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Investigation into the Design & Manufacture of a GPS Based Tracking Camera

by

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Project submitted as part of the requirements for the award
of

BEng (Hons) Electrical & Electronic Engineering

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Declaration

I, Steven Woodford declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

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FORM OF CONSENT

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Abstract

The following document has been prepared in order to outline the work undertaken for the major project element of the BEng Electrical & Electronic Engineering. The purpose is to design and build a tracking camera system for use in trials activity at QinetiQ Aberporth. Following research into various techniques GPS technology is selected as the basis of this system, partly down to the area of operation and the challenges this incurs.

With this method chosen, the basic system operation will involve the transmission of a remote units GPS position back to the main unit wirelessly, a range and bearing between the two units can then be calculated, steering a camera accordingly to maintain the object within the camera FOV.

With the complexities encountered during the project, and the heavy dependency on software implementation for the chosen solution, the final system had to scaled back in terms of the scope. The software development was a steep learning curve, which had a knock on effect on the other tasks required.

The final system although not meeting the exact criteria set out, does offer the ability to transmit the positional data of one object wirelessly, and allows the main unit to calculate the bearing and distance between the two.

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1. Introduction

1.1. A brief history of QinetiQ

In July 2001 QinetiQ was formed when the MOD split their Defence Evaluation and Research Agency (DERA) department. When this split occurred some parts of DERA were renamed as DSTL (Defence Science & Technology Laboratory) which remains part of the MOD, while the other parts from DERA formed a private company, QinetiQ.

The name QinetiQ derives from the scientific term kinetic, and was decided upon following analysis of the strengths and capabilities housed in the business [1].

QinetiQ offers a broadly diverse range of services within the defence and technology sector, ranging from the aeronautical to maritime, space exploration to national security, naming but a few [2].

The site at Aberporth is classed as an air range, it mainly deals with aircraft trials, however it can also be utilized for Naval and marine activities, or any other research and development activities that require the use of a large range area.

“The Range Danger Area covers some 6,500km² of Cardigan Bay from sea level to unlimited height” [3].

1.2. Aberporth Background

Aberporth Range was established at the start of the Second World War for the use of the royal artillery. In 1940 the Projectile Development Establishment was evacuated from Fort Halstead, Kent, and rehomed at Aberporth from fears of attack. This would become the first of many test and evaluation capabilities provided at the site. Over the years the range has developed along with technology to continue the test and evaluation of new missile systems and equipment. In 1966 the first instrumented target barge was deployed in Cardigan Bay, prior to this buoys and basic rafts had been used for bombing trials.

The present day site looks very different compared with 20 -30 years ago with the declining defence budget and the continued rationalization. The nature of the site has also changed, with the majority of work being carried out on air and sea launched systems. The equipment has evolved to provide the current capabilities and continue to meet customer requirements. To provide a safe trial many factors need to be assessed, with lots of work in preparation. Even if everything is serviceable and ready for the trial lots of delays and cancellations can occur owing to the weather conditions, over which no one has any control [4], [5].

Some of the main facilities used to deliver a safe trial are:

Surveillance radars: although the airspace above Aberporth is closed to the public during trials activity, it's necessary to monitor this continually in case of any aircraft approaching. The air controllers use the information gathered from the Radars to provide safe flight paths to both civilian and military aircraft.

Tracking Radars: are crucial in order to carry out any trial; two separate Radars provide this function at Aberporth, with one of them being able to track up to 40 targets on its own. During a trial everything involved would be tracked, aircraft, various targets, stores etc. This is to ensure safe distances are maintained at all times, and it provides invaluable data to the Trials Conducting Officer, In Flight Safety Officer and the customer.

Telemetry Section: Used in the reception and decoding of all the data transmitted back during a missile flight. They also receive the video transmitted back from aerial and surface targets.

Aerial targets: Provide a dynamic aerial target that can be used either for air-to-air firings, Radar tracking and various other roles.

Surface Targets: Provide either dynamic or static surface targets that can be used for various roles from bombing targets to equipment platforms.

There are various other departments and facilities that also help in the general running of the site and trials delivery, but too many to list here.

The author's position within QinetiQ is that of an ST (Surface Target) Technician. Along with a team of four others who are responsible for the design, build, maintenance and operation of the electronic equipment on the target barges. Along with the standard electronic

instrumentation that's used on the target barges there's also bespoke solutions designed and built for new projects/trials.

1.3. Project Overview

With a brief overview of the Aberporth range, and the different sections that contribute to the various trials activities, it should allow a better understanding of the purpose of this project in supporting some activities from the Surface Target element. A selection of targets and instrumentation platforms are utilised by the department. It's common for customers, whatever their requirements, to wish to have the availability of video footage, either of the target or impact. This imaging can be used for scoring in terms of accuracy/ repeatability etc, safety aspects for example- is the target clear of personnel or marine mammals, has the ordinance detonated correctly etc. Video footage is also helpful for publicity material.

A routine activity could consist of a large instrumentation platform, with a smaller pontoon moored in the vicinity, the pontoon would be the impact target with the cameras and other equipment at a safe distance on the instrumentation platform, an operator would then control the camera to maintain the target in the camera field of view (FOV). This can pose a challenge in higher sea states due to the pitch and roll of the platforms, where it's attempted to have the target as large as possible within the FOV, whilst avoiding spending the majority of time looking at either the sea or sky. A variation on this activity only uses the instrumentation platform, and rather than using a smaller platform as the target, the customer is provided with an offset GPS position. This can pose additional problems for the camera operator, in ensuring the camera is positioned correctly through the use of the on board compass and calculating a bearing.

The aim of this project is to create a system that could be used in a variety of similar activities, either to take some of the work load from the operator, or maintain a target within the camera FOV with minimum user intervention. As the platforms move with changes in the tide, the camera will still be able to maintain a suitable image. With development the system could also

be used for tracking dynamic targets such as Unmanned Surface Vessel's (USV), which is another option offered to the customer.

To give a better overview of the types of targets mentioned, the image in Figure 1 shows a legacy Laser Guided Bomb (LGB) target and a smaller 5m pontoon, although the distance between the two is fairly small, this can vary significantly depending on the requirement, also there may be several 5m pontoons surrounding the main barge, which adds an element of confusion.



Figure 1 - LGB target with 5m Pontoon

A newer Instrumentation platform can be seen in Figure 2, this performs the same function as the previous mother barge, with an increased instrumentation offering.



Figure 2 - Updated Instrumentation Platform

In addition to the 5m pontoon pictured in Figure 1, some activities require the use of a dynamic target, one of the offerings for this type of activity is a remotely operated USV similar to the C13 picture in Figure 3.



Figure 3 - C-13 USV

To categorically define the project in terms of a draft title, it will be an investigation into the feasibility of tracking an object, with the aim of keeping it within a camera FOV.

1.4. Planning

1.4.1. Aims

The following information had been prepared to highlight