if the overall DL PRB usage is 70% usage or above (Busy site).

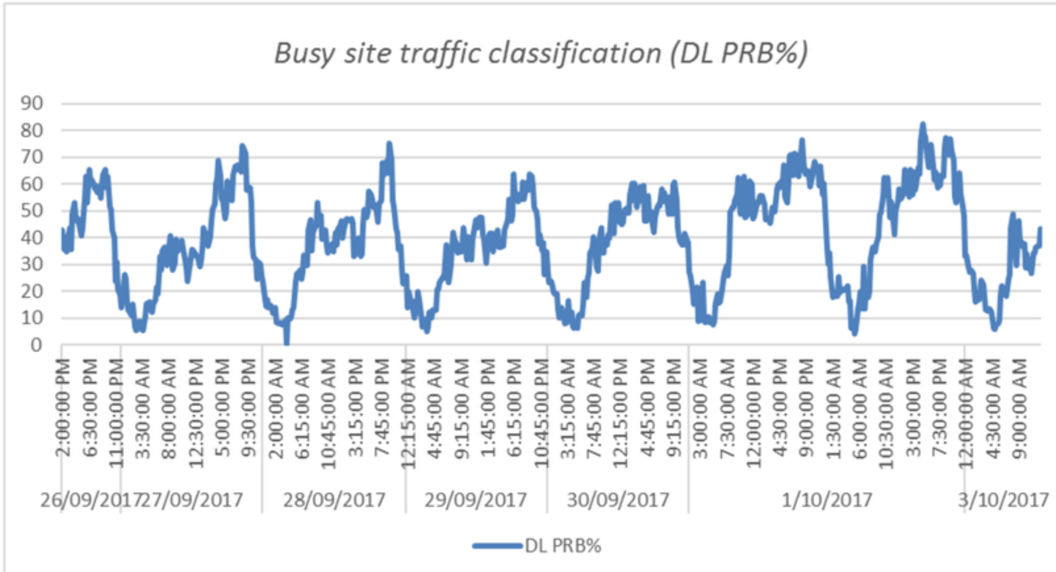

Figure 14. Busy site traffic classification (DL PRB%)

This is a busy site as the cells are struggling for resources, [50] whereas if the DL PRB is consistently under 60% the classification would be typical as the site is not struggling for resources and therefore isn't requiring the sample power allocation of a high site. These definitions have been determined by looking at site data which tells a story of user demands, which can be categorised either high or typical and used as a basis shown below in a snap shot of both types visually represented.

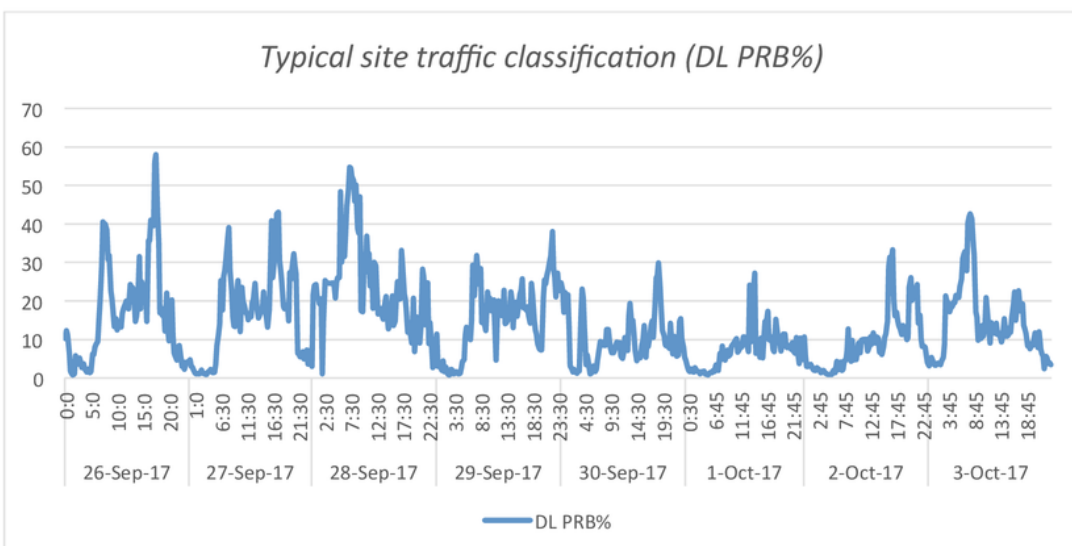

Figure 15. Typical site traffic classification (DL PRB%)

Chapter 3

Project Design & Experimental Procedures

This section will unpack the procedure of creating the system from off the shelf components and how it was achieved and why. The purpose, based on the scenario and current methodologies for measuring Electromagnetic fields, is to determine the RPS 3 limits. A personal monitor does this by taking the voltage input and digitalising it as a percentage of the standard. By measuring this it is possible to determine the real value at the theoretical boundary on the red and yellow zones. This is achieved by taking far field measurements.

3.1 Scenario

The deployment of this system will only be suitable in a specific location due to its design, which has been tailored to a roof top base station (this is the EME zone projecting over the roof top). The set up is the following rooftop with an Antenna.

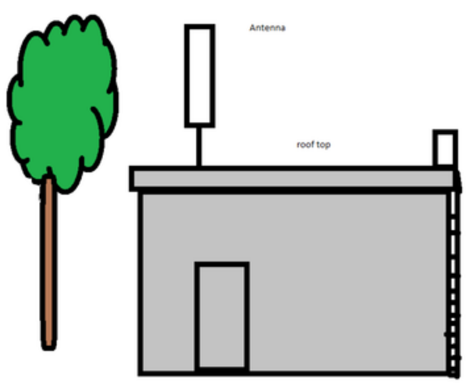

Figure 16. Roof top scenario

That is designed to be placed in the direction of the Antenna between the red and yellow zones.

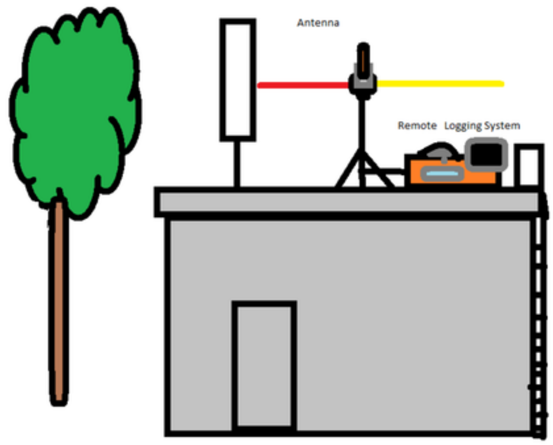

Figure 17. Roof top zone set up

In most cases there will be no shelter and the set up will be exposed to the wind, the rain, the sun and any other environmental factors (wildlife…etc.) depending on the site. Safety has been built-in from the very beginning of the project and was assessed at all stages, as this was essential to the success of the project. The requirements of the roof were that it had to be easily accessible for putting the equipment up and not hazardous, therefore plenty of roof space was necessary as setting up on the very edge isn't sensible and increases the risk to the equipment, the RF worker that sets up the project and the public. If it were to fall it would be catastrophic.

3.2 System Design

Sub-systems are communications, monitor, physical structure and power (was provided on site in our trial but if not will be a solar system) assembly of which constructs the remote monitoring system.

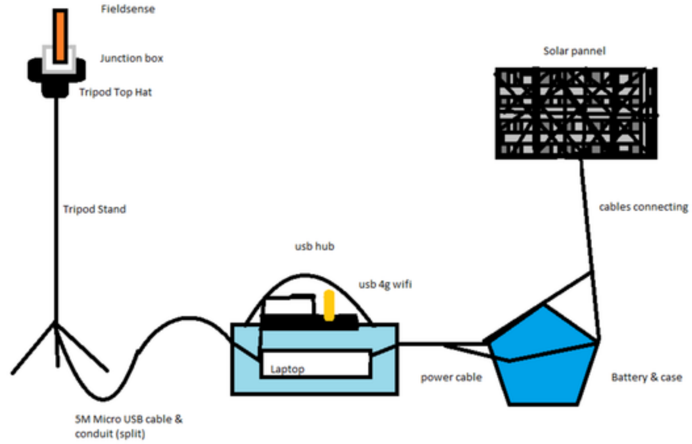

Figure 18. Diagram of the remote logging system

Physical Structure Specifications

For calculation purposes the physical structure needs to be 2-3 meters high due to standards set by RSP3 [61] and has been designed to be IP rated so that it is waterproof and weather resistant. All elements that could be moved should be secured with sand bags and rope if necessary.

