I2 Report

Assessing and improving performance of telecommunication monopole antennae

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2018

4th year MEng Group Project

I certify that all material in this thesis that is not my own work has been identified and that no material has been included for which a degree has previously been conferred on me.

Signed..

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ECMM102

Title: Assessing and improving performance of telecommunication monopole antennae
Word count: 11360
Number of pages: 38

Date of submission: Monday, 07 May 2018

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Abstract

Group project investigating monopoles with this section interested in the final output section. Monopoles represent the future of telecommunications today, primarily for the ubiquitous 4G technology. With 5G technology on the horizon in only a few years' time, it is very important for the integrity of the output signal to be as good as it possibly can be. The aim of this report is to explore methods in which the integrity of the output signal may be improved in any way, and how wind affects the serviceability of a monopole. I use an FM radio application to record data received from an FM station and a custom-made Android application to measure internet speed over time from the monopole, which is a rough metric of its serviceability. This project's outcome finds that integrity of FM signal can be partially rectified, but only under certain circumstances, and the methods needed can vary on a case-by-case basis. For the monopole serviceability experiment, I conclude that a light wind appears to have some effect on the output signal of the monopole, but more experiments under different circumstances are needed to obtain a more definitive conclusion.

Keywords: Monopole, integrity, signal, digital, analogue, wind

Acknowledgements: Jose Capilla and Arqiva for their invaluable help with this project in providing data and resources and organising monopole field trips

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1. Introduction and background

In our modern world, society is powered by and dependent upon technology. The main driver of this curiosity, naturally, is the medium of telecommunications to connect people from all over the world in an instant. The bedrock for global communications starts locally, namely in the form of communication towers. The continued operation of such towers is paramount to humanity's desire to communicate and, if they were to cease functioning, it would be considered akin to a natural disaster.

Telecommunication towers are typically tall structures on top of which sits an antenna, and it is this that transmits the signals. These signals may be transmitted in a line-of-sight or equally in all directions. Naturally, a taller tower may transmit further, but its structure will be more unstable. A tower's structure and base are very important to the antenna atop, as a problem with the tower, even a small one, may amplify and result in a big difference to the output signal.

Figure 1: Tokyo Tower (Japan Times, 2016)

These towers can transmit many distinct signals of varying frequencies across a wide range of uses: notably radio, television and mobile internet. These signals are typically transmitted in the form of radio waves with the signal received by a corresponding receiver within range. As these towers are utilised very frequently, with some towers in large cities (such as Tokyo Tower or Crystal Palace) reaching millions, it is essential that the reliability and integrity of these signals are as good as they can possibly be.

It is essential for a tower not only to transmit reliably at all times of the day, but also to ensure that the integrity of the signal must be excellent up to a certain range. For analogue signals, this means that there should be little to no noise in the output signal, and for digital signals, data loss should be kept to a minimum, ideally zero. It is also the responsibility of the receiver to perform any signal processing that it sees fit to improve integrity on their end.

1.1. Individual aims

The aim of this individual project is to discover how wind affects the serviceability of a monopole, and to offer suggestions for how the serviceability can remain high at all times. I am also interested in the range of transmission, not specifically of a monopole, but of a tower in general, and wish to discover the range of a transmission tower transmitting FM signals, and to pinpoint when the integrity of the signal begins to break down and to suggest possible solutions for rectifying this.

1.2. Individual objectives

Prior to any experiments being conducted, sufficient research must be carried out beforehand. This is to be done in the form of a literature review, where as much relevant information about antennae and towers must be collected and assessed, so we have a very clear idea of what work should be undertaken in the main project and what areas should be expanded upon.

After many different sources have been read and investigated, it is important to explain the key concepts present in the project. Specifically, it will be very important to explain the different methods of transmitting information from an antenna, using both analogue (AM and FM) and digital methods. Understanding these well will be essential to understanding the following sections sufficiently.

The next objective is to design and program an Android mobile application that can measure Internet speeds over some time period and save the data to a file. The application will be used on nearby monopoles that transmit mobile internet signals both under normal operating circumstances and during the shaking of the tower, where the integrity of the signal may be affected.

The other objective is to measure FM radio signals from a transmission tower across various distances to observe how distance affects the integrity of the received signal. These distances will be 1, 2, 5, 10 and 20km from the transmission source.

The next part is to visit a functioning monopole and to use the Android application to measure the internet speed transmitted during both circumstances, and also to get the FM readings at the distances specified.

The final step is to bring together all of our data and analyse it appropriately, and, in the case of the FM signals, perform any post-processing when appropriate, and discuss the results.

1.3. *Group aims*

This project is a constituent part of a larger group project with six other group members to offer solutions to improve the monopole structure, as it is deemed highly important for ubiquitous coverage of mobile services across the UK. With 1500 monopoles operated by Arqiva (Arqiva, 2017) and the gradual shift towards 5G, it is very important for the structure of the monopole to be of excellent quality, which in turn, will improve the final output signal. Other members of my group are assessing properties of the monopoles such as wind loading, vibrations, foundation and the structural integrity of the monopole. The aim of the entire project is to improve the serviceability of the monopole structure for telecommunications uses in the future.

1.4. *Group objectives*

Structural Properties

This section relates to determining the effect of the monopole's natural frequency and how it varies is important to determining its final performance metric. The natural frequency is determined by stiffness, damping and mass.

- Isolate natural frequencies; consider the effects of varying antennae; determine fatigue

Reducing Effect of Wind Loading

Forces from wind can be considered lift or drag forces. Lift forces can activate the natural frequency and the drag forces can cause large deflections at high speed, which can greatly affect the integrity and cause damage to the monopole.

- Show that wind loading causes monopole vibrations; determine deflection of monopole; investigate vortex-induced vibrations (VIV) and how to mitigate them

Serviceability and performance of structure

Investigate performance of monopole with various wind conditions, which includes my section of investigating the integrity of the output signal.

- Carry out cost-benefit of structural health monitoring system; determine to what extent wind loading has on output signal

2. Literature review

In examining potential solutions to the persistent problem of the serviceability of a monopole being affected by internal or external conditions, it is important to delve into a wide range of literature that will help broaden our horizons as to both what the potential problems may be and how to mitigate these problems as easily, cheaply and effectively as possible.

2.1. Mast rotations and antenna performance

A paper by E.J. Rees (2009) details the correlation between mast rotations and the performance of the corresponding antenna. It states that guyed masts which hold transmission antennae are flexible structures that rotate under wind load. This rotation has the effect of reducing coverage in the target area, and the severity of this reduction will depend upon the magnitude and direction of the wind (i.e. a vector), the structure of the guyed mast, the antenna and the target population.

For the case of a digital signal, as opposed to an analogue one, a reduction of coverage could result in a complete loss of signal for some users. This is because the integrity of a digital signal must be completely preserved, as every bit (binary digit) of the signal must be correct or else the receiver will get no signal. For analogue signals, this is not the case, as a high integrity is only preferred, rather than essential. With a reduction of coverage, the receiver will only receive a diminished signal rather than no signal at all.

The paper describes a case study at Winter Hill mast north of Manchester due to this mast having the largest population coverage of any other structure in the Arqiva portfolio. Most of the population in this coverage area lived within the north-east and south-west quadrants. The greatest proportion of households would be affected by south-westerly winds. The aim of this paper is to present the findings of this study.

Turbulence intensity varies with height above ground level, aerodynamic roughness and the length of the fetch in the wind direction. The study described in the paper uses the average value for turbulence intensity in the top third of the mast, as the fluctuation near the top of the mast will be influenced almost exclusively from gusts in that area and any gusts in the lower two-thirds will have a negligible effect. For the twelve directions featured in the study, the turbulence intensity varies little, ranging from 0.093 to 0.117.

To calculate the convolution integral, a relationship between the hourly mean and gust wind speeds needed to be established. The following links the loaded length to the duration of the static gust:

$$Gust\ duration, t = \frac{1.5a}{V_0}$$

Gust wind directions for the twelve directions or interest ranged from 1.5 to 1.9 seconds. A gust factor may be derived from the previous gust duration. In the UK, this gust peak factor as a function of gust duration may be derived:

$$g_1 = 0.42 * \ln(\frac{3600}{t})$$

Using these equations gave gust peak factors ranging from 1.29 to 1.33 for the twelve directions. With this new information, a convolution integral may be calculated.

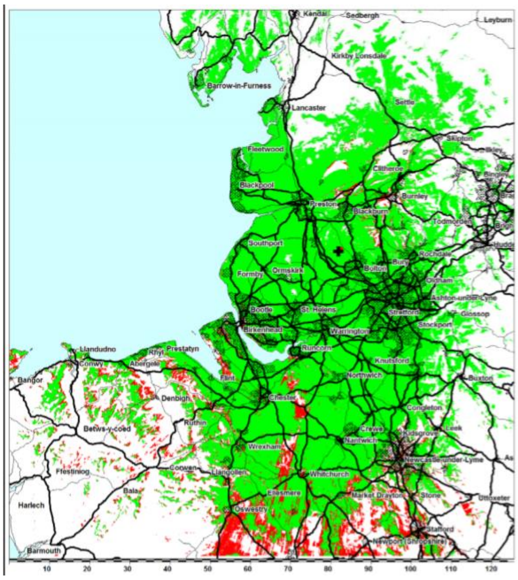

Figure 2: Winter Hill coverage map for south-westerly (41°) winds with a 1.4° mast rotation, where green regions represent a retained signal whereas red regions represent a lost one (Arqiva, 2007)

The findings of the report show that there does indeed seem to be a correlation between wind direction and loss of coverage. In the image, it shows that a south-westerly blowing wind induces a significant loss of coverage within the south-western quadrant and minor signal loss within the north-eastern quadrant, with little to no effect in the north-west or south-east quadrants.

