Automated Measurement of Ambient Electromagnetic Noise

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The earth’s atmosphere, electromagnetically, is extremely noisy, does this transfer to the sub-sea medium, if so how much? This forms the basis of this paper, to gain a better understanding, experimentally, how the noise transfers from the atmosphere to below the water. There is an increasing interest in specialised forms of electromagnetic (EM) wave communications in dissipative media, such as seawater. This brings a necessary demand for information of the ambient electromagnetic noise. This information will aid in the predication of a systems performance in terms of signal to noise ratio and bit error rate. This project follows on from the previous investigations in earlier years, to further design and develop a remote monitoring facility. The designed and developed system is capable of continuously monitoring the naturally occurring EM noise at an electrically quiet location (rural, underwater), the data is stored for a post-processing. The interval between data download and power re-charge is entirely dependant on storage load and type of power connected, as a degree of flexibility was built in to allow for various conditions. The processed data, includes power spectral density, for analysis and archiving. The equipment design focused on frequency bands of particular relevance to sub-sea EM wave signalling, TLF through to HF, this was achieved with a system band of 1 Hz - 3.5 MHz although it is intended that the overall system design should be capable of adaptation for VHF and UHF bands. The system design was successful in producing a system capable of recording noise in the range of ±1mV in steps of 488nV. The main difference between this system and previous versions is that this system is a differential system as opposed to single-ended system. The system was deployed in Lake Burely Griffin where data captured confirmed attenuation with an increase of depth.

I. Introduction

In developing a system, a fundamental component is understanding the environment the system intends to operate and perform. In the RF world, environments vary from underwater, terrestrial and space. Apart from the permittivity of these mediums, the main concern, for RF, is EM noise. Understanding the EM noise of an environment, will lead to better system designs and performance based upon the information garnered. Therefore having an extensive knowledge of EM noise the affect it has on SNR and BER, is a key aspect of RF system design.

Underwater, there are three main ways to communicate wirelessly optically, acoustically and by electromagnetic wave. When we use electromagnetic waves to communicate underwater, the attenuation of the signal increases exponentially with frequency as depicted in figure 1. This attenuation is greater in salt water than in fresh water, however, in both cases still results in very low ranges. While above water the noise is high, theoretically we expect that underwater that the noise level to be quite low in comparison, due to the lossy medium of sea water. There will be a transfer of some noise from the atmosphere to the water, but how much and how far does the noise travel. This forms the basis of my project to, experimentally, gain a better understanding how the noise transfers from the atmosphere to below the water. This project is, designing and implementing, a portable system that is capable of conducting a site survey for EM noise, this system needs to be able to be deployed underwater and on land. It will consist of three main parts, antenna assembly, which will have three loop antennas pointing in an X,Y & Z direction. The second is the power system which consists of a 12V battery or DC via voltage supplier from the mains. The third and final system is the receiver system, this will made up of three sub-systems, signal conditioning, signal conversion and micro-controller/storage. The BW that this system will capture is from TLF to approximately 10 MHz. The other part of this project looks at the data produced by the system, and what may be gleaned from it.

This report will begin with a background on EM noise, what it is and where it emanates from, how EM noise is characterised and measured. The design approach taken for this project and why it was chosen. This will be followed by a look at the work conducted by Alan Clarke (2013) and Jordan Brown (2014), as these previous projects are closely related to this project. This report will conclude with the work I have achieved thus far and expected work to be completed by the end of the project. The nomenclature for this report may be viewed in Annex A.

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II. Research

A. Electromagnetic Noise

When it comes to wireless communications there are two distinct types of EM noise, that which is generated internally of the receiver and that which is external to the receiving antenna.

Internal noise of a receiver system, comes from a number of sources two of the main causes are, thermal noise, is caused from losses in the transmission lines, antenna circuits and the receiver itself.[1] The second, shot noise, which is caused by electrons randomly moving through a semiconductor junction.[2] Both of these are commonly known as white Gaussian noise.

The EM noise that this project is mainly concerned with, is that of external EM noise to the receive antenna. This external to the system EM noise is defined by the ITU as, ’a time varying electromagnetic phenomenon having components in the radio frequency range, apparently not covering information and which may be superimposed on, or combined with, a wanted signal.’[3] This EM noise may be generated from three different sources.