Tripod

Standardised equipment and off the shelf component that has min of 35 mm diameter and load of 50Kg with a top hat should be a speaker stand as this fit the requirements, and ideally made of aluminium as this is lighter and can more easily be lifted to the roof top environment, creates less corrosion, and is ideal in extreme weather. [63] The heights of the tripod were adjustable between 2 m and 3 m. A tripod from Altronics for $ 109 fits these requirements [57].

Figure 19. Tripod

Non-standardised

A self-constructed monitor mount made of Polyvinyl chloride (PVC) with a conduit connector requires less long-term maintenance as it is already waterproof as the plastic is strong and durable, with the addition of a plug for the open end to act as a seal combined with a standard camera crew to secure the monitor to the removable lid. In addition, by using a small size drill the lid was modified so that there is a micro USB size hole to connect a micro USB through to the monitor and another screw to secure the base of the monitor to the lid. The connected lid can then be screwed back into the base.

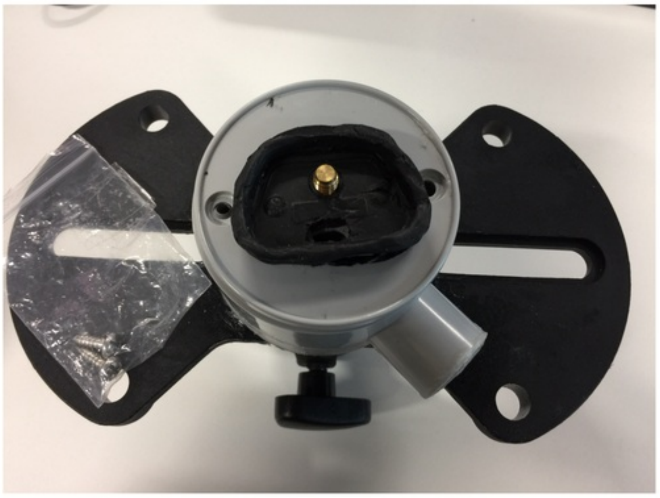

Figure 20. Base for monitor

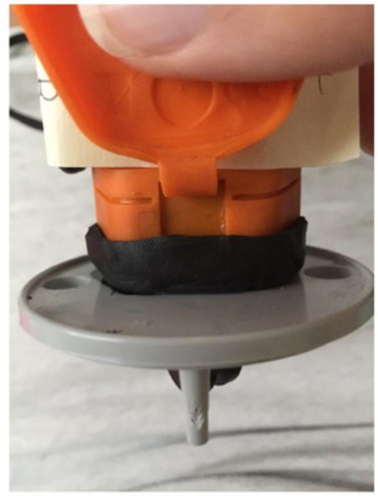

Figure 21. Lid attached to monitor

Using two tech screws with washers the conduit is connected to the tripod top hat. These screws were selected as they are self-taping, which is ideal to easily connect both together, to give the desired results.

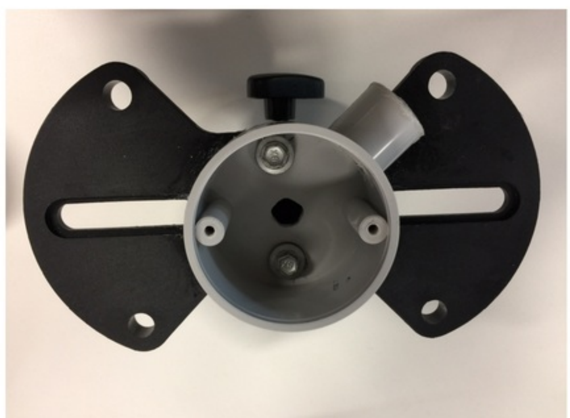

Figure 22. Top view of monitor base

Silicon is then applied around the edge of the base and the plug from both the inside and the outside to seal any gaps where water could enter.

Figure 23. Monitor stand base

For the remote monitoring system, the existing cap would need to be altered so that it can be screwed to the base but modifying the existing cap would destroy the necessary waterproofing capacities for uses outside the system. To remedy this an alternative cap was created by moulding Surgu [56], which is a mouldable plastic that is waterproof and regarded better than using a silicon adhesive as it is stronger and more durable. To form the cap, take a very thin film of plastic such as glad wrap (also known as cling film) is placed over the bottom of the monitor and then moulded before leaving to set for 24 hours. The glad wrap prevents anything getting to the connection of the monitor.

Figure 24. RF personal Monitor cap

Waterproofing

Due to the roof top environment, waterproofing is essential to prevent electrical components from failing and reducing the risk of injury, as they will be exposed to the outside elements. The design implements used were:

Silicon Adhesive – UV resistant and waterproof

Conduit – to conceal cables

Case – for laptop with water seal

Conduit/cable glands 4-8 mm [68]

Conduit plug

Junction box

PVC tubing

Pelican case [67]

All of the above are a form of protective layer to encapsulate the system.

Figure 25. Waterproof box and case

Communications

The required equipment includes windows 10 with a loaded version of the FieldSense software on a laptop. The selected laptop is a Dell inspiron 11 300 with 4 GB of Random-access-memory (RAM). A USB Wi-Fi modem to connect to the Internet was also used, as connection was required to access the data logs remotely. The method for remoting into the laptop was via Chrome remote desktop using an apple application to monitor the remote system and achieve regular updates.

Solar power system

In Sydney, the minimum hours of full sunlight are 3 hours a day with the max 8 hours. This need to be accounted for in calculations as is needs to be suitable for a max of one week or 7 days in total [58] [59]

It's unnecessary to have an uninterruptible power supply (UPS) as this would just be backing up a battery with a battery, being run directly off a solar system. A suitable solar panel would be a flexi camping 80 W12 V solar panel with U shaped stand that easily can be lowered.

Calculations

The Amps estimated draw varied between 1 A and 2.31 A

Therefore, estimate that will draw 1.75 A will be used in calculations but will more than likely be less

Theoretical used by the system

1.75 Ah per X 24 h period = 42 Ah

With a 12 V battery X 100 Ah = 1200 watt hours

This then divided of the number of hours of day light i.e. 8 giving 150 W therefore because solar 20% leeway would ideally need 180W as to cover but this is excessive anywhere from 80W -120 W will be suitable and be practical as roofs generally have limited space onsite.

In the worst case

Panel 7A (6-7.5 A) for 120 W over 3 H = 21 AH

42AH-21 AH

100AH/21AH = 4.7 days (without battery charging)

Most likely

7 AX 5H = 35AH

42AH-35AH=7Ah

100AH /7AH=14 Days

The best case will produce

7A x 8 H =56AH

42Ah -56AH= -14 AH, Which will be able to fill up the reserves of the battery or will go to waste if full as the controller will stop over charging but it's hard to tell exactly because the sun is unpredictable.

Components:

Battery

Is essential to use storage for the solar system to ensure the system batteries last through the night. This also means that the laptop can run for 24-hour periods as it is important that the equipment continues to measurer 24 hours per day.

AGM

For Absorbed Glass Matt the depth of discharge is 50% and is the most economical choice available. Its lead acid battery differs as it has a low internal resistance and if it was regular would need to top charge every 6 months as Deep cycle only reduces 3% per month with no damage and if left for several months is durable. The variation in the required range of 30 - 120 AH is a mid-sized battery.

Gel

Is roughly the same physical size of AGM but costs more. Whereas the Gel is easier as it's maintenance free, provides leak proof solution, charges with ease and falls mid range in between AGM & Lithium-ion batteries.

Lithium-ion

Is very effective with 80% depth of discharge (DOD). It is also the safest but expensive due to the quality of the battery.