With south-westerly winds, the antenna will be pointing towards the ground at the south-west and towards the sky at the north-east, which explains why some customers in these regions may be losing signal. Users in a direction normal to the direction of the wind shouldn't be affected.

In response, two additional guidelines were established for masts:

- 99.9% population coverage, 100% of the time
- 99.9% availability, for 100% of the population

This means that a tower must be able to serve at least 99.9% of its receivers at all times, and that any given customer must be able to receive service at least 99.9% of the time.

2.2. Ionospheric propagation and the relationship between height of antenna and effectiveness of communications

A useful paper by R. Dean Straw and Gerald L. Hall (1999) attempts to find a correspondence between the physical height of an antenna and its effectiveness with communication. Particularly, the paper focuses on horizontally-polarised antennae at heights of 35, 70 and 120 feet above ground at short-wave frequencies as well as some background on how high-frequency radio waves may use the Earth's atmosphere to travel long distances. Vertically-polarised antennae are not considered in this paper due to their relatively reduced effectiveness.

Communications in the high-frequency (HF) spectrum over distances greater than around 15 to 25 miles must send transmissions through the Earth's ionosphere. The high-frequency spectrum is defined by the frequency range of 3 to 30MHz (megahertz). The region of interest presented in this paper is known as the F Layer of the ionosphere, existing at approximately 130 to 260 miles above the surface of the Earth. The interesting property of the ionosphere is that it will refract and bend radio waves. The region and amount of ionization of the F Layer depends upon many factors and its exact state is considered extremely varied. Some factors may include latitude, the time of day and the current season. The F Layer disappears at night and at periods of low solar activity due to lack of ultraviolet energy required to sustain it.

Radio waves typically travel in straight lines with a slight tendency to bend downwards due to refractions in the air. The amount of bending depends upon the frequency of the wave and the intensity of the ionization levels of the atmosphere. For distances over 15 to 25 miles, it is simply not possible to communicate with a direct path due to the curvature of the Earth. For longer distances of hundreds or possibly thousands of miles, it is necessary to utilize the radio waves' property to curve slightly downwards to achieve this. The HF band is unique as frequencies outside the 3 to 30MHz range do not portray consistent results during ionospheric propagation.

An important consideration of transmitting radio waves through the ionosphere is that the angle of incident must be in the correct range. If the angle is too high, then the refraction of the wave will only be small, causing the wave to travel into outer space instead of refracting back towards the Earth. As the angle is lowered, there will be a threshold at which the transmitted wave will begin to return towards Earth. A smaller angle of incident will correspond to the wave returning to Earth at a larger distance.

In theory, if a wave travels at an angle of 0º (tangential to the Earth's surface), the maximum distance that the wave can travel is around 2500 miles. However, the Earth can sometimes act as a reflector of waves coming in from the ionosphere, so a wave may be reflected into the ionosphere a second time, causing the wave to be further propagated to an even further point. One of these iterations of the signal entering the ionosphere and coming back to Earth is known as a *hop.* A significant loss of signal occurs with each hop as the ionosphere absorbs energy from the wave. While in theory, as many as 4 or 5 can occur under certain circumstances, it is not feasible to expect more than 2 or 3, which is considered normal. Due to the nature of these hops, it is possible for a signal to travel over many thousands of miles instead of merely being limited to the range of a single hop.

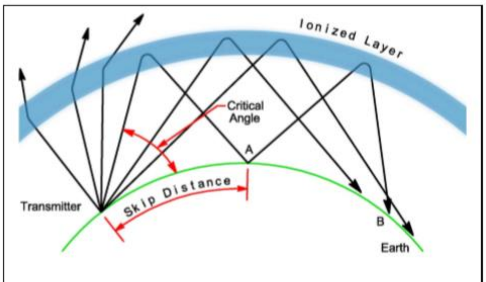

Fig 2—Behavior of radio waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to return to Earth and are lost to space. Waves entering at angles below the critical angle reach the Earth at increasingly greater distances as the angle approaches the horizontal. The maximum distance that may normally be covered in a single hop is 2500 miles. Greater distances may be covered with multiple hops.

Figure 3: Diagram of refraction of HF waves in an ionized layer for various angles of incidents showing incidents with one and two hops (Straw, R.D., Hall, G.L, 1999)

In this study, a simple horizontal half-wave dipole antenna is used as a performance standard to which alternate systems may be compared. As the Earth reflects HF radio waves, it is modelled as a perfect reflector in this experiment. The waves reflected from the Earth may combine in some way with waves emitted from the antenna at some angle above the horizontal.

At some angles, the reflected wave and the emitted waves will be exactly in phase, where constructive interference will occur, resulting in a wave which is the sum of its two constituent waves. On the other hand, the two waves may be completely out of phase, where destructive interference will occur, causing the resulting wave to be equal to the difference between the two.

The angles at which the maxima and minima occur depend on the antenna’s height above ground. This height is not measured in absolute units, such as metres or feet, but rather by wavelength or the signal emitted. A constant physical height (such as 70 feet) will represent different electrical heights at different frequencies. A height of 70 feet represents one wavelength of 14MHz, two wavelengths of 28MHz and half a wavelength of 7MHz.

For the experiment, a Yagi beam antenna is used. The following plot varies the angle of transmission from 1 to 30º and shows the percentage of time that the 14MHz band is available for communication from Boston, Massachusetts to Europe. In addition, there are three extra plots representing Yagi antennae at heights of 35’, 70’ and 120’ and showing their gain, in decibels (dB).

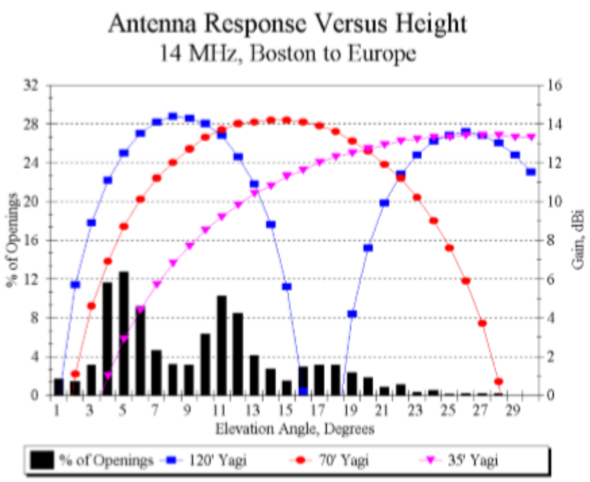

Figure 4: Plot of elevation angle versus time availability and elevation angle versus gain for various wavelength heights (Straw, R.D., Hall, G.L, 1999)

The 120’ Yagi seems the best choice, but is greatly diminished at higher angles, so the 70’ Yagi could be justified to be the best overall choice, but only above a certain angular threshold. For an antenna of a specific frequency, the height (in terms of the signal’s wavelength) and its angle of elevation play a crucial role in the transmission of signals, especially over longer distances.

2.3. *Electromagnetic interference between antennae and their underlying structures*

An article appearing in the 2nd International Conference on Microwave and Millimeter Wave Technology Proceedings by Wang Sheng and Lee Erping (2000) details the possibility of electromagnetic interference between a communications antenna and its supporting tower. They propose that such interference requires special attention during the design phase to properly control any potential effects the interference may induce.

The study conducted in the paper attempts to model the effects of electromagnetic interference for antennae atop metallic support towers using a simulation. These simulations predict the radiation levels in the antenna. The studies may aid in the design of new electronic systems in the future.

The study aims to access the interface of the antenna support tower on the antenna radiation pattern at specific frequency bands. The study also aims to identify the worst-case scenario for antenna coupling and to propose possible solutions to reduce it. The electromagnetic field strengths at critical zones are also presented.

The radiation pattern of an antenna can be derived by applying some voltage source and applying the following equation to compute the field:

$$\vec{E}(\vec{r}_0)=\frac{jk\eta}{4\pi}\frac{\exp(-jkr_0)}{r_0}\times\{\int_L[(\hat{k}\bullet\vec{I}(s))\hat{k}-\vec{I}(s)]\exp(j\vec{k}\bullet\vec{r})ds$$
$$+\int_S[(\hat{k}\bullet\vec{J}_S(\vec{r}))\hat{k}-\vec{J}_S(\vec{r})]\exp(j\vec{k}\bullet\vec{r})dA\}$$

Figure 5: Equation used to calculate the radiation pattern of an antenna (Sheng, W, Erping, L, 2000)

The experiment is conducted using two pairs of Yagi antennae mounted on top of the tower. One pair are 3-element antennae, operating at the VHF (very high frequency) band (typically between 30MHz and 300MHz), whereas the other pair are 5-element antennae, operating at UHF (ultra high frequency) band (typically between 300MHz and 3GHz). The antennae are all given a voltage of 1V with a coaxial line resistance of 50Ω.

The 3-element antennae are given the labels Antenna 1 and 2 respectively. The 5-element antennae are given the labels Antenna 3 and 4 respectively. The radiation patterns for antenna 1 (VHF) are simulated in the range 30MHz to 80MHz and the patterns for antenna 3 (UHF) are simulated in the range 255MHz to 400MHz. Below are the H-plane and E-plane radiation patterns for antenna 1 in the VHF range at 30MHz and 80MHz.