Firstly there is cosmic background noise, which emanates primarily from the galaxy or sun. Secondly there is man-made, which emanates from many sources, a couple are but, power grid and machinery. Thirdly is atmospheric noise, primarily emanating from lightning and absorption from atmospheric gases.

Cosmic noise tends to be at higher frequencies (15 MHz and above), this is outside of the scope for this project therefore will not be discussed, but if further development of this project is to be conducted, increasing the BW from 10 MHz to greater, then cosmic EM noise should be considered.

Atmospheric EM noise is predominantly based on lightning strikes, which vary with proximity, season, time of day and frequency. Man made EM noise is also random in nature dependant on the type of machine, frequency on the power grid and the proximity.

B. Electromagnetic Noise Characterisation

To characterise EM noise, it is common practice to normalise it by taking the noise power and dividing it by a reference temperature, Boltzmann’s constant and the BW. This is shown in equation 1.

\[ f_a = \frac{P_n}{kT_0B} \]  

This results in \( f_a \), the noise factor which is turned into the \( F_A \), noise figure, as shown in equation 2.

\[ F_a = 10\log f_a \]  

Figure 2: Attenuation of Freshwater and saltwater with respect to frequency

Figure 2 depicts the previously discussed three types of EM noise. The man made noise consists of four solid lines which represents, quiet rural, rural, residential and business. Atmospheric noise is represented by the broken lines, and is split into night and day. Lastly cosmic EM noise, represented by the dotted line. This graph illustrates what one would think intuitively, with the man made EM noise, the quiet rural being the quietest in terms of EM noise and a business area being the noisiest. Counter-intuitively though, atmospheric EM noise is more prevalent at night than day.

The graph also shows the \( F_a \) against the frequency. The \( F_a \) represents a measurement of the degradation in the SNR between the input and output.[4] Therefore as figure 2 depicts the noise figure is more dominant in the lower frequency ranges, particularly atmospheric noise as it heads towards the 100 kHz.
C. Design Approach

The design approach I have taken is one of modular design. This approach serves many purposes, the main one, being able to interchange modules with the existing system. Another major benefit, will be that future students will be able to easily carry on and or modify the project. The advantages of modular design, in particular for my project, are efficiency, as testing is achieved before final assembly; Individual testing, each module may be individually tested. The most important advantage is interchangeability with existing modules.

In Modular Design the initial step is to compile all the important and fundamental information regarding the system. This information is analysed and the basic specifications and constraints are worked out. A functional diagram is then drawn up for each of the functions. The functional block diagram is then arranged in the required order, appropriate for the system. Now that the design is settled, a circuit diagram may now be derived from the from the functional blocks, which then maybe connected to from a complete circuit schematic. Where possible each module was tested either by simulation and or physically (breadboard), before being given the green light to assemble the complete circuit board.

III. Past Iterations

A. 2013

Alan Clarke’s project involved the design, construction and operation of a system capable of automated measurements of ambient EM noise at low frequency. The recorded data was intended to aide in current and future design of underwater communications systems.

Alan’s completed system was able to develop an automated portable three axis system. Alan’s project focused on the design of the system. Although he was able conduct several EM site surveys. Analysis, of the measurements from Alan’s system, that were taken in air, freshwater and seawater, were able to confirm diurnal variation and attenuation of EM ambient noise with an increase in water depth.

Alan’s system is still currently active recording data up to 48 kHz BW, as depicted in figure 3, the data from this system will form part of a data mining exercise in the latter part of the report.

![Figure 3: Alan Clarke’s System Set-up](image)

B. 2014

Jordan Brown’s project was to develop an efficient system for the continual measurement and analysis of (region specific) ambient EM noise. The analysis of this information will help develop an understanding of long-term diurnal and seasonal trends in order to optimise communication systems.

Jordan, with the aide of an COTS Terasic Daughter Board and a specifically designed underwater antenna, compiled several measurements, which confirmed the attenuation increased with depth.

IV. System Design

A. Differential System

While the system, that was developed had increased specifications in most areas, the main point of improvement, is adopting a differential system over the previously used single-ended systems.