Summary

Cost Analysis (Approx. May change due being independent parameters changes due to influences in the market)				
AH	70	75	80	100
AGM	$240.00	$249.00	$249.00	$ 181
Gel	$306.00	$298.00	$395.00	$278.00
Li-ion	N/A	$999.99	$1,049.00	$1,613.00

Figure 26. Cost break down of battery types

After accessing the practicality in addition to cost vs. benefit it is evident that the weight of the battery needs to be taken into consideration, as it will need to be carried on the roof. The AGM deep cycle battery was the perfect solution, as it won't cost thousands but hundreds. Therefore, a 100 Ah AGM was chosen as the weight is 5 Kg less but either cheaper, although this depends on retailer, or the same price as 80 Ah. It's preferable to use a battery with as long a life span as possible due to the location and that it will be left long time periods.

Portable Fold-Up Solar Panel

Solar as a whole has its disadvantages. It's fragile and the initial set up costs are expensive. On the other hand, the benefit is that it's portable and ideal for a remote location without the need for a generator or electrical running wires running long distances causing tripling hazards. In the long term it's also cheaper, as there are no electricity costs. The minimum system requirement is 80W but the more power that can be supplied the better, as the average hours of day light in Sydney fluctuates from 3-8 hours.

Monocrystalline

This is one of the older, most efficient, dependable photovoltaic ways of creating electricity [64]

Its core benefits are:

- Longevity – lasts for approximately 25 years without need for maintenance.

- Efficiency – able to convert to the highest amount of power compared to any other photovoltaic cell.

- Minimal installation costs - it is readily available and costs are cheaper than other types available due to using technology that's been around since 1970's

- Heat resistance – able to withstand extreme temperatures and doesn't have a reduction in output like many others due to the heat.

Amorphous

Has a lower manufacturing cost, large variety of voltages and shapes. The down side is lower power efficiency than monocrystalline and absorption is more complete due to the multi-layering [26]

Polycrystalline

Very close to the efficiency of monocrystalline by using p-type cells. The main advantage is that they cost less, have a lower heat tolerance, and use cheaper silicon. Although disadvantages are that it covers more space and is less efficient [66]

Summary

Monocrystalline is the most economical that is available at the moment. It is also readily available for purchase and is the best at producing electricity. Also, the constraints of the scenario mean that there large amounts of space are not necessary.

Cost Analysis (Aprox. May charge due being independent parameters changes due to influences in the market)					
W	80	100	120	140	160
Ebay	$129.00	149.00	$152.00	$179.00	$ 195.00
Out bax camping	N/A	$169.00	$189.00	$219.00	$185.00
Sunyee-au	N/A	N/A	$163.95	N/A	$187.99

Figure 27. cost break down of solar panels

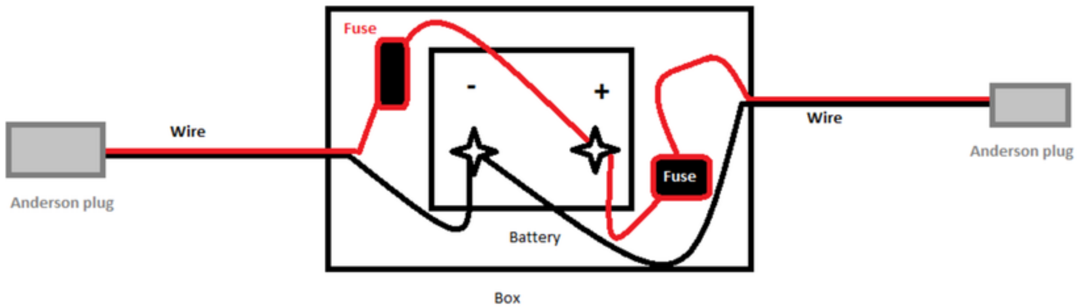

Figure 28. Battery box set up

A pelican box is weather proof and has a handle for ease of carrying. Four holes were drilled and a wire tail of 0.7m was left as excess so that the battery can easily be removed and replaced. The Anderson plugs clip into the foldable solar panel and or a car charger socket. As laptop car charger takes 12 V and converts to 19.5 V for the laptop to charge.

Fuse

By using the guideline that a fuse is rated at 125% of the normal operating current. [60]

Fuse rating = (Power/Voltage) x 1.25

Fuse rating = (120W/12V) x1.25

Fuse rating =12.5 A

Fuse rating $\approx$15 Amp

You have to select the next fuse up as ten would blow instantly due to the current

Labour

This was put together by using a selection of tools such as a crimper for both non-insulated and insulated lugs for the end points and butts for joining the cable.

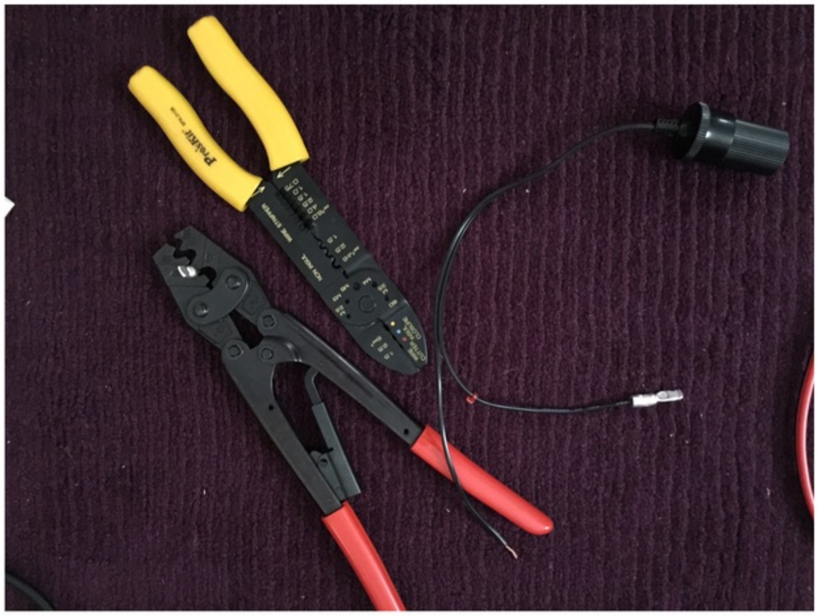

Figure 29. non-insulated crimper and 8 setting crimper, wire striper &cuter

To do this a cable striper and cutter for creating bare wire for joining the twisting the bare end to create an ideal joint are needed. A screwdriver for adding L brackets to secure the battery from moving around inside the case is also needed. A solar system was a secondary objective and was created for future site without power. To set this up, insulated tools for connecting to the 100Ah battery are necessary as a safety precaution. The final product ended up resulting in a durable solution ready for rollout (figure 30 & 31).

Figure 30. Battery case and connections

Figure 31. Outside of the battery case

3.3 Methods and Techniques

Different settings require different approaches such as the laboratory test in controlled environment vs. the field where there are more elements to be aware of and traffic is live and not simulated. The methods to achieve this included designing the system for the environment of the roof top then resourcing parts on an Ad hoc basis as this is a stage project in the Agile approach and has allowed for a trial an error method of selecting materials based on effectiveness. Planning is essential to the method as, for example, in the field prototype, the site needs to be able to have easy access. It needs plenty of anchor point to be able to easily lift the equipment up to the roof top level of the antenna sector.

3.4 *Controlled Pilot*

The sets in the controlled pilot are important for assessing the ability to go ahead and what needs to be altered. Software testing was carried out in radio Laboratory using the setup method in Figure 32. This was run continuously as a trial implementation with an RF emitter. This includes a laptop with windows 7, the FieldSense software [43], RF personal monitor FieldSense, micro USB and power source, which, once connected and setup should continuously run the application once the laptop lid is closed.

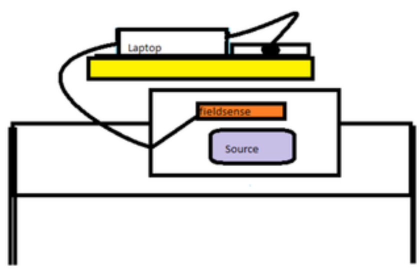

Figure 32. Testing of the monitor with an RF source in radio laboratory

The hardware was tested on a roof top environment at Optus Centre Sydney (OCS). Permission was gained to set up the structure with sandbags and tethered using strong but slightly elasticised rope as there was a need to be able to have some movement, in order to withstand the elements. It was left out for a 3-day period to confirm that the set up was optimal. During the three-day period two solutions were trialled, one resulting in a set up with the communications box under the tripod that was weighed down by both the tripod and the sandbags and for the other set up they were weighted down individually using attached anchor point for the sub-system.