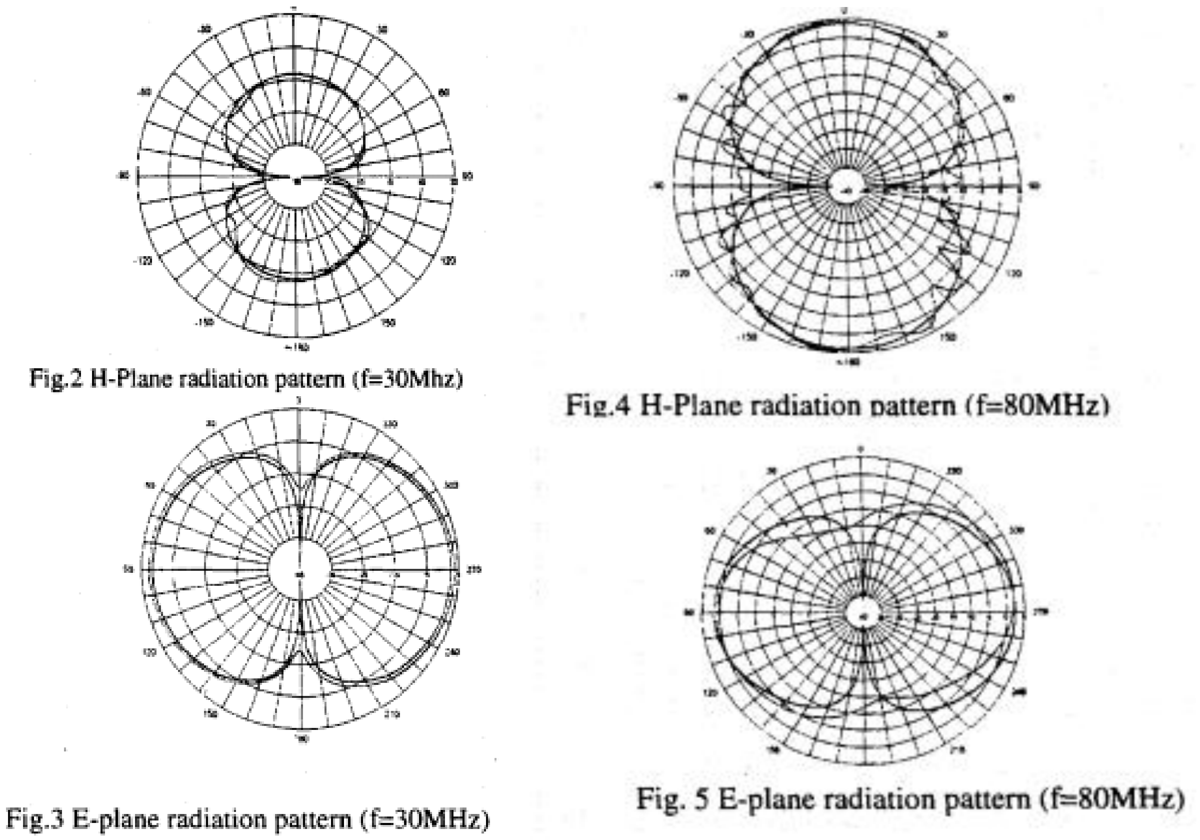

Fig.2 H-Plane radiation pattern (f=30Mhz)

Fig.4 H-Plane radiation pattern (f=80MHz)

Fig.3 E-plane radiation pattern (f=30MHz)

Fig. 5 E-plane radiation pattern (f=80MHz)

Figure 6: Radiation patterns for antenna in the VHF range (Sheng, W, Erping, L, 2000)

The figure shows that for the VHF band, the tower will slightly affect the antenna radiation patterns, but less so in the 30MHz case. On the other hand, for the UHF antenna, the effects of the tower interference are much more severe. At the higher band, the E-plane pattern is mainly affected by the antenna, but the H-plane pattern is mainly affected by the tower itself.

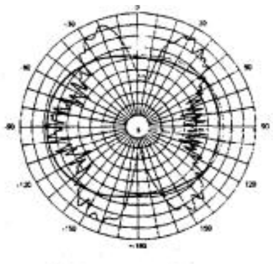

Fig. 6 H-plane radiation pattern

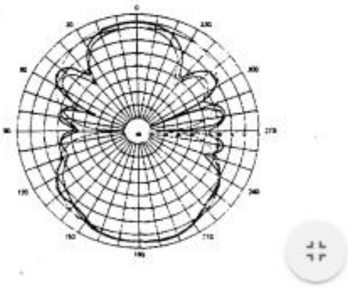

Fig 7 E-plane radiation pattern (f=255MHz)

Figure 7: Radiation patterns for antenna in the UHF range (Sheng, W, Erping, L, 2000)

The final part of the study relates to antenna coupling. The two couplings are as follows: antenna 1 transmits and antenna 2 receives, antenna 3 transmits and antenna 4 receives. When the antennae are cross-polarised, the coupling is less than if they were co-polarised. To reduce coupling, the antennae should be set up orthogonally.

In the article's conclusion, the authors deduce the following conclusions from their studies: the effect of the E-plane and H-plane components of the radiation pattern depends largely on the operating frequency, but also may be affected by the azimuth and elevation angles. Sometimes, the tower itself may affect the radiation pattern.

For the two VHF Yagi antennae, the coupling can be as high as 0.1465 at 45MHz during co-polarisation, but during cross-polarisation, the maximum coupling obtained was $3.64 * 10^{-4}$. For the UHF band, the maximum coupling obtained is significantly higher at 0.0496 with a frequency of 345MHz. Polarisation of the antennae is obviously considered a very important factor in the context of this study.

This study outlines some very important considerations for my own project. Specifically, if an antenna transmits at too high a frequency, then due to its irregular radiation patterns, the integrity of the signal may not be very good, possibly leading to a very poor output signal in the case of analogue or a complete loss of service in the case of digital.

3. Theoretical background and experimental work

To understand the purpose and outcomes of this report, it is very important to have a solid grasp of the underlying theoretical concepts paramount to the results presented.

The first key concepts essential to understand relate to analogue radio signals, specifically AM (Amplitude Modulation) and FM (Frequency Modulation), followed by an understanding of digital signals in both radio and television, followed by a description of an Android application used to measure internet speeds over time, which will be utilised in the following section.

3.1. Amplitude Modulation

Amplitude Modulation, or AM, as it is often shortened to, is a very simple method for transmitting audio over distances. The fundamental concept behind AM is that a fixed high frequency sinusoidal signal, known as a carrier wave, is sent from sender to receiver. For the sender to transmit actual information, in the form known as a modulating signal, the information present in the modulating signal is modulated onto the carrier wave by varying its amplitude. The final output signal is known as the modulated carrier.

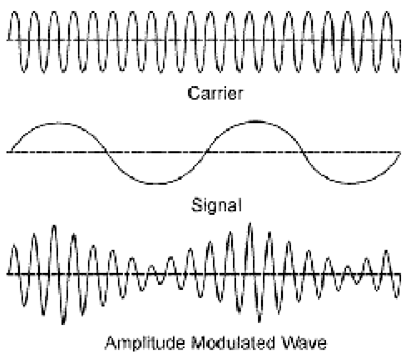

Figure 8: Diagram visualising the concept of Amplitude Modulation (Davis, L., n.d.)

The final modulated signal has the desired signal data encoded onto the carrier wave using the amplitude to represent the waveform of the required signal. This is done as higher frequency waves can travel further distances through the air than low-frequency ones, making the information able to travel much further.

Once the modulated signal is received, it must be demodulated back into its original information signal. This can be done with a very simple low-pass filter, which removes the high-frequency component represented by the high-frequency carrier wave while retaining the low-frequency components representing the original information signal. The functionality of this low-pass filter can be seen in the following diagram.

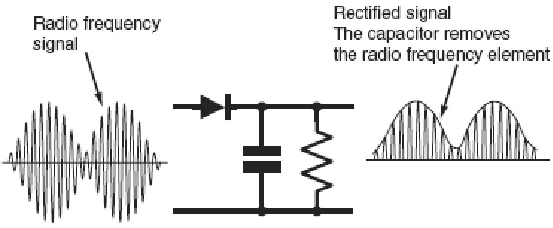

Figure 9: Amplitude Demodulation using low-pass filter (Poole, I., 2008)

Amplitude Modulation is extremely trivial to implement, often requiring only simple hardware. However, a major caveat of AM is that its noise will greatly affect the output signal as the actual information is encoded in the signal's amplitude, and as noise largely affects the amplitude, the integrity of the signal may be greatly affected a lot of the time.

The signal of an amplitude modulated wave has an electric field E at any given point which varies across time with the following expression:

$$E = E_0(1 + m\cos 2\pi f_s t)\cos 2\pi f_c t$$

Equation 1: Equation for electric field E for an AM wave

where m is a constant of modulation, between 0 and 1, and E_0 is a constant (Isaac Physics, n.d.).

There exist specified frequency bands on which station operators are authorised to transmit. All radio signals will contain sidebands due to the modulation process. This means that the final modulated signal will contain frequencies slightly higher (upper sideband, USB) and slightly lower (lower sideband, LSB) than that of the carrier frequency. For interference between radio channels to be minimised, each broadcast must be given a specific bandwidth of which the length is equal to twice the sideband length, or the difference between the lower and upper sideband lengths.

In theory, if an arbitrary jurisdiction decided to allow radio operators to broadcast AM radio in the range of 500 – 1000 kHz with a 5 kHz sideband, that would mean that each broadcast would require 10 kHz of bandwidth, so in this case there may only be up to 50 stations broadcasting at any given time without interference.

In the real world, there exist three main spectrums for AM transmission: long-wave (low frequency, LF), medium-wave (medium frequency, MF), and short-wave (high frequency, HF).

In various countries, frequency bands will be agreed upon by some governing body, which is Ofcom in the United Kingdom and the Federal Communications Commission (FCC) in the United States. In the FCC's document regarding frequency allocations (Federal Communications Commission, 2017), it details various frequency bands ranging from VLF upwards in both the US and other regions of the world.