Single-ended system takes one input from each signal antenna to the amplification stage. The measurement of this
signal is the difference between it and ground. Single-ended systems rely on the signal source being grounded, and the following stages having the same value ground. One advantage of this type of system is that the initial amplification stage is not required to be co-located with the antenna array as the antenna array’s ground may provide shielding to the signal wire, by utilising co-axial cable. The key element for this system is ensuring a common ground for all elements of the system. When using single-ended systems it important to ensure it is balanced, otherwise noise errors may be introduced. Single-ended systems are highly sensitive to noise errors. While the systems purpose is to analyse noise levels, we are only interested in the noise seen at the antenna array, not noise which has been induced further down the line. This noise is added where the signal carrying wire acts as an aerial, having the EM noise induced on it. Therefore in the single-ended system it is very difficult to distinguish, if not impossible, between the external signal EM noise and the instrumentation noise.

With a differential system, instead of grounding one input, both signal wires turn out from the antenna array straight into the initial gain stage. These two inputs are split to either positive or negative, and by utilising differential amplifiers as depicted in figure 4, and voltage which is induced after the antenna array, will be common to both signals and will cancelled out by the differential amplifier. To ensure that any EM noise induced after the signal is common to both signals, twisted pair cables were utilised, mainly of the CAT-5 variety. Therefore by utilising the differential system I ensure that the EM noise captured is truly the ambient EM noise as seen by the antenna array and not EM noise which has been induced after the array.

B. System Assemblies

As previously stated, five sub-assemblies make up the Automated ambient RF measurement system. The antenna system and 40dB initial gain stage, which feeds into another 20dB gain stage before moving onto the signal processing block, all of which is controlled by the micro-controller, which also transfers the digitised data to the microSD card read/writer. There is also a power system which is required to operate the system, this power output requires a maximum of 12VDC and a minimum of 6VDC. As there is an existing system (Alan Clarke’s) a modular design approach was taken so that the prototype designs may be tested in conjunction with the existing system.

Figure 4: Differential Amplifier[5]

Figure 5: Block Diagram of Automated ambient RF measurement system

Figure 5 illustrates a basic block diagram of the whole system. The systems denoted by the purple colour (Signal conversion & Signal Processing and Storage) are the main focus of this project, they were completed initially before the amplification stages were completed. The antenna array from Alan Clarke’s existing system were utilised.
C. Antenna Array and 40dB Gain Assembly

Two of these amplifiers are cascaded for each channel. The power for the rail voltage is supplied by a DC-DC voltage regulator and inverter, MCP1727-3302E/MD IC, LDO, 1.5A, 3.3V, 8DFN NC7S04 Tiny Logic HS Inverter, respectively. The power for the regulator circuit is supplied via a connection from the incoming cable from the second stage amplifier. This stage is illustrated in figure 7.

D. 20dB Gain Assembly

As the system is a balanced system, utilising twisted pair CAT-5 cable for signal transfer, the system was designed with the major gain stage directly at the incoming signal (Antenna Array). The amplifier stage consists of six AD8138 Low Noise, differential amplifiers. The second stage amplifier provides a final 20dB of gain and is a similar set-up to the initial gain stage, only one differential amplifier is required for each channel. The external DC voltage supply is connected to this board, which is required to be less than 12V and greater than 6V. The power supply is recommended to be capable of supplying one amp of current, as the nominal current drawn from the two amplification stages is 480mA. The RJ45 connector situated above the DC power jack, as illustrated in figure 8, conveys the amplified signal (60dB) to the signal processing daughter board. The other RJ45 connector, receives the 40dB amplified signal from the first stage and also sends down the DC voltage.

E. Signal Processing Assembly

Two main parts make up this particular sub-assembly, the ADC and the FIFO IC’s, this sub-assembly takes the conditioned analog signal from the second amplifier stage and converts it into a digital output. The parts chosen for this sub-system have a major influence on the system as a whole. Both with the amount of data, the RBW, collected and the dynamic range that could be represented.