3.5 *Field Prototype*

This preliminary drawing of the software hardware sub systems together is yet to be tested on site and will be placed in line of sight of the antenna.

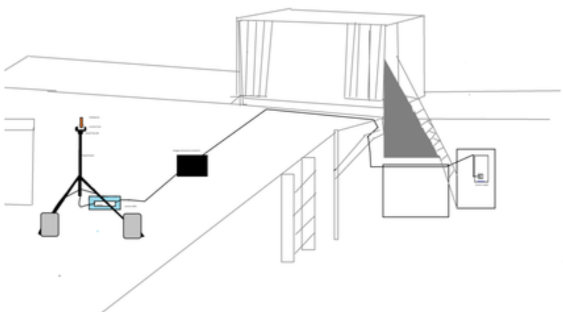

Figure 33. The system on site

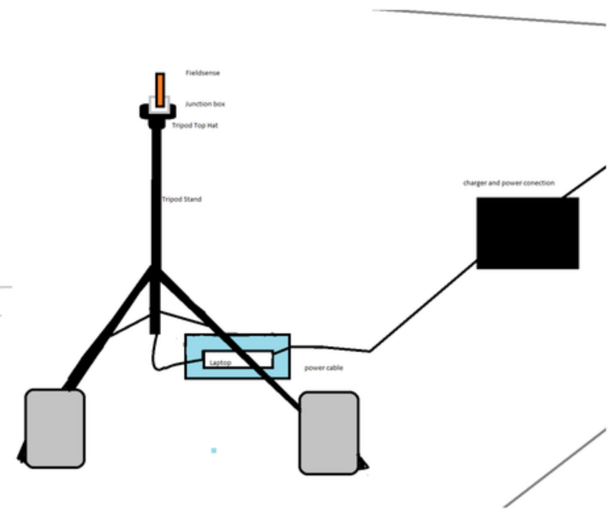

Figure 34. Close up of equipment

The procedure is to:

1. Setup (includes securing and putting the sub systems together as one)
2. Monitor from remote login
3. Regular equipment checks (1-2 days)
4. Removal
5. Analysis results in take to find the averages for 6 min intervals to find the reality of the zones, present.

Set up

The setup of the system as designed in figure.33 first take the extension power cord form the outdoor power point in figure.35 with a water proof seel once connected, fed up through the conduit on site to the roof then attach the second extension cord, add an IP rated connector to roughly where the edge of the red zone is by reading the EME drawing [13] that where updated by Total Radiation Solutions TRS, which is normally found on the RFNSA website [6]

Raise the equipment by using a 3:1 rope system and make sure to bring a supervisor when working at heights bring up smaller pieces using a ladder (as anyone can climb and is not that safe) and use the provided “safe work method” statement set up on site. There should be a minimum of at least two people on the roof top.

Figure 35. Power source Optus equipment

Figure 36. Roof top access via ladder

Figure 37. Conduit to the roof

Figure 38. Roof top space

Once the kit is on the roof connect the power supply (end of the extension cord to laptop power adapter/pack) to the computer in a waterproof box making sure that the laptop is raised so that air can circulate through the box. Including the end of the micro USB cable that is USB to the laptop and the USB Wi-Fi modem for remote connection.

Then raise the tripod to half way and feed the string with a wait to the bottom, then use this to carefully put the cord up to the top of the tripod

The placement of the tripod needs to be on the edge of the red zone perpendicularly faced to the Antenna as shown in the diagram below at the red lobe extent.

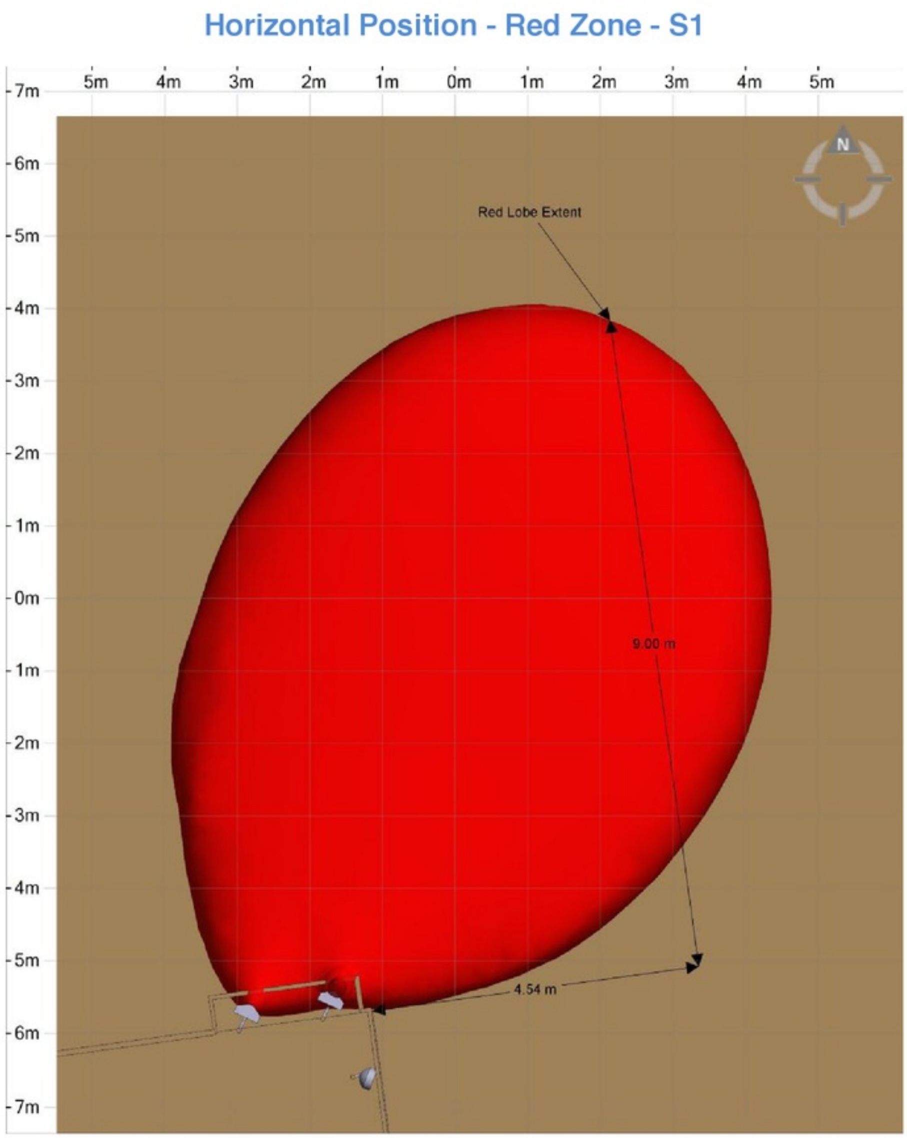

Figure 39. Horizontal view of red zone, EME drawings [13]

Then raised to the height of 0.10 m from the centre of the antenna which came to 2 m high as shown in the vertical view, making sure to attach the monitor to the top fixture checking that it is still connected. A thin film of plastic has been added around, for example, the plastic bags so that the USB link is protected from moisture present in the air at night and rain will trickle of the plastic and not come into contact with the device.