VLF is almost exclusively reserved for crucial communications functions and not for general broadcast. The band from 9 to 11.3 kHz is reserved for meteorological and radio navigation. The first general-purpose broadcasting band is from 148.5 to 255 kHz, in the low frequency range, but this only applies in Region 1 (Europe, Africa and some parts of Asia) and not in the United States. For the mid-frequency band, it is typically between 530 and 1605 kHz, but will vary slightly by region. Finally, for the high-frequency case, broadcast is allowed in a few select bands, such as 2.3 to 2.498 MHz, 3.2 to 3.23 MHz and 7.3 to 7.4 MHz (Federal Communications Commission, 2017).

3.2. Frequency Modulation

In a very similar fashion to amplitude modulation, frequency modulation also makes use of a carrier wave and an information wave. However, the information contained in the modulating wave is encoded into a frequency spectrum with a central value equal to the value of the carrier wave. Therefore, the final modulated signal is not of fixed frequency, but fixed amplitude, with the information in the modulating wave being encoded as a frequency value rather than an amplitude value. This is better demonstrated in the following diagram.

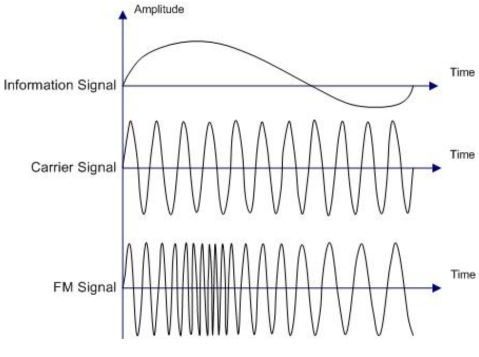

Figure 10: Diagram for Frequency Modulation (Pediaa, 2015)

In a similar fashion to AM, there will also be sidebands present, but in the case of Frequency Modulation, these are a feature of the modulation rather than undesirable. The lower sideband represented by the lowest present frequency will represent the minimum value of the information signal and the higher sideband representing the highest present signal will represent the maximum value in the information signal. The average frequency signal present will naturally represent the average value of the information signal.

While an Amplitude Modulated signal can travel a longer distance, especially at night when there is minimal ionospheric interference, the distance at which a Frequency Modulated signal can travel is much more local. On the other hand, an FM transmitted signal is generally of much higher quality due to its underlying information being encoded in the transmitted frequency, rather than amplitude, making the signal far less vulnerable to noise, which typically alters a signal's amplitude rather than its frequency.

One disadvantage of FM over AM is that it is also much more difficult to set up, requiring a significantly more complicated setup for both transmitting and receiving. FM also tends to occupy much more bandwidth, resulting in far fewer channels in a given frequency spectrum.

The bandwidth occupied by FM signals varies for different applications across various frequency ranges. For any given FM signal, there exists a specific deviation, such as ±5kHz, which states how much the frequency will deviate from its base frequency. In this case, the total bandwidth occupied by the FM signal will be equal to 10kHz, which is the difference between the signal's maximum and minimum frequency values.

Broadcast stations typically operate in the range of 88.5 to 108 MHz, with typical deviations around ±75kHz. This is called Wideband FM (WBFM) and the bandwidth allocated is typically 200kHz (Poole, I, n.d.). This means that for any given channel, there must exist a gap of at least 200kHz (0.2 MHz) between the channel and its adjacent channels on the frequency spectrum. If there exists a hypothetical channel at 88.5 FM, then the next available channel must be no lower than 88.7 FM to avoid interference.

A higher bandwidth would naturally imply a higher quality of signal at the expense of allowing fewer broadcasts on a given spectrum. An alternative exists called Narrowband FM (NBFM), utilising deviations of only around ±3kHz, allowing more broadcast transmissions at the expense of the quality of the signal (Poole, I, n.d.).

3.3. *Analogue television*

Although discontinued in the UK and much of the rest of the world, it is still important for us to understand how analogue television functions as a potential transmission medium, which was heavily utilised in the past. This will also aid us in our understanding of digital television. The signal that is received by an analogue television set is known as a composite video signal and can be transmitted using radio waves, typically within the VHF spectrum (Very High Frequency), up to 300 MHz and the UHF (Ultra High Frequency) spectrum from 300 MHz onwards. Sound is typically handled separately (Brian, M, 2001a).

In the United States, the FCC allocated 3 separate bands for certain TV channels in 6MHz chunks. 54 to 88 MHz corresponds to television channels 2 to 6, 174 to 216 MHz corresponds to television channels 7 to 13 and finally, within the UHF spectrum, 470 to 890 MHz corresponds to channels 14 to 83 (Brian M, 2001a).

The composite video signal for a colour transmission is a single signal with all of the required components embedded onto it. These consist of the luminance signal, controlling the intensity of each pixel, the chroma signal containing the colour information for each pixel and the synchronisation signal, which controls the scanning of the signal on the display, or in other words, used to determine where the pixel should be located on the screen (National Instruments, 2018).

In the case of a purely black and white television, there will be no chroma component, only a luminance signal and the synchronization signal. The waveform for such a signal looks like the following.

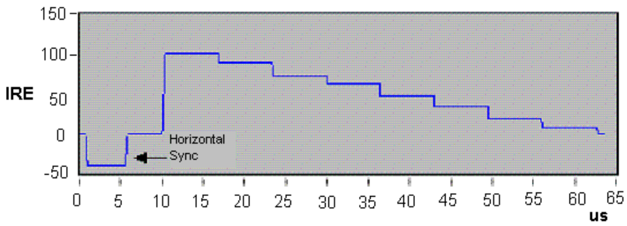

Figure 11: Y Signal, a component of a complete composite video signal (National Instruments, 2018)

This signal component is known as the Y Signal of the final composite signal and is used to describe the light intensities across the horizontal line. The horizontal sync component is a specific pre-defined voltage and is used to signal that the current line is complete and to begin preparation for the next horizontal line.

In addition to defining the light intensity for each pixel in the row, there is also an (optional) chroma component that can be superimposed onto the Y Signal if colour is desired. This chroma signal in isolation can be visualised below.

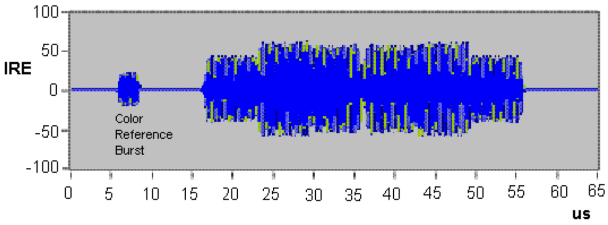

Figure 12: C Signal, used to encode colour information in a television signal (National Instruments, 2018)

The colour information for each pixel in a given row is encoded within the signal, with a short colour burst preceding, which is only used for testing purposes and is not considered part of the final signal.

The final signal, known as the Y/C signal or S-video, is created by taking the arithmetic sum of the two signals, Y + C.

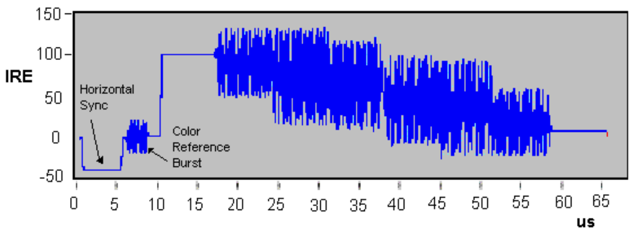

Figure 13: Y/C Signal, final signal to be interpreted by television receiver (National Instruments, 2018)

The final signal consists of the horizontal sync signalling a new line, followed by a 'back porch' and a colour burst, followed by the signal representing the arithmetic sum of the colour and intensity signals (National Instruments, 2018).

3.4. *Digital radio and television*

While AM and FM analogue radio is still widely in use today, a new alternative has become a very viable option in recent years, which is digital radio. The main idea behind digital radio is that information is transmitted and received as a digital signal, or simply a sequence of binary digits in the form of 1s and 0s. This contrasts with an analogue signal, which is simply a continuously-varying voltage signal. The advantage is that a given transmitted signal will be interpreted in the same way by two independent receivers provided the data reaches it uncorrupted. Digital signals often give very high sound quality as they are much less prone to interference than their analogue counterparts. However, you either get the signal or you do not; there is no middle ground like there is with analogue AM or FM signals (Ramsay, R, 2011).

In addition to the sound signal, digital radio also allows for the transmission of metadata for the broadcast, which may consist of song title, album art or news feed, provided the digital radio receiver contains a display. Radios may contain on-board storage allowing for pausing and rewinding of radio by storing data on the storage for some period (Ramsay, R, 2011).

In the UK and much of Europe, including France, Germany and The Netherlands, the preferred standard for digital radio is known as DAB, or Digital Audio Broadcasting. A newer version of DAB is called DAB+, introduced in 2007, which uses AAC encoding rather than MP3 encoding for a higher-quality signal. The advantages of DAB over FM are: more bandwidth allowing more stations, its higher sound quality and its increased energy efficiency. On the other hand, digital signals tend to have less range than analogue signals (Best Radios, 2017).

DAB typically operates on part of the VHF spectrum in various ‘blocks’, which range from Block 5A with a frequency of 174.928 MHz up to Block 13F with a frequency of 239.200 MHz. Channels 11B (218.640 MHz) to 12D (229.072 MHz) can be multiplexed for general-purpose broadcasting allowing for many different radio broadcasts to exist on the same frequency and be switched to (i.e. multiplexed) at will. If quality is desired over abundance, then a given channel will allow fewer channels in its multiplex, but if abundance is required, then more channels will be allowed at the expense of quality (Electronics Notes, n.d.).