1. ADC

In selecting the appropriate ADC for this system, two main constraints needed to be taken into consideration, BW and DR. The BW constraint for this system was effectively greater than 2MHz, recording the ambient noise from 1 Hz - 3.5 MHz, applying the Nyquist theorem \( f_s = 2 \times BW \rightarrow BW = \frac{f_s}{2} \), therefore the minimum sampling rate required by the ADC is 7 Msp, the AIC utilised delivered 20 Msp. The other constraint, which is set by the IEEE standard for an EM site survey, is DR, a minimum DR of 50 dB is required. The DR was determined using the following formula \( DR = 20 \log \left( \frac{\text{max} \cdot V}{\text{min} \cdot V} \right) \). The part chosen which fulfilled or exceeded the constraints, was the ADC 'Analog

To construct and test certain aspects of the design, the project is utilising several CAD software packages. To construct the three PCB’s the freeware student version of Eagle software was utilised, the schematics which may be viewed in Appendix A, then developed into PCB layouts as shown in figure 6, this software then outputs a generic set of files (gerber files), which are utilised by manufacturers to construct the physical circuit. To test certain aspects of the circuit design, such as the timing circuit, Altium software is being utilised to run simulations to confirm the appropriate response.
Device 9235. This is a 12 bit, 20 Msps, 3V ADC. Based upon the specification off the ADC data-sheet, the 20 Msps will give the system a BW of 10 MHz, which was later revised to 4 MHz. The minimum voltage is determined by the number of bits, $2^{12} - 1 = 4095$, $minV = \frac{maxV}{4095}$. This gives a DR of approximately 72 dB. The ADC chosen uses a pipeline architecture, this type of architecture approaches speed of a flash ADC, but much lower complexity. A disadvantage is the latency, with the AD9235, have a latency of 7 clock cycles, 350 ns. This issue was overcome by setting a half second delay in the micro-controller for the ‘write enable’ on the FIFO. The data was chosen to be digitised in the format of off-set binary, where all zeroes represent the lowest possible input, -1V in this system, all ones the highest value, 1V, and a one in the MSB followed by all zeroes represents 0V.

2. FIFO

The FIFO is used to create a buffer, which gave the system flexibility when it came to the signal processing and storage sub-assembly. Without the buffer the system will be limited to the speed and processing power of the micro-controller, resulting in it being primarily used as a gateway to the storage device, the buffer will possible allow the micro-controller to carry some signal processing. The FIFO specifications decide the RBW of the system, $RBW = \frac{fs}{N}$. As there is three antenna inputs, and to ensure accurate data three ADC’s will be utilised in conjunction with the FIFO, this will give a total output of 36 bits.

The depth of the FIFO is 8192 bits. This will give the system a RBW of approximately 2.44 kHz. As the speed of this sub-system is synchronised with the lowest speed which is that of the ADC at 20 MHz, the FIFO write clock to will be synced at this speed. This will be achieved using a crystal oscillator circuit to provide the 20 MHz clock. This clock speed means the acquisition time is approximately 410$\mu$s. The stored data on the FIFO was read out and stored on a microSD card, via the micro-controller.

F. Signal Processing and Storage Assembly

The digitised data from the Signal Processing Daughter Board assembly, now requires either processing, at this stage in the system this requires the data to be downloaded from the SD card and processed with the aide of Matlab. The micro-controller chosen for this system is the, COTS, Arduino DUE. The Arduino Due, has a 32 bit core, 54 digital I/O with a 84 MHz clock.[8] This micro-controller was chosen for several reasons. The 54 digital I/O, covers the incoming data from the FIFO (36 Bits) and still has ample I/O pins for the logic control. As this is an open source micro-controller, there is a substantial amount of online support and a wealth of resources, to assist in the application of this micro-controller. The flexibility of the Arduino Due is another asset, while the Arduino Due is currently being used for the rudimentary operation, of control and data transfer a future goal is to process the data, conducting a DFT on the digitised data as it ingresses from the FIFO, with the Arduino Due.

1. FPGA

Prior to settling on the Arduino Due micro-controller, the project investigated the possibility of implementing a FPGA to conduct real-time signal processing and storage. After several consultations with professional engineers, Shane Brandon and Kathryn Day, the feasibility of implementing a FPGA was possible and most likely provide an advantageous outcome, however the time constraint of the project and the extensive learning overhead prevented the FPGA from being a viable option for this project.

V. System Characterisation

The system was characterised in three stages. Once the characterisation was conducted, of the individual stages, the entire assembly was connected together and tested.
A. Signal Processing Daughter Board

Due to the complexity of this board and the fact that it contained under IC via’s meant this particular PCB was manufactured off site, once received the board was populated by TSG, which is pictured in 9. Upon receipt of the board from TSG, some basic un-powered continuity checks were completed, this was followed by powering up and checking the correct voltages were present at the right locations, power rails, logic pins. During this process a minor design error was identified with the 20 MHz timing circuit, this was easily rectified, by cutting a track on the PCB. Once all the basic testing was completed, the micro-controller was coded to label all the digital I/O from the ADC’s and out of the FIFO, this was followed by systematic process of the steps required to store data on the microSD shield. This is represented in the flow diagram 12. The complete Arduino Due code may be viewed in Appendix B.