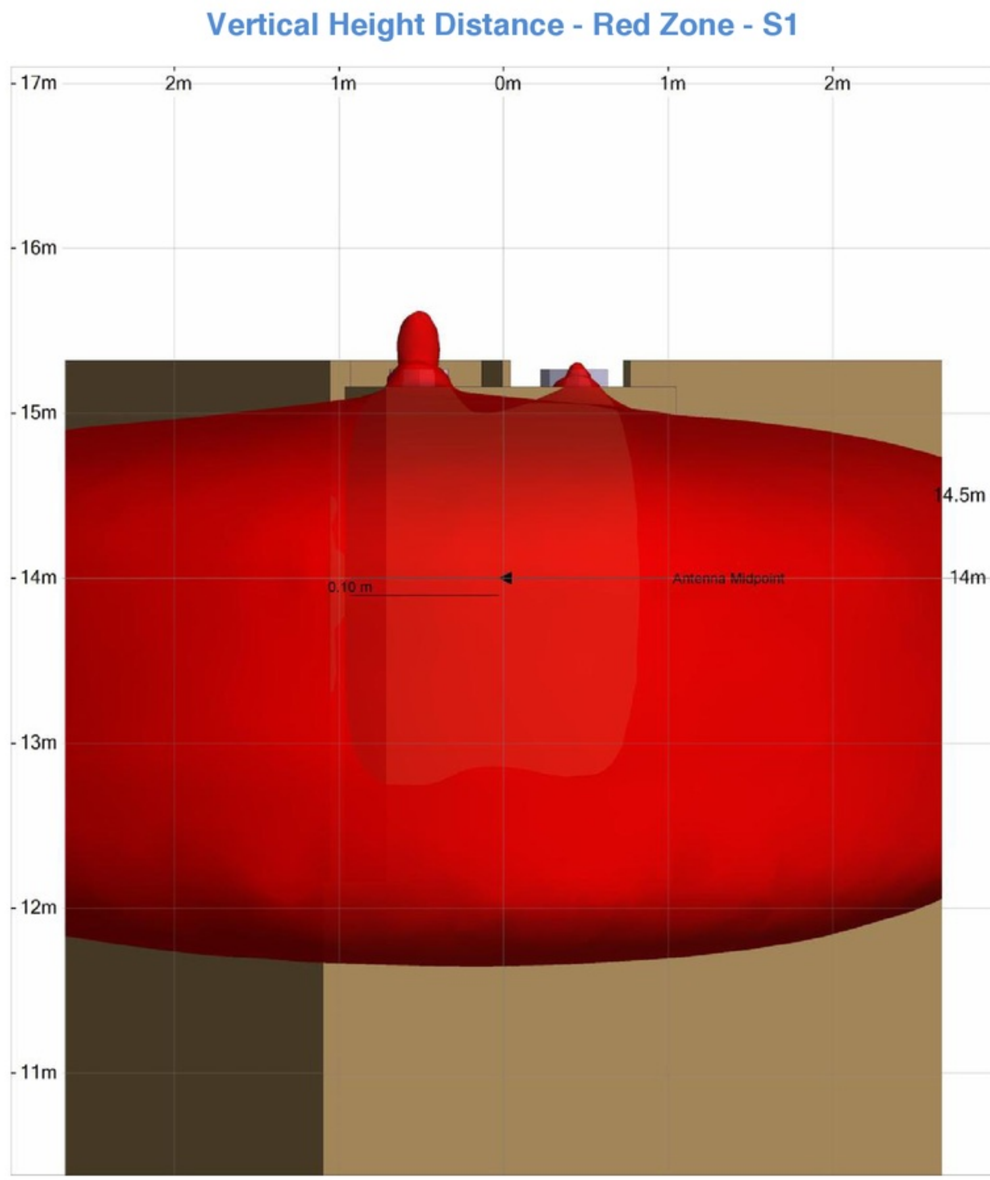

Figure 40. Vertical view of red zone, EME drawings [13]

By measuring at this point it is possible to contrast the actual values at this point to the theoretical 100% and later on use this to map out the zone.

Monitoring

Then via a remote desktop connection to the on-site laptop that has a mobile connection to the internet, Google chrome was used to daily access and analyse the data using the on-site laptop or the remote desktop.

Analysis

The data were analysed using excel to find the sliding average, looking at timestamps comparing to the one prior time the exposure, to get the interval this was then used instead of backfilling the data as the device only stores recorded changes in values. The Field Sense device records one sample every one-second. As ARPANSA RPS3 allows the use of a 6-minute sliding average each one-second sample would be average over the previous 359 samples to provide the sliding average. This is then taken and contrast with traffic data for DL PRB utilisation graph to see the tracking between at the traffic period changes every 15 minute period, therefore have taken the EME exposure and 6-minute sliding average to find the maximum value for 15-minute interval.

Chapter 4

Results & Discussion

The Laboratory/ controlled roof top Pilot Result provides information on the functionality of the components of the remote EME system and as seen below shows that off the shelf components with a bit of tinkering can yield results that prove cumulative EME levels can be correlated with traffic data/profile over a given period of time. The Field Prototype shows the implementation in a real world scenario and discusses the outcomes of the results.

4.1 Controlled Pilot

The first trials of the software failed to run for 24-48 hour period until implementing Appendix A in A this workaround enable the pilot result, shown that both the software last for period longer that 7 days figure 41.

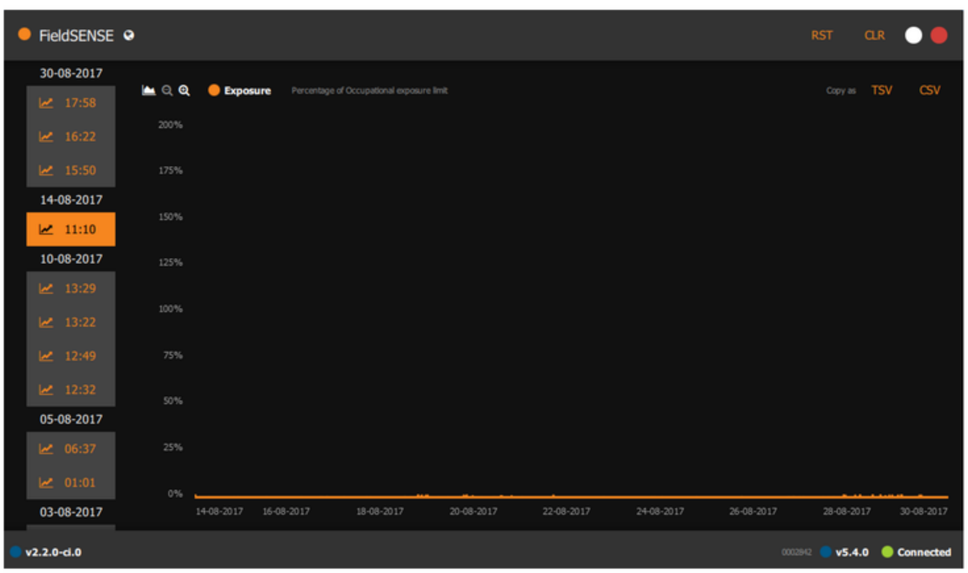

Figure 41. Graph of the 14-day trial

Roof top pilot confirmed that the hardware component sufficiently weather proofing and securing. The system is now fit for purpose as the equipment with stand the element in fig. 42. As result the set up of communications box can fit under the tripod to that weighed down by both the tripod and the sandbags was the ideal setup as eliminating the need for an anchor point for the sub-system.

Figure 42. 3-day physical structure trial

The off shelf components with a bit of tinkering can yield result that proves that data will show the EME power profile over a given period of time and ready for trialling on site.

From the pilot, it was discovered learn that the data quality was good for example 2017/08/15 06:00:13, 2, 2, 1.95447 as it can give up to five remainders and take record every second but store only the incremental changes therefore will need to be insert via excel and means can achieve 6 mins averaging in post processing. There is large sample provide bellow:

 # Timestamp, Exposure [%], E Field [%], H Field [%]

2017/08/14 11:10:24,1.95447,1.95447,1.95447

2017/08/14 11:11:35,1.95447,1.95447,1.95447

2017/08/14 11:11:35,2,2,1.95447

2017/08/14 11:11:36,2,2,1.95447

2017/08/14 11:11:36,1.95447,1.95447,1.95447

2017/08/14 11:11:37,1.95447,1.95447,1.9544

Here you can see that also provide both details for E & H and not just exposure able to see how the alter and proved the integrity of the data outputted. EMSS is currently working on providing a fix for the software error, as it hadn't previously been tested extensively. The workaround in Appendix A currently provide a method of continual logging for over the minimum logging period of a week. This work around consisted of a script in python, python was chosen because it is efficient and therefore utilises very little memory, which ideal when the monitor create vast amounts of logs [38]

4.2 Field Prototype

To once set up and left to run by using the method in chapter 3, the following image shows the achieved deployment

Figure 43. Prototype position toward the antenna on the boundary line of the red zone