In much the same fashion that digital radio has become a viable alternative to analogue radio, there is also the medium of digital television. The key difference being that analogue television has now been completely phased out as of the Digital Switchover of 2011/12, unlike with radio, where both analogue and digital radio broadcasts continue to coexist as of 2018.

In a very similar way to digital radio, the new digital television works by transmitting binary data in the form of 1s and 0s. If the data is uncorrupted, the receiver will be able to perfectly reconstruct the original broadcast exactly as it was intended. In addition, digital signals do not degrade over distance unlike their analogue counterparts. Digital transmissions also require less bandwidth, resulting in potentially more channels in a given frequency space (Miller, M, 2009).

In the United States, the FCC allocates broadcasters 19.39 Mbps (Megabits per second), which is equivalent to 19,390,000 bits of information per second. A broadcaster is also given the option to split up this bandwidth to broadcast multiple sub-channels, in a process known as multicasting. For example, a broadcaster on channel 20 could set up channels 20.1 and 20.2, each having a bandwidth of around 9.7 Mbps. The reason for this is that there are several formatting options for a digital television transmission (Brain, M, 2001b).

The most common ones are 480i, 480p, 720p, 1080i and 1080p. In this context, ‘i’ stands for interlaced scan and ‘p’ stands for progressive scan. With interlaced scan, half of a complete frame is sent 60 times per second, meaning a complete frame will be received 30 times per second, for an effective refresh rate of 30Hz. With progressive scan, a full frame is received 60 times per second, resulting in a true 60Hz refresh rate. The numbers preceding represent the vertical component of the resolution of the resulting image. 480i is equivalent to analogue television and represents a resolution of 704x480 pixels at an aspect ratio of 4:3 (the ratio of the number of horizontal pixels to the number of vertical pixels). This format is known as standard definition, or SD. 720p, 1080i and 1080p are known as high definition formats, with a new aspect ratio of 16:9. Therefore, they operate at resolutions of 1280x720 and 1920x1080 respectively (Brian, M, 2001b).

In recent years, the next logical leap in resolution, known as ultra-high definition, or UHD, has gradually been gaining popularity. This format operates on the same 16:9 aspect ratio as its HD predecessor, but has a higher resolution of 3840x2160, with the format being known as 2160p, or also commonly referred to as 4K, in reference to its horizontal component being close to 4000.

In the coming years, there is expected to be dramatic advances in this technology with the eventual introduction of 8K television and the phasing out of commercial analogue radio in favour of an entirely digital solution.

3.5. Design of an internet speed tracker application

In preparation for the experiment I will be conducting in the next segment, I have developed an Android application designed to measure Internet speed over time. It works by establishing a connection and downloading a small file over the Internet. It then will determine the size of the file, in bytes. Before the file starts downloading, the program will take note of the current Unix time (in milliseconds), and will take note of the time after the file has finished downloading. Unix time is defined as the number of seconds that have elapsed since 00:00, January 1st, 1970, and is the standard metric used to measure time on a computer. It can also be extended to measure milliseconds and nanoseconds.

The time difference taken to download the file is the time at the end minus the time at the start, which is the time taken to download the file. With metrics for the number of bytes received and the time taken to receive them, the Internet speed between the two distinct time points can then be derived. Like velocity, we can only work out the speed between two points and not the instantaneous Internet speed, as that would require a infinitely small hypothetical timeframe.

The program gets a range of Internet speeds by running the download sequence 100 times and storing both the speed and the corresponding ending Unix time in a text file, which can be saved and analysed later. The speed will be stored as Kilobytes per second, which can be derived by dividing the number of bytes per second by 1024 (as there are exactly 1024 bytes per Kilobyte). It is necessary to store the Unix time with each sample as the Internet speed could potentially be inconsistent and data points may not be evenly-spaced in time.

```
@Override
protected String doInBackground(String... paramVarArgs)
{
    try
    {
        //Gets current time
        long startTime = System.currentTimeMillis();

        //Gets URL from passed arguments
        URL url = new URL(paramVarArgs[0]);
        HttpURLConnection con = (HttpURLConnection) url.openConnection();
        InputStream is = con.getInputStream();

        Bitmap bmp = BitmapFactory.decodeStream(is);

        Bitmap bitmap = bmp;
        ByteArrayOutputStream stream = new ByteArrayOutputStream();
        bitmap.compress(Bitmap.CompressFormat.JPEG, quality: 99, stream);
        byte[] imageInByte = stream.toByteArray();
        long lengthbmp = imageInByte.length;

        double numKB = (double) lengthbmp / 1024.0;

        long endTime = System.currentTimeMillis();
        long takenTime = endTime - startTime;
        double seconds = (double) takenTime / 1000.0;
        double KBPS = numKB / seconds;

        return Double.toString(KBPS);
    }
```

Figure 14: Android ASyncTask to measure Internet Speed

The program utilises the Android's ASyncTask functionality to perform the downloading process and calculate the Internet speed and returns this value to the main thread, where it can be appended to the text file and optionally displayed on the user's device. The user interface may also include a counter which displays the data point number currently being collected.

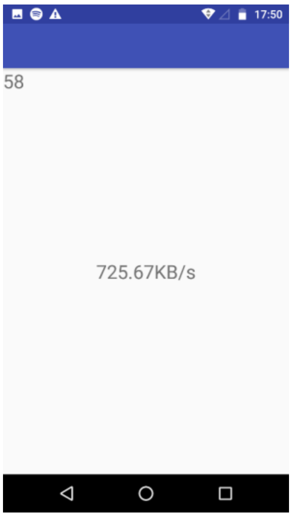

Figure 15: Testing the internet speed tracker application on a Wi-Fi network

In the above image, it shows the application in use over a Wi-Fi network. The 58 in the corner represents that the speed of 725.67 KB/s is the 58th speed sample to be collected out of 100.

The experiment to be conducted is to measure the mobile Internet speed from a monopole both while it is stationary and when it is undergoing a shake test, to see how the shaking, or a fast wind, could potentially affect the monopole's serviceability.

When the data has been gathered, it will be saved to a file called *internet_speed_test_{unix_time}.txt,* where *unix_time* is the measured Unix time (in milliseconds) recorded at the beginning of the program's execution. As Unix time is a monotonic value, this file name is guaranteed to be unique. The file structure is designed to store 100 tuples, with each tuple storing the Unix millisecond time at the end of the given test and the internet speed obtained (in Kilobytes per second) from the test respectively.

The data can then be imported into a Python or Matlab script where it can be used to make a graph showing internet speed measured over some time period.

Before the presentation of the results obtained from the monopole field trip, I have decided to test out the functionality of the application by measuring the typical internet speeds in a home environment using Wi-Fi rather than 3G/4G. The data obtained was imported into a Python program where it could be manipulated and displayed.

The first thing I did was to get the starting time of the experiment in Unix millisecond time, which was the first value in the first tuple of the data. I then subtracted this value from every time value contained in the file. This process effectively normalises the data by making the starting point for the time axis to be 0, rather than some arbitrarily large value which has little context. Graphing the time on the x-axis (in milliseconds) and the data on the y-axis (in Kilobytes per second), we get the following depiction for a typical scenario of internet speed over time using Wi-Fi in a typical home setting.

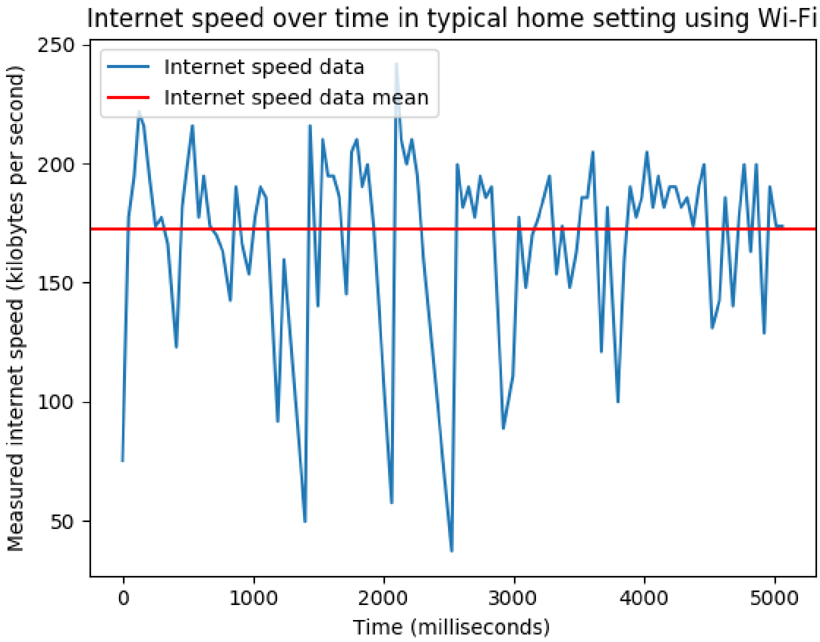

Figure 16: Depiction of internet speed over time using Python's matplotlib library

The results show that the effective internet speed at any given point in time is highly variable and fluctuates greatly. This is due to the thousands or possibly millions of different factors that can determine the internet speed at any given point.

Also, on the graph is a single red line depicting the arithmetic mean all the samples measured. While the data itself can be highly variable, the metric of an arithmetic mean can provide some sense of the expected measure of performance in a given timeframe.

4. Presentation of experimental or analytical results

The findings of this project can be characterised into two main experiments. The first of these is the investigation of how the integrity of an FM radio signal changes as the distance of the receiver increases. In this case, the FM receiver is an Android phone application that can record audio from radio stations. Recording an FM signal will automatically digitise it and retrieve its underlying information signal and save it to a file (specifically, the AAC format).