![Flow diagram of Arduino Due Operations](image)

Upon completion of the code, the first step was to input sine waves at varying frequencies and process the stored data. Figure 13 illustrates the some of the results of the input signals after being processed in Matlab. The signals shown here begin at 300 kHz and increment up in 3, 7 and 10. Figure, 13a, show the system working as designed, with a minor drop in amplitude. Figure 13b, where the Nyquist frequency is approached, indicates the sine wave is slightly distorted at 3 MHz, before becoming unrecognisable at 7 and 10 MHz, also of note is the expected decrease in amplitude. This data was processed in Matlab to produce a frequency response which highlights more clearly the amplitude response, as shown in figure 14.

![Processed Data plot from inputting various Frequency Sine Waves at 1V Pk-Pk](image)

![Frequency Response of Signal Processing Daughter Board](image)
B. Amplification Stage One and Two

The two amplification boards were less complex than the signal processing daughter board, this enabled these boards to be manufactured and populated here at UNSW, Canberra by TSG. The boards are illustrated in figures 7 and 8. As with the signal processing daughter board, basic continuity checks were conducted, prior to conducting powered tests. The basic testing concluded with nil issues. The main test conducted here indicated everything worked as expected.

The second stage amplifier was initially tested by inputting a 50mV Pk-Pk sine wave and observing the output, on an oscilloscope, which showed a 500mV Pk-Pk sine wave. A number of frequencies were tested to ensure the amplifier worked consistently across the entire system bandwidth. An issue was identified on the Z channel, as it was not outputting any signal, after faulty finding, indications were that a connection was not adequate between the a pin and the pad on the AD8138 IC, this was rectified with a touch of solder, which solved the issue.

The first stage testing replicated that of the second stage except the initial input test voltage was reduced to 5mV Pk-Pk to accommodate for the much larger gain. The outputs were as desired across all three channels.

C. Whole System Test

The entire system was connected together, the antenna array from Alan Clarke’s system, shown in figure 3a, was utilised in conjunction with my two amplification boards and signal processing daughter board. Several data sets were taken, figure 15, represents a channel from the data set. The main points to see here is the difference between the instrumentation noise floor and that of the received ambient EM noise, is easily distinguishable which is ideal, as the whole point of this project is to monitor external ambient EM noise. The AM RF band is 535 kHz to 1700 kHz, clearly visible on the newly developed system are several local Canberra AM radio stations,

- 666 kHz - ABC Canberra
- 846 kHz - ABC Radio National
- 1054 kHz 2CA
- 1322 kHz - ANC International Holdings

Looking at the old system compared with the new, a notable difference is in the bandwidth, with the new system, a bandwidth of 3 MHz and the existing system approximately 45 kHz. The only advantage the existing system has, is its RBW is 1 Hz, compared with the new system which is 2.4 kHz. This maybe improved with a deeper FIFO or a faster ADC.

D. Underwater Test Lake Burley Griffin

On the morning of 18 October 2015, the newly developed system was tested in freshwater at Lake Burley Griffin, Canberra, 0600h local time. Several measurements were taken at different depths, with the overall depth measure at 2.1m. As illustrated in figure 16.
Upon closer analysis of this, as shown by the zoomed in plot of a local radio station, 666 kHz - ABC Canberra, in figure 17. This figure illustrates the level of attenuation of the signal as depth is increased until it nears the bottom, and the signal is strength gets higher. Figure 17 clearly shows the signal above the water is the strongest, then at 1m there was approximately a 6-7 dB loss, with largest attenuation recorded at a depth of 1.5m. Then as the antenna approaches the bottom the attenuation of the signal decreases as transmission through the land affects the antenna.

VI. Data Processing and Data Mining

Analysis of the collected data, can be used to investigate any number of aspects regarding EM noise, from diurnal, monthly and seasonal activity, to tracking storm activity.