Secondary safety precaution (tethering) wasn't necessary as the sand bags more than secure the tripod. The following is a sample of the data as produced vast amounts of entries due to the constantly varying levels produced were recorded.

```
# Timestamp,Exposure [%],EField [%],HField [%]
2017/09/26 08:11:26,0,0,0
2017/09/26 08:11:26,16.6353,16.6353,7.60379
2017/09/26 08:11:27,16.6353,16.6353,7.60379
2017/09/26 08:11:27,10.9908,10.9908,5.50846
2017/09/26 08:11:28,10.9908,10.9908,5.50846
2017/09/26 08:11:28,20.4659,20.4659,8.53159
2017/09/26 08:11:29,20.4659,20.4659,8.53159
2017/09/26 08:11:29,19.0999,19.0999,6.62262
2017/09/26 08:11:30,19.0999,19.0999,6.62262
2017/09/26 08:11:30,10.4961,10.4961,4.37552
2017/09/26 08:11:31,10.4961,10.4961,4.37552
```

They're copied into excel for analysis as and text then separated into columns by using text to column and selecting delimited by commas then ran interval formula =TEXT(current timestamp-cell prior"ss")* exposure cell to be able to get the 6 min sliding average =SUM(INDIRECT(CONCATENATE("E",(MATCH((current timestamp -TIME(0,6,0)),Timestamp colum,1)))): exposure cell)/(6*60)

Using max formula to for finding the peak values of 15min period calculated by floor (cell address, 1/96)

	A	B	H	I	J
1	Date	Time	Ave % traffic	peak exposure %	peak sliding ave %
60		15:0	17.725	49.0942	3.562658722
61		15:15	21.3	4.37552	2.863353
62		15:30	25.05	50.2377	12.30800972
63		15:45	21.7	22.4404	13.55063669
64		16:0	24.625	24.0453	12.31265461
65		16:15	21.85	23.498	12.38350911
66		16:30	23.975	22.4404	12.72856006
67		16:45	21.775	22.4404	11.10813533
68		17:0	21.4	22.9631	10.69392594
69		17:15	28.575	24.6054	13.58744383
70		17:30	29.35	25.1785	14.45739253
71		17:45	32.45	27.6077	15.19977528
72		18:0	22.6	25.1785	15.11369042
73		18:15	25.175	25.765	13.24080925
74		18:30	21.175	26.9793	11.85030692
75		18:45	16.8	22.9631	11.32776703
76		19:0	23.475	25.765	15.2410435
77		19:15	21.35	23.498	10.85198753
78		19:30	13.425	23.498	9.283460111
79		19:45	13.525	26.3651	12.19335425

Figure 44. Excel data sheet

From this data the following graph was created

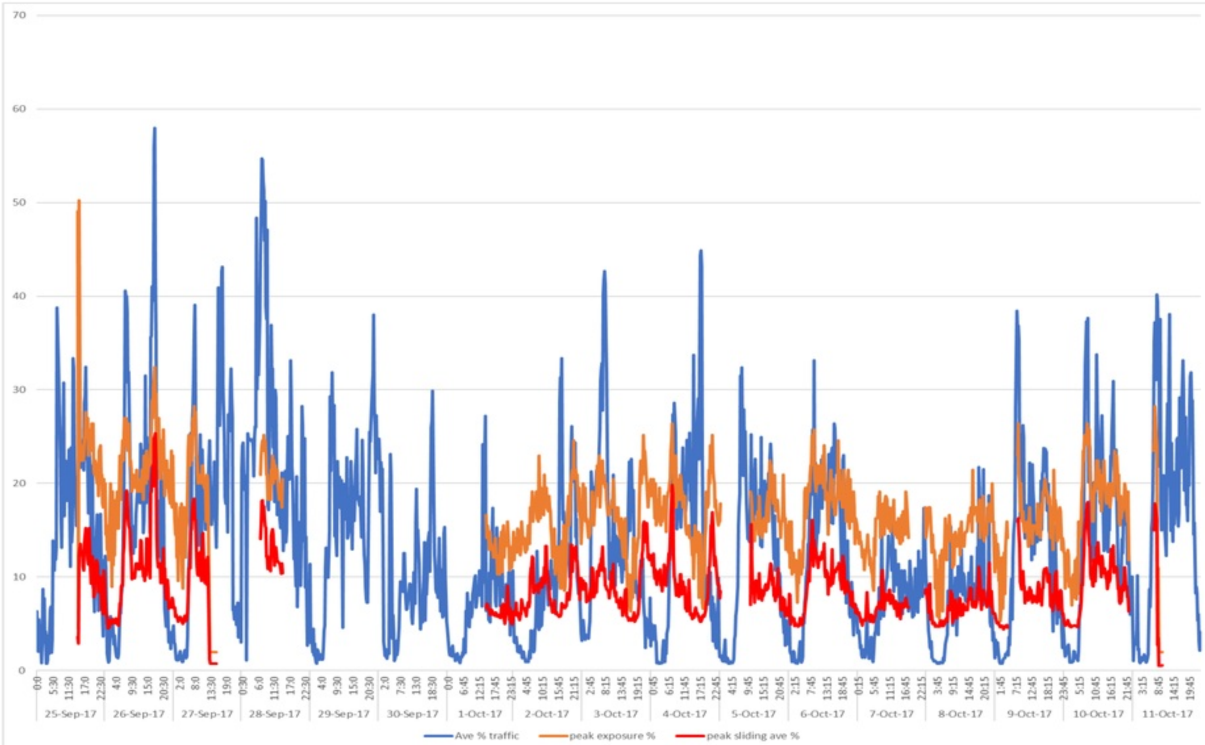

Figure 45. Correlated Results

The graph depicts the relationship between exposure and the traffic. This clearly displays the interdependence of the varying traffic to EME. From this, you can see that the sliding average the RPS3 allows never goes above 25%, which is a ¼ of the theoretical of 100% at the boundary point of the red zone. The pilot signals are always running and are never turn off, therefore, the EME reflects the minimum emissions at this point, where the traffic is at its lowest, typically in the middle of the night.

When looking at the data displayed on the graph there are point where the peak exposure (orange) and 6 min sliding average (red) disappears due to the reliability issue that were over come with on the fly workarounds, which involved restarting the devices are regular interval (6-8 hour periods) and retrieving the non-active log this enabled the laptop to deal with the data being displayed via FieldSense software therefore the laptop was producing ram leakage as rendered as a JEP image. This wasn't found in the pilot to because the source was generally handset therefore for didn't fluctuate dramatically every second, were as whilst implemented in the field faced different issues. For future use it would be recommend that a script is developed then implemented to improve the reliability, this would be achieved by taking 15 minute interval data dump from the monitor with restarts every 15 mins so that the software doesn't have to deal with large amounts of data thus making it manageable.

The relationship between the measured power and the modelled exclusion zones can be interpreted as follows. The remote logging system was located at the edge of the modelled occupational EME exclusion zone. At this location, the measured worst case for the 6-minute sliding average recorded was 25% of the modelled value and more typically was just under 20% of the modelled value. Taking the worst case of 25%, which is a quarter of the modelled value that also equates to a 6dB reduction of the total power used to model the exclusion zone. This means that all of the transmitter powers recorded in the RFNSA for both Optus and Vodafone could be reduced by 6dB.

Technologies power for the sector measured are representative of both 3rd and 4th generation mobile services such as long-term evolution (LTE) and Wideband code division multiple access (WCDMA) next the type of service the frequency number is written in Mhz. Therefore, the project looks at total powers including Vodafone for this study used the assumption that their traffic profile would be similar due to the sites positioning and suburban area, which reasonable to do so for a joint site.

There are conversions that need to be done before final calculations can be made as must be added in when in a linear scale not logarithmic therefore the following is convert to Watts before finding the cumulative power.

Vodafone:
3G
WCDMA900 47 dBm x 2
WCDMA2100 48 dBm
4G
LTE850 47 dBm x 2
LTE1800 49 dBm x 2

$P_V(w)$= 2x(10^((47 dBm-30)/10))+ 10^((48 dBm-30)/10)+ 2x(10^((47 dBm-30)/10))+ 2x(10^((49 dBm-30)/10))
=2x(50.119)+(63.096)+(50.119)+2x(79.432)
=372.318 W

Optus:

3G

WCDMA900 46 dBm

WCDMA2100 47 dBm x 2

4G

LTE1800 49 dBm x 2

LTE2300 43 dBm x 4, 45 dBm x 4

LTE2600 46 dBm x 2

LTE700 44 dBm x 2

P_O(w)= 10^((46 dBm-30)/10))+2x(10^((47 dBm-30)/10))+ 2x(10^((49 dBm-30)/10))+ 4x(10^((43 dBm-30)/10))+ 4x(10^((45 dBm-30)/10))+ 2x(10^((46 dBm-30)/10))+ 2x(10^((44 dBm-30)/10))

=2x(79.433)+4x(19.953)+4x(31.623)+2x(39.811)+2x(25.119)+2x(50.119)+2x(39.812)

=635.074

Total Power:

P_t(w)= P_V(w) + P_O(w)

=372.318 + 635.074

=10007.392 W

$P_{t(dBm)}$= 10log$_{10}$(10007.392) +30

= 60.032

Therefore, max power minus the reduction

= 60.032 – 6

= 54 dBm

Convert back to SI unit for power

=10^((54 dBm-30)/10))

=251.189 W

The results illustrate the discrepancies between the theoretical levels that measured values.