The second experiment consists of measuring the Internet speed over time from a monopole that is part of a wider mobile network. This will be achieved by using the custom-made Android application discussed previously. The process consists of downloading a small file from the internet, measuring the number of bytes received and the time taken to receive those bytes and using the information to calculate the effective speed. The previous process is repeated 100 times to get 100 distinct samples to plot a rough graph of internet speed over time.

4.1. Investigating the integrity of FM broadcasts over distance

The aim of this experiment is to assess how the integrity of an FM signal decreases the further away from the FM transmitter a receiver is placed. FM has been chosen over its AM counterpart as the effective range of an FM broadcast is far less than that of AM, making the gradual breakdown of an FM signal easier to visualise and assess.

The FM transmitter we are interested in is Kilvey Hill transmission station in Swansea, Wales and the broadcast we will measure is 96.4 FM The Wave (96.4 MHz). It is important to use a constant radio station as a control variable for all our tests.

Figure 17: Photo of Kilvey Hill transmission station taken from around 1km away

The distances we are interested in are 1km, 2km, 5km, 10km and 20km from this transmission tower. This can be visualised in the following diagram of concentric rings drawn on top of a map of the Swansea Bay area.

Figure 18: Concentric rings surrounding Swansea Bay representing distances of 1, 2, 5, 10 and 20km from Kilvey Hill Transmission Station (Courtesy of Google Maps and GmapGIS)

We are interested in measuring the signal at each distance and assessing where exactly we may need to start to consider using DSP techniques to rectify any problems and improve the overall integrity of the received signal.

The analogue signal is captured by the receiver and then digitised at a rate of 44.1 kHz, twice the believed maximum audible frequency for humans of 22,050 Hz. The Nyquist Theorem states that for a signal to be digitised correctly, the sampling rate must be at least double the highest frequency present in the signal. In this case, 44.1 kHz is enough to capture any audible frequency.

The following plots show a small visible sample of the waveform for each of the distances stated above, in ascending order. Each plot will be at the same scale (same number of samples across the graph). This is achieved by using the software package Audacity.

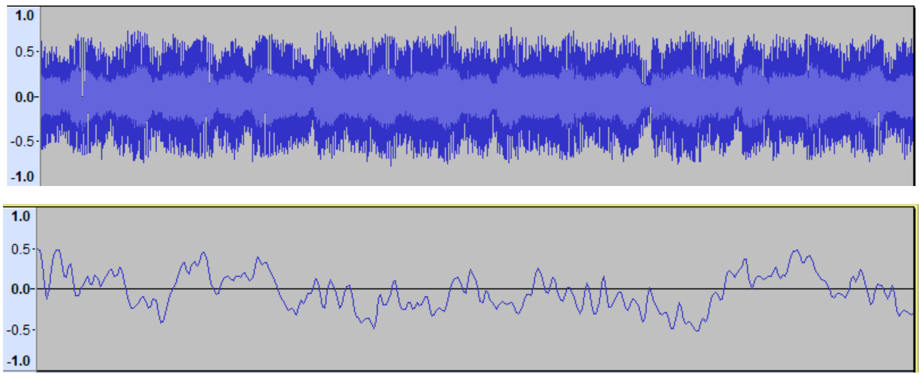

Figure 19: Entire waveform (top) and waveform sample (bottom) at 1km from transmitter

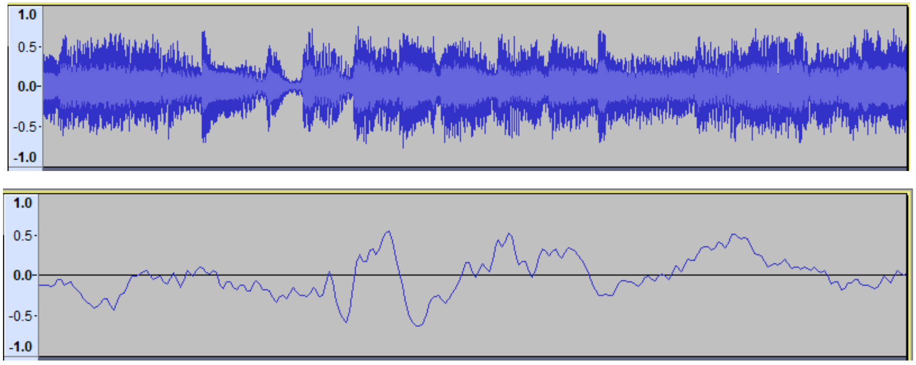

Figure 20: Entire waveform (top) and waveform sample (bottom) at 2km from transmitter

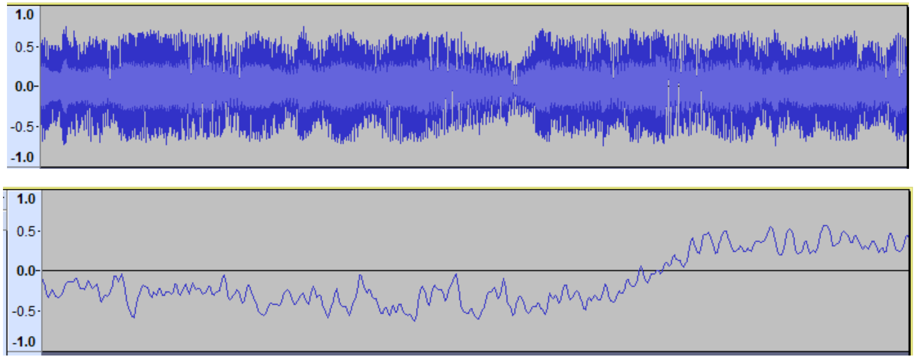

Figure 21: Entire waveform (top) and waveform sample (bottom) at 5km from transmitter

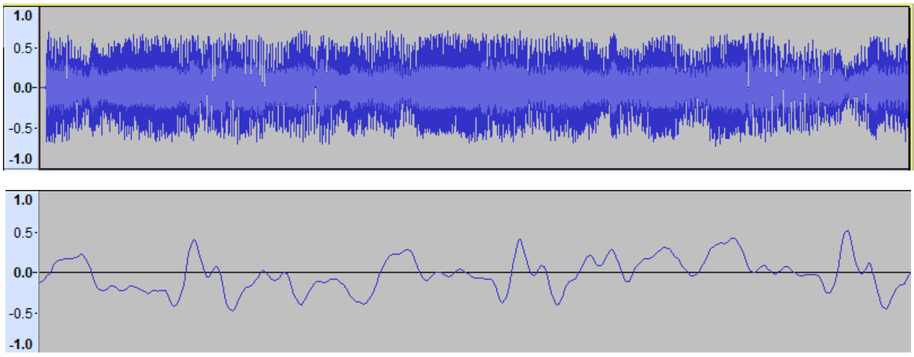

Figure 22: Entire waveform (top) and waveform sample (bottom) at 10km from transmitter

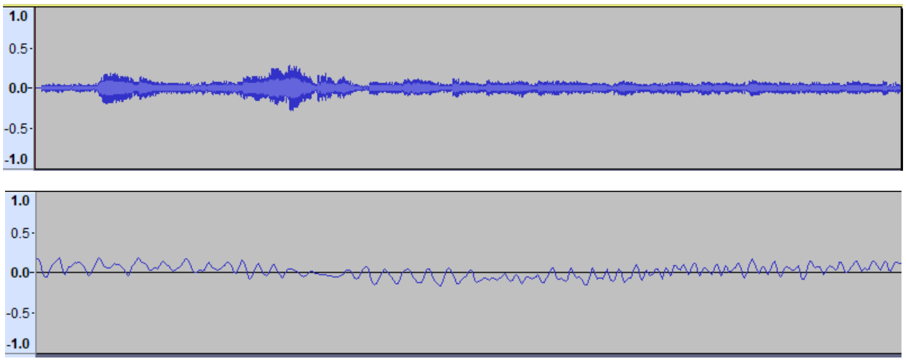

Figure 23: Entire waveform (top) and waveform sample (bottom) at 20km from transmitter

The integrity of the signal is barely different for the distances of 1, 2, 5 and 10 kilometres, and shouldn't require any additional action, but at 20km, the integrity breaks down dramatically. The amplitude of the signal is significantly less than the others and includes a great deal of noise not present in the others.

To improve the audibility of the signal, the first thing that could be done is to amplify the signal to bring its sample values up to the typical range expected from a high-integrity signal. After that, a digital filter could be applied to remove some of the noise present in the signal. While this solution is far from perfect and may remove some of the information contained in the signal, it should yield a net improvement to the integrity of the signal.

This desired post-processing can be achieved by using digital filters and amplifiers which can be defined programmatically using Python and applied to the samples contained in the signal, which has been pre-digitised at a rate of 44,100 samples per second. This work will be done in the following section.

4.2. Investigating how shaking of monopole affects internet speed

The aim of this experiment is to determine how well a monopole providing a mobile network can perform under unforeseen circumstances. To achieve this, I have made an internet speed tracker Android application that can measure the internet speed provided by the monopole over a short period of time. This works by downloading a small file and dividing the number of bytes received by the time taken to get a value for the Internet speed between two distinct time periods. This is repeated 100 times to produce a rough graph of speed over time.

The test will be conducted under two separate conditions, the first of which is under normal circumstances and should not produce any results that significantly deviate from speeds expected from a mobile network. The next test will occur simultaneously with the shake test to see how well the service can be retained when the monopole is standing at a slight angle. This test can roughly model the monopole being subject to fast winds and assesses how much the service may be affected during such occurrences. Under these circumstances, the service may be significantly affected, causing a drop in the average measured Internet speed, or possibly partial or complete loss of service.

The data was collected from Marley's Moor monopole in North Devon in the morning of the 3rd of May, 2018.