The data measurements recorded utilising Alan Clarke’s system, contain a multitude of information. Depending on your line of enquiry, the data is there to be processed.

A. Lightning

The largest contributor to EM noise, beginning at a few Hz continuing to hundreds of MHz, is lightning. Lightning usually occurs during an electrical storm, and is caused by an electrostatic discharge. The earth has an estimated 2000 storms daily, and the ground is struck over a 100 times a second, one lightning discharge can carry upwards of 10000 amps.[10] Figure 18 is a plot of lightning in the frequency domain EM spectrum. Looking at figure 18 and comparing it to figures 19a and 19b, there is a distinct correlation to the Blue (North-South) and Green (East-West) antennas. The reason for this is that on the, 18 March 2015, Canberra had an electrical storm, early in the day. Hence why figure 18 resembles to a degree figures 19a and 19b. To further illustrate this figures 19a and 19b, plot eight data sets collected on the 18 March 2015 at UNSW Canberra plots which signify the local time that measurements were taken, hourly from 11am to 6pm.

Figure 16: PSD of data recorded at Lake Burley Griffin, Canberra, 18-10-15,0600h ESDT

Figure 17: zoomed PSD of data recorded at Lake Burley Griffin, Canberra, 18-10-15,0600h ESDT
These plots were chosen, as they represent the effect atmospheric EM noise has on the ambient EM noise, and that it is the major cause of fluctuations of the EM noise level. Looking at the green and blue antenna, of figures 19a and 19b, in particular the 11am and 12 pm plots, the measured ambient noise level is higher than the corresponding times the following day shown in the green and blue antenna graphs of figures 20a and 20b. The reason for this stark contrast was that on the 18 March 2015, an electrical storm passed over Canberra. The storm was close to the site in the early to mid morning, this explains the peak noise measurement at this time. Another thing this information conveys, is the direction of the storm as it passes over Canberra. This is again seen in the green and blue antenna, in figures 19a and 19b, at 11am the data shows the ambient EM noise is largest in the green antenna plane relative to the blue antenna.

Figure 19: PSD of an Electrical Storm at UNSW Canberra, 18-Mar-15

One hour late the PSD indicates the blue antenna has the larger ambient EM noise level relative to the green antenna, although the margin in difference between the EM noise level is less in the latter instance. These measurements suggest that the storm was predominately in the direction of the green antenna plane, shifting with time towards the blue antenna plane.

VII. Conclusion

This project has delivered a system capable of taking automated measurements of EM noise, on land and underwater. This was achieved through planning and research. Understanding the environment around us, to better create, design and construct. This was the project in a nutshell. Specifically to design an automated ambient EM noise logger. This system will needed to function above and below the water, particularly underwater, as this is the area of most interest, as it is theorised and minimally tested. The fact that, underwater, the lack of noise is an area that has untapped potential. The theory covered in this project is extensive. The main theory covered was with regard to EM noise. As this project looks at measuring the ambient EM noise in the environment, therefore external EM noise (outside the receiver system)is the major focus. External EM noise is placed in three major categories, man-made, atmospheric and cosmic. Man-made and Atmospheric EM noise makes up the bulk of the noise at the lower end of the RF spectrum, TLF - VHF and cosmic noise is from VHF to THF.

EM noise is characterised using the noise factor shown in equation one and is usually plotted as the noise figure, shown in equation 2. Figure 2 demonstrates the use of the noise figure, showing the three types of external EM noise. This
figure also shows intuitively that there is higher levels of man-made EM noise in more built-up areas. The design for the automated EM noise logger, needed to satisfy certain criteria, both internally and externally. Internally the system requirements are, automation, greater than 1 MHz BW, less than 5 kHz RBW and a DR greater than 50 dB. These specifications were met, with the developed system, having specifications of 3 MHz BW, RBW of 2.4kHz and a DR of 72 dB. Externally the system requirements are that the system is easily portable, durable and able to operate underwater. These criteria were also achieved with the system extremely light and portable, with the option to either run off mains power or battery.

A modular approach was taken to design the system, this modular approach is highlighted in figure 5 with the purple blocks being the main focus of this project. The design phase focused on the designing and constructing a daughter board compatible with the chosen micro-controller, the Arduino Due. This was achieved to allow for programming time will the amplification stages were being constructed.