Chapter 5
Conclusion

Overall, it was possible to look at the real value of EME exposure and apply the six-minute sliding average to confirm that they are well below the limits, that there is a relationship to the traffic of a site by tracking both together to understand the relationship. Based on these findings, it was possible to determine the power of the system in relation to the maximum supplied to the RFNSA [6] to the max we found using to the sliding average data.

It was essential to use the off the shelf component. This was achieved by putting together the sub-system of communication, monitor, physical structure and solar system. Forming the remote monitoring system from this, Optus now has evidence that the concept of implementation through pilot study and prototype is feasible and that it just is a matter of refining the system before having a large test case.

The project shows that it is possible to look at the exclusion zones and take the first steps solving industry problems with using the precautionary approach, which are not reached at typical traffic sites therefore a tailored approach is more reasonable. This is still a cautious approach and includes a more appropriate factor as from the data you could reduce the zone by ½ or ¼ of the size and it will still contain considerable amount of safety for an RF worker. The next step is to verify the results to determine a new preventive methodology that is reasonable for both the industry and the public, as the public demand for affordable high quality communications cannot be ignored.

In conclusion, the project accomplished the primary objective, secondary objective four and eight, providing much needed insight into portraying the cumulative EME exposure by using an RF monitor to collect data over a period of three weeks.

Chapter 7

Future Works

To be able to achieve the remaining secondary goals, it will be necessary to process, analyse and visualize date sets from real time logging system. These data can be stored on servers, thus making up big data. Big data brings about the ability interpret data on a much larger scale, which taps into various areas of methodology. As this project only looked at a small test case it was not possible to implement big data. But as site are exponentially growing and could be adapted for a variety of environments, not just rooftops, larger scale studies could be achieved by the use of (IoT) Internet of things applications [34, 35]

The real-time data could be linked to a computer, where it plots the exclusion zones in IXUS software that create the visualisation of radiation zones. These visualisations are then turned into real-time images through emerging technologies like Virtual Reality (VR) or Augmented Reality (AR) so the images can be seen through a device or a head set.

To be able to implement these new concepts we would first need the ability to directly connect to the data stream in real-time without having to save the data to memory, thus having the ability to complete the secondary objectives in, for example, a real-time alarm system. The future of EME looks bright and exciting as smart cities become a reality and bring with them smart antennas.

Chapter 8

Acronyms

ACMA – Australian communications and Media Authority

AR – Augmented Reality

ARPANSA – Australian Radiation Protection and Nuclear Safety Agency

CW – Continuous Wave

EME - Electromagnetic energy

EMF - Electromagnetic fields

HF - High Frequency

IoT – Internet of Things

NATA – National Association of Testing Authorities

RF - Radiofrequency

RPS 3 – Radiation Protection Standard no. 3

UHF –Ultra High Frequency

VHF – Very High Frequency

VR – Virtual Reality

Chapter 9
Glossary

This glossary uses [8] & [15] for its definitions.

Averaging time

The interval of time over which quantities, power terms are averaged to assess exposure, as is a practical way to measure discussed in more detail in Section 2 of the Standard (RPS3)

Controlled area

A controlled area is an area, place or zone with exposure to RF fields may reasonably be expected to exceed general public limits or occupational for health and safety.

Dynamic range

Use the frequency limits from the RPS 3 as reference point to give as a percentage of the standard this in the FieldSense case the given DC voltage from RF fields strength looks at these conditions and outputs a percentage of the standard.

Electromagnetic energy

The energy stored in an electromagnetic field shown as joule (J).

Exposure

Which occurs whenever a person is subject to RF fields.

Equivalent power flux density

Is the magnitude power flux density that corresponds a plane wave through free space

Magnetic field

Magnetic field vector *(*H) the strength is expressed in amperes per metre (A/m).

Electric field

Electric field vector, *(*E) the strength is expressed in volts per metre (V/m).

Frequency

Is the number of full sinusoidal cycles in electromagnetic waves in 1 second; usually expressed in hertz (Hz).

General public exposure/ public exposure

The exposure of RF fields suitable for the general public.

Hertz (Hz)

The unit shows frequency, (*f*). One hertz equals one cycle per second.

Instantaneous

Parameters that must be measured very small time interval (typically 100 microseconds or less).

Non ionising radiation

Will not produce ionisation i.e. radio frequency radiation and does not have sufficient energy to damage DNA.

Occupational exposure

Exposure allowed for RF worker, person who is trained and aware of RF fields when on duty.

Radiation

The emitting of waves/particles as energy radiates comes in the form of ionising and non – ionising.

Radiofrequency (RF)

Electromagnetic energy within the frequency range of 3 kHz to 300 GHz

Reference levels

Practical parameters that are used for determining compliance with RPS3 standards

RF field

Is the physical field made up of electric and magnetic states quantified by field strengths, creating three regions:

(a) *Reactive near-field*—that region of the field that immediately surrounds the antenna and the reactive near-field boundary is $\lambda/2\pi$ m, λ being the wavelength in metres.

(b) *Radiating near-field*—that region of the field, which extends between the reactive near-field region and the far-field region, wherein radiated fields predominate and the angular field distribution is dependent upon distance from the antenna.

(c) *Far-field*—that region of the field of the antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ or 0.5λ, whichever is the greater, from the antenna.

Pilot

Small scale experimental testing that is conducted to determine the feasibility, time, cost and suitability before developing a full-scale system.

Power flux density

The degree of movement of RF energy in a area normal to the direction of wave propagation watt per square metre (W/m^2).

Prototype

The preliminary version first version which other form are developed from this basis

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Appendix A

Python Code

A1 Work around code

```
import pyautogui

#open fieldsense
pyautogui.click(514, 740)

pyautogui.PAUSE = 1
pyautogui.FAILSAFE = True

#close
pyautogui.click(1106, 27)

pyautogui.PAUSE = 1

#open fieldsense
pyautogui.click(514, 740)
```

A2 Automation script

```
import pyautogui
import datetime
pyautogui.PAUSE = 1
pyautogui.FAILSAFE = True

#open fieldsense
pyautogui.click(514, 740)

#click on most latest log
pyautogui.click(85, 99)

#clicks on CSV to copy
pyautogui.click(1095,85)

#note pad to open new
pyautogui.click(562, 744)

#click on note pad
pyautogui.click(1176, 382)

#paste
pyautogui.hotkey('ctrl', 'v')

#save
pyautogui.hotkey('ctrl', 's')

# today's date
today = datetime.date.today()

#type date
pyautogui.typewrite(str(today))

#to save the name of the file
pyautogui.press('enter')

#close window
pyautogui.click(1206, 80)
```

Appendix B

B1 Standards – Radiation Protection Series No.3 (RPS3)

(Pages 12, 69,70 &109) [8]

Quantities and Units

Electromagnetic fields are quantified in terms of electric field strength **E**, expressed in volt per metre (V/m) and magnetic field strength **H** expressed as amperes per metre (A/m). Electric fields are associated only with the presence of electric charge, while magnetic fields result from the physical movement of electric charge (electric current). An electric field exerts forces on an electric charge and similarly, magnetic fields can exert physical forces on electric charges, but only when such charges are in motion. Electric and magnetic fields have both magnitude and direction (i.e., they are vectors). A magnetic field can also be specified as magnetic flux density, **B**, expressed in tesla (T). The two quantities, **B** and **H**, are related by the expression:

$$\mathbf{B} = \mu\mathbf{H} \tag{1}$$

where μ is the constant of proportionality (the magnetic permeability); in a vacuum and in air, as well as in non-magnetic (including biological) materials, μ has the value $4\pi \times 10^{-7}$ when expressed in henry per metre. Thus, in describing a magnetic field for protection purposes, only one of the quantities **B** or **H** needs to be specified.