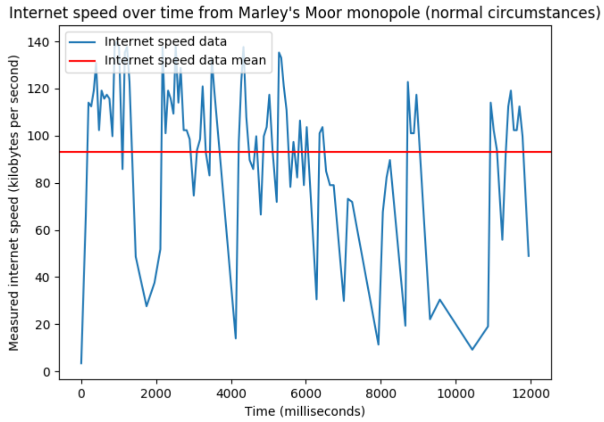

Figure 24: Internet speed at Marley's Moor over time under normal circumstances

The data shows that the effective internet speed varies greatly over time, very similar to the Wi-Fi test conducted previously. However, the average speed measured sits at around 92kB/s. This is very normal, and it is around what is expected from a monopole using current technology.

Now, we will compare and contrast the results obtained for the internet speeds during the shake test, which effectively simulates a light wind.

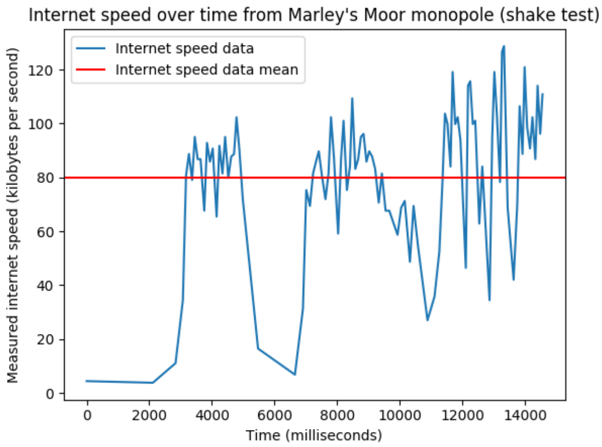

Figure 25: Internet speed at Marley's Moor over time during the shake test

The shake test reduces the average internet speed measured from 92kB/s down to around 80kB/s. From a light wind, we do not expect any significant drops in service, so these results are around what we should be expecting.

Another facet that is interesting are the two sharp drops in the first half of the signal data from around zero to two seconds in and at around six seconds in. Drops to near-zero values may be a consequence of a sudden loss of service, which should be expected from this test.

5. Discussion and conclusions

This section involves the critical analysis of all the elements presented in the previous section with additional interpretations. The first section is the discussion which contains some additional processing on the results previously obtained, such as filtering and amplifying of signals, and the relevant discussion of new ideas and interpretations.

The second section details important and relevant conclusions obtained from the results previously.

The third and final section is an advice piece to potential future research based on this project with suggestions on how to as research existing results further, as well as further ideas that may be worth investigating.

5.1. Discussion

The bulk of this discussion will relate to the results obtained in the first experiment, specifically, the results obtained when measuring FM radio signals at various distances from the source. The important facet here is to determine when the integrity of the radio signal becomes low enough to justify the implementation of additional post-processing.

For 1, 2 and 5km, the integrity is very good and largely consistent, and no additional action should be required. By 10km, the integrity is somewhat worse off with the overall signal looking considerably noisier than its lower-distance counterparts, but it may still be difficult to justify post-processing at this point.

However, at 20km from the source, the quality of the signal takes a very noticeable nosedive with a significantly decreased amplitude and large amounts of noise. We could attempt to rectify this by using a digital amplifier and a digital filter. This can be done in the Python programming language by exporting the signal data from Audacity and importing it where it may be altered appropriately.

A simple digital amplifier is to take each sample contained in the signal and to multiply its value by some amount. Naturally, this may result in some samples falling outside the -1 to +1 range. In this case, these samples should be clipped to their corresponding extreme value of -1 and +1 respectively.

Amplifying the signal obtained at 20km from the source by a factor of 2 yields the following:

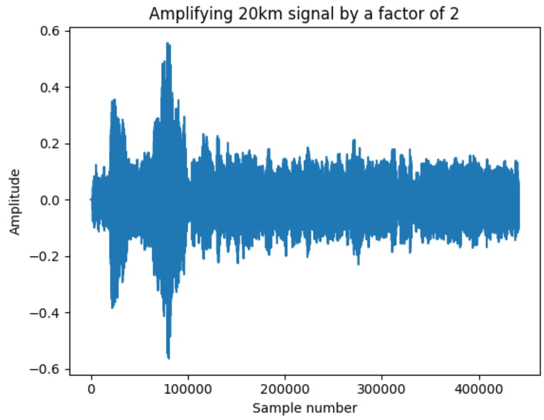

Figure 26: Signal received from 20km amplified by a factor of 2

The above shows that amplification of the signal goes some way into rectifying the issue of the lower amplitude present in this signal. However, the amplitude range is not quite as large as the signals received at shorter distances. In this instance, we could suggest an amplification of 3 or 4, but the ideal amplification factor will vary depending on the signal.

Amplifying the original signal by a factor of 4 yields the following result:

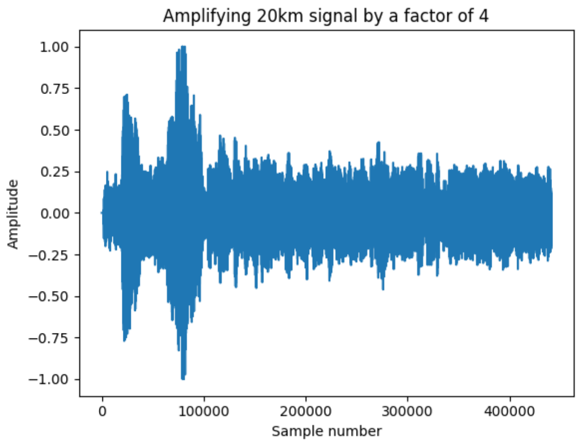

Figure 27: Signal received from 20km amplified by a factor of 4

In this plot, the amplified signal further resembles the other signals in terms of amplitude range. However, there is still a lot of noise present within the signal, which could be removed by using a digital filter. In addition, all samples with value exceeding +1 or preceding -1 are clipped to their respective limit. In this case, we will be using a low-pass filter to remove all frequencies that are higher than a specified cut-off frequency. A simple but effective low-pass filter is a two-term moving average filter. This works by taking the current sample and the previous one and computing the arithmetic mean of them and setting the sample to that value.

Algebraically, this may be expressed by the following equation:

$$y(n) = \frac{x(n) + x(n-1)}{2}$$

Equation 2: Equation for two-term moving average filter

For example, the 100th sample of the output will be the average of the 99th and 100th sample of the input. This process will be repeated for all samples in the input to calculate the new output, which will be smoother than the input.

This principle can be extended by having a moving-average filter for any number of terms. Of course, the more terms there are, then the more 'smoothed' the output signal will be, but more of the underlying information signal will be lost. In effect, the higher the number of terms, the lower the cut-off frequency for the low-pass filter.

Below is an unfiltered segment of the original signal which is 1000 samples long:

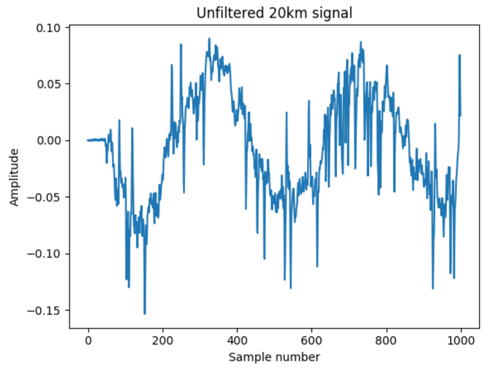

Figure 28: Unfiltered signal

Applying a two-term moving average filter on the above signal yields the following:

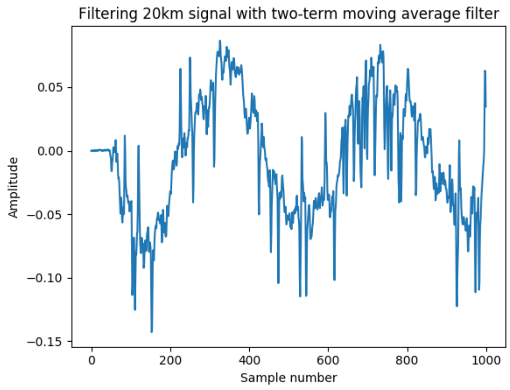

Figure 29: Signal after two-term moving average filter applied

In general, a k-term moving average filter can be described by the following equation:

$$y(n) = \frac{\sum_{i=0}^{k-1} x(n-i)}{k}$$

Equation 3: Equation for k-term moving average filter

In this instance, we can see that some noise has been removed from the original signal, but in this case, it would be advisable to continue with more terms. Using a four-term moving average filter yields the following:

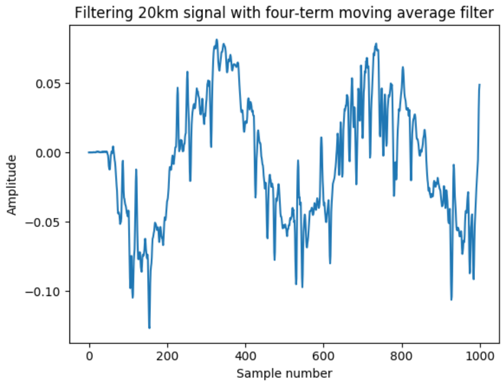

Figure 30: Signal after four-term moving average filter applied

The noise in the signal has been reduced, but at the expense of some information in the signal. If we kept going and implemented an eight-term moving average filter, we get the following result:

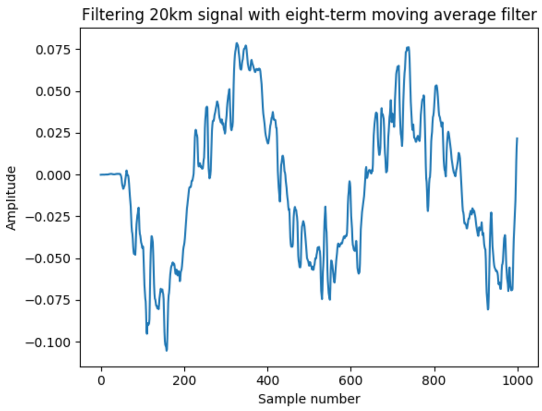

Figure 31: Signal after eight-term moving average filter applied

We can see a substantial decrease in noise in the signal, but what is also noticeable is that some of the higher frequency components present in the signal have also been filtered out.