The system was validated and verified, through a series of standard checks to ensure the system either met or exceeded the specifications. These test ranged from filter characterisation to continuity checks.

Looking at previous reports to gain valuable insight into different aspects of the project has been beneficial. The first variant in 2009 was a manually operated system that achieved underwater readings. In 2010 the system concentrated mainly on the antenna design, from the data measured daily variations in EM noise were confirmed. The system currently providing data, pictured in figure 3, was developed in 2013, it is automated and semi-portable, taking measurements above and below the water. Finally 2014, managed to develop a new automated system capable of operating off a battery. This system was able to be operated above and below water, with a BW of 10 MHz.

The design of the system was conducted on Eagle CAD program, with simulations of logic circuits being achieved in Altium CAD program. There are three main IC’s which were decided upon, a 12 bit, 20 Msps ADC, 36 by 8192 FIFO and the Arduino Due as the micro-controller. As noted earlier, the option of implementing a FPGA was considered, after consultations the option was abandoned as the risk was assessed to high to the project, due to the steep learning curve and the time constraint.

The data can deliver a plethora of information, the two examples discussed earlier, show how the data may be interpreted to find and identify transmitted signals. In the current BW available there are many transmitted signals visible in the PSD. Lightning being the largest contributor to ambient EM noise, was demonstrated with the data taken during a recent electrical storm in Canberra, in close proximity to the antenna arrangement. The PSD, generated during the storm clearly indicates the impact that lightning has on ambient EM noise. This also demonstrated how the electrical storm may be tracked using this system.

Therefore in summary a system was designed and developed with, 3 MHz BW, 2.4kHz RBW, capable of taking and storing a sample every three minutes. The system is truly portable. While the new system exceeds previous systems in just about every way, the main point of difference was that this newly developed system utilises differential amplifiers, letting the system to be a differential one. As explained earlier this gave the new system greater disparity between the instrumentation noise floor and the sampled EM noise. Something the previous systems struggled with, as they utilised single-ended approach.

While the main focus of this project was to design, develop and construct a portable system capable of taking automated measurements of ambient EM noise, some options were included which may lead to future design evolutions.

VIII. Future Work

As a future project, there are several areas to which this study may be progressed. As this was a prototype system, further site surveys would be recommended, to further verify the system and gain valuable data from those areas surveyed.

Another aspect is the micro-controller, currently the Arduino controls the system operation and data storage for post-processing, there is scope for the Arduino to do the signal processing itself. Further design is required for the system to be housed correctly.

The ability to set the system underwater at a desired depth, untethered, eliminating any chance of transmission down the tether-line. Another option would be to transmit the data measured back to a base station, which would enable the system to left unattended for long periods of time.

Future students may also investigate the possibility of designing a solar power supply. A solar power supply in conjunction with auto transmission of data to a base station, would make the system completely autonomous.
IX. Acknowledgements

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Nomenclature

\begin{itemize}
  \item $b$ Bandwidth Equation 1
  \item $F_a$ Noise Figure
  \item $f_a$ Noise Factor
  \item $f_s$ Sampling Frequency
  \item $k$ Boltzmann’s constant $1.38 \times 10^{-23} J K^{-1}$
  \item $t_0$ Reference Temperature Kelvin
  \item ADC Analog to Digital Converter
  \item BER Bit Error Rate
  \item BW Bandwidth
  \item CAD Computer Aided Design
  \item COTS Commercial off the shelf
  \item DFFT Discrete Fast Fourier Transform
  \item DR Dynamic Range
  \item ELF Extremely Low Frequency
  \item EM Electromagnetic
  \item FIFO First In First Out storage IC
  \item FPGA Field Programmable Gate Array
  \item HF High Frequency
  \item IC Integrated Circuit
  \item IEEE Institute of Electrical and Electronic Engineers
  \item ITU International Telecommunications Union
  \item LF Low Frequency
  \item MF Medium Frequency
  \item Msps Mega samples per second
  \item N Number of Samples
  \item PCB Printed Circuit Board
  \item PSD Power Spectral Density
  \item PSD Power Spectrum Density
\end{itemize}
RBW  Resolution Bandwidth  
RF  Radio Frequency  
SNR  Signal to Noise Ratio  
TLF  Tremendously Low Frequency  
UNSW  University of New South Wales  
VLF  Very Low Frequency  

References

University of New South Wales