In the far-field region, the plane wave model is a good approximation of the electromagnetic field propagation. The characteristics of a plane wave are:

- the wave fronts have a planar geometry;
- the **E** and **H** vectors and the direction of propagation are mutually perpendicular;
- the phase of the **E** and **H** fields is the same, and the quotient of the amplitude of **E**/**H** is constant throughout space. In free space, the ratio of their amplitudes $|\mathbf{E}|/|\mathbf{H}| \approx 377$ ohm, which is the characteristic impedance of free space; and
- power flux density, **S,** i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields by the expressions:

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \tag{2a}$$

$$|\mathbf{S}| = \frac{|\mathbf{E}|^2}{377} = 377|\mathbf{H}|^2 \tag{2b}$$

The situation in the near-field region is rather more complicated because the maxima and minima of **E** and **H** fields do not occur at the same points along the direction of propagation as they do in the far-field. In the near-field, the electromagnetic field structure may be highly inhomogeneous, and there may be substantial variations from the plane wave impedance of 377 ohms; that is, there may be almost pure **E** fields in some regions and almost pure **H** fields in others. Exposures in the near field are more difficult to specify, because both **E** and **H** fields must be measured and because the field patterns are more complicated; in this situation, power flux density is no longer an appropriate quantity to use in expressing exposure restrictions (as in the far-field).

Far-field measurements

In the far-field the RF power flux density (S), the electric field strength (E), and magnetic field strength (H), are interrelated by the following expressions:

$$S = E \times H$$

$$E = \sqrt{(Z \times S)} = \sqrt{(377\ S)},\ \text{i.e. } E^2 = 377\ S$$

$$H = \sqrt{(S/Z)} = \sqrt{(S/377)},\ \text{i.e. } H^2 = S/377$$

$$E = Z \times H$$

where

E = electric field strength, in volts per metre

H = magnetic field strength, in amperes per metre

S = electromagnetic power flux density, in watts per square metre

Z = characteristic impedance of free space, in ohms ≈ 377 Ω.

In the far-field of an RF source, relevant E, H and S limits will not be exceeded for frequencies above 10 MHz if any one of the RF power flux density (S), the electric field strength (E), or the magnetic field strength (H) can be shown to be less than the relevant limits specified in Tables 6, 7 and 8 in Section 2 of the Standard. At frequencies below 10 MHz in the far-field, measurements or evaluations of the E field are sufficient to determine compliance with E and H reference levels.

Near-field measurements

For a RF source operating at a frequency with a wavelength in air of λ m, the distance from the RF source to the reactive field boundary is $\lambda/2\pi$. In the reactive near-field, the field impedance, Z, will not necessarily be equal to 377 ohms. Therefore both electric and magnetic field strengths should be measured unless the impedance of the field is known.

However, in the radiating near-field it can be shown that the wave impedance is within 10% of the free space impedance at distances greater than about 0.5 λ from the antenna so that E, H or S may be measured to determine compliance with the reference levels. However, this approach should be cautiously adopted when making measurements near the reactive field boundary.

Many instruments which purport to measure RF power flux density actually measure the square of the electric or magnetic field strengths, but have a meter calibrated to indicate equivalent plane wave power flux density. The quantity sampled shall be deemed to be less than the reference level if such an instrument registers a value less than the equivalent level of RF power flux density for a plane wave. The expressions given in this Annex may be used to determine the equivalent level. There are instruments currently available that are able to measure H fields of frequencies of up to 300 MHz.

TABLE A1

ELECTRIC, MAGNETIC, ELECTROMAGNETIC, AND DOSIMETRIC QUANTITIES & CORRESPONDING SI UNITS

Quantity	Symbol	Unit
Conductivity	σ	Siemens per metre (S/ m)
Current	**I**	Ampere (A)
Current Density	**J**	Ampere per square metre (A/m²)
Frequency	f	Hertz (Hz)
Electric field strength	**E**	Volt per metre (V /m)
Magnetic field strength	**H**	Ampere per metre (A/ m)
Magnetic flux density	**B**	Tesla (T)
Magnetic permeability	μ	Henry per metre (H /m)
Permittivity	ε	Farad per metre (F/m)
Power flux density	**S**	Watt per square metre (W/m²)
Specific absorption	SA	Joule per kilogram (J /kg)
Specific absorption rate	SAR	Watt per kilogram (W/ kg)

Appendix C

C1 speciation of field sense pages 9 & 10 [14]

- **Frequency range of operation** .... 50MHz - 6 GHz
- **Frequency response** .... Shaped (Occupational/Controlled)
  - ICNIRP(1998)
  - FCC [NCRP] OET65 (1997)
  - Canada Safety Code 6 (2015)
  - IEEE C95.1 (2005) *(see associated table p10)
- **Sensor polarisation** .... Isotropic
- **Isotropy** * .... ± 3dB
- **Probes** ....3 orthogonal E and 3 orthogonal H field
- **Result type** ....Time-averaged RMS power density
- **Calibration interval** .... 2 yearly
- **CW damage level**....... 26 dB above Standard/ 40 000% of Standard
- **Battery type** ....2 x 1.5V Size AAA(LR03) Alkaline
- **Battery life** ....6 months—1 year (average usage)
- **Weight (incl. batteries)** ....0.25 lb, 115 gr
- **Dimensions** ....146 x 26 x 42mm
- **IEC 60529 rating** .... IP64 (battery cap closed)
- **Temperature range** ....-20°C to 50 °C
- **Fall detection** .... 3 axis accelerometer

Frequency response[1]

Frequency [MHz]	**ICNIRP** (1998)	**FCC/NCRP** (1997)	**Canada SC6** (2015)
50—80	0.5 ± 3.5 dB	0.5 ± 3.5 dB	-1.5 ± 3.5 dB
80—400	2.0 ± 3.0 dB	2.0 ± 3.0 dB	0.5 ± 3.5 dB
400—700	1.3 ± 2.3 dB	2.9 ± 2.1 dB	1.3 ± 2.3 dB
700—3000	0.3 ± 3.2 dB	1.2 ± 3.8 dB	-1.0 ± 4.0 dB
3000—6000	0.0 ± 3.5 dB	0.0 ± 3.5 dB	-1.5 ± 2.5 dB

Appendix D

D1 Equipment list *pages14-16 [13]*

Diagram Ref	Owner Ref	Owner	Type/Make/Model	Height (m)	Bearing (°)	Mech. Tilt (°)	Elec. Tilt (°)	Pol	System/Function/ Sector	Power (Watts)
11-V		Vodafone	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	WCDMA900	50+50
11-V		Vodafone	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 1800	80+0+0+80+0+0 +0+0
11-V		Vodafone	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	WCDMA2100	0+0+0+0+63.1+0 +0+63.1
11-V		Vodafone	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 850	50+50
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 700	25+25
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	WCDMA900	0+40
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 1800	0+0+80+80+0+0 +0+0
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	WCDMA2100	0+0+50+50+0+0 +0+0
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 2300	20+20+20+20+3 2+32+32+32
12-O		Optus	Panel/Argus/RV4PX310R	14	25	0	0 to 10	Cross	LTE 2600	0+0+0+0+0+0+4 0+40

Appendix E

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
1	2/8/17	Initial meeting	Hfraser	R.Veal6
2	9/8/17	Regular meeting	Hfraser	R.Veal6
3	16/8/17	"	Hfraser	R.Veal6
4	23/8/17	"	Hfraser	R.Veal6
5	1/9/17	"	Hfraser	R.Veal6
6	8/9/17	"	Hfraser	R.Veal6
7	13/9/17	"	Hfraser	R.Veal6
Semester break	29/9/17	"	Hfraser	R.Veal6
8	6/10/17	"	Hfraser	R.Veal6
9	10/10/17	"	Hfraser	R.Veal6
10	17/10/17	"	Hfraser	R.Veal6
11	25/10/17	"	Hfraser	R.Veal6

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
12	*02/11/17*	"	[illegible]	"
12	*03/11/17*	"	[illegible]	"