It is important to find the right balance between how much noise is deemed acceptable in the signal and how much of the underlying information we wish to preserve. For this particular signal, it would seem that an eight-term moving average filter strikes a reasonably good balance.

In the extreme example of too much filtering, we could consider a 100-term moving average filter, which yields the following after being applied:

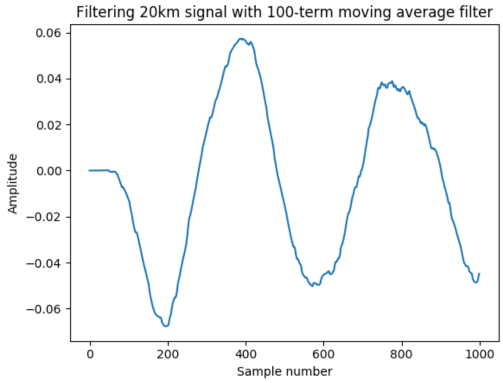

Figure 32: Signal after 100-term moving average filter applied

In this example, we can see that while there is practically no noise present in the above signal, almost all of the information has been lost, except for the extremely low frequencies.

20km may be too far to rectify fully the issues present in the signal, as a great deal of information will have been lost with distance. However, for shorter distances where the integrity has been reduced, but not quite nosedived, it may be extremely effective to amplify and filter, and the integrity of the signal could see significant improvements as a result.

It largely depends on the situation to what degree it is appropriate to amplify and filter by and may vary significantly.

5.2. Conclusion

For the FM receiver test, I conclude that while Digital Signal Processing methods may be effective under some circumstances, there is a point in which too much information has been lost from the signal and it is simply not possible to rectify the signal. On the other hand, certain techniques such as amplification and filtering can help a great deal in some circumstances. However, these vary significantly and can include distance, state of the transmitter and state of the receiver. The amount of amplification and filtering also varies and should be reviewed on a case-by-case basis. I conclude that the optimal amplification of the 20km signal is by a factor of 4 and the optimal number of terms in the moving average filter is 8.

With the monopole experiment, the results obtained are not quite as conclusive as with the distance broadcasting experiment. While the results did show a reduction in the average internet speed recorded over 100 samples, it is possible that it may have been a one-off fluke. While it is expected that deflections in the monopole should affect serviceability negatively, the deflections in the shake test were very small and we shouldn't expect any significant reduction as a result. However, the two big dips to near zero values during the shake test are very interesting and may be a result of a temporary loss of service.

5.3. Further research

This project contains many areas which could effectively be elaborated upon in future work.

More varied circumstances could be investigated relating to the FM transmission test. AM transmissions could be considered, in which data can be measured at different times of the day, as the distance of AM transmission varies as the amount of radiation in the ionosphere varies. Digital signals and television could also be considered. More precise distances could be measured, such as measuring in 1km increments between 10 and 20km, as that is the threshold where FM integrity begins to break down significantly. Simultaneous measurements can also be done to measure exactly the same signal at exactly the same time at different distances and being able to have a frame of reference when using DSP techniques to determine their effectiveness.

For the internet speed test, it would be helpful if there were more variables within our control. If the amount of deflection could be controlled, then much more varied and useful results could be obtained. More samples could be collected at once to get a more accurate picture of internet speeds in the longer term, as only 100 samples could very likely produce anomalies.

6. Project management

It is very important to plan a project effectively for the successful progress of goals and objectives over a long period of time, in this case over two University terms. A good project plan strongly correlates to a successful project and vice versa.

6.1. Project planning and execution

The project was undertaken in two main sections, corresponding to the first and second University terms of the current academic year. Each term had a different set of requirements to undertake to ensure the project progressed successfully and with as few problems as possible.

The first term was entirely related to planning rather than implementation, with careful consideration required to ensure that we entered the second term with a very clear idea of what needed to be done with the limited amount of time that we had. This was important as we only had an 11-week window in the second term to use University facilities for our project, so managing our time effectively was extremely important. The first term consisted of conducting weekly or bi-weekly meetings with the group and supervisor to discuss what we had done over the previous week and to formulate new objectives for the coming weeks. For each session, we took notes that would help us with various facets of our projects, such as general advice, email contacts and mathematical formulae. A log book was kept where crucial information discussed in meetings was written to help with the formulation of ideas relevant to the project.

Towards the end of the first term, it was important to plan what we were going to do in the second term and when we were going to do it. We could keep track of this by using a Gannt chart.

In the second term, work on the project officially began. At all times in the term, continuous research was carried out on both literature to discuss, and various sources to aid us in understanding concepts related to the project. Weekly meetings with our supervisor continued, with the same purpose as last term. In addition, we also planned a field trip to a monopole to collect data for our projects, under the supervision of Arqiva engineers. For this project, the data collected on the field trips were the internet speeds over time both while the monopole was stationary and when it was undergoing a shake test, effectively simulating wind.

The other part of my project relating to measuring FM signals at certain distances was done outside of University term time in the Swansea Bay area.

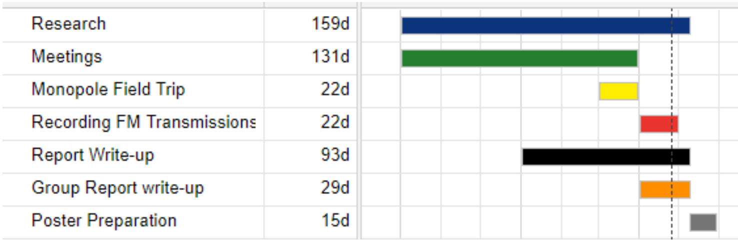

Figure 33: Project Gannt Chart (Courtesy of Smartsheet)

The Gannt chart outlines the exact events that should be carried out over the course of the project. The start date of the project is set to October 1st and the end date is set to May 9th with a poster day on May 29th.

At all times, research should be undertaken; whether that was reading literature to be used in the literature review or researching resources to aid understanding, it was important to gather resources and learning as much and as frequently as possible over the course of the project.

Another event that should be carried out were the weekly meetings with our supervisor. These meetings could only occur during term time, so the scope of these could only extend to the last Friday of March, when term finishes.

The months of March and April were set aside to collect data, specifically, for the monopole field trip and measuring FM signals from a transmission tower respectively. I decided to allocate entire months to these objectives to allow for any unforeseen circumstances. From January 1st onwards, the individual report write-up begun, with work on the group report starting from April 1st. After the individual and group reports were finished, then our group could focus on preparing for the final poster day on May 29th.

The project was completed well within the allocated budget, with the only expenses required relating to travel, such as a bus trip to get to a spot 20km away from the transmission tower.

6.2. Health, safety and ethical concerns

When undergoing the monopole tests, it is very important to wear PPE (Personal Protective Equipment), including a high-visibility shirt and a hard hat (provided by Arqiva), to both be visible and to protect the head from any potential falling objects. It is also important to make as little impact as possible so as not to disturb local wildlife or farmers during our visit.

During the measuring of FM signals outside of term time, it was important to make sure that I was not trespassing into any unauthorised sector to measure the signal and to remain exclusively in public areas at all times.

7. Contribution to group functioning

The overall group aim was to study monopoles, with some extension to allow for the study of other similar structures, such as transmission towers. Other members of my group were concerned largely with the mechanical and civil aspects of a monopole, such as structure, aerials, foundation and wind, whereas my project focussed on the final output signal, whether that was radio, internet or television.

On the monopole field trip, the work carried out was mutually beneficial to all members. The monopole shake test was undertaken primarily for the collection of data relating to monopole vibration, but simultaneously, I was able to collect my own independent results regarding internet speed over time. The shake test was helpful for me, as it loosely simulates a monopole's potential reaction to wind. Getting data for these circumstances will give me some idea of how natural conditions impact the serviceability of the monopole while also being beneficial to other members of my group for their own purposes.

7.1. Source, path and receiver concept

The entire group objective can be thought of as a sequence of elements used to describe the serviceability of a system, known as the source, path and receiver concept. Other members of my group were investigating the source and the path elements in detail, whereas I was investigating receiver elements.

The source section relates to the structure of the monopole and to investigate methods in which the integrity of the signal can be increased. This relates to investigating ways in which the structural integrity of the monopole can be improved, therefore improving the final signal.

The path section relates to the transmission medium that the signal relays across. In this specific case, this relates to the environment that may play a role in affecting the signal. This may include air interference, or the signal losing serviceability by travelling a long distance and through objects, such as buildings.

Finally, the receiver element relates entirely to the receiver of the signal (e.g. a radio or television) and is concerned with improving the integrity of the signal after it has already been received, using Digital Signal Processing methods such as amplification or filtering.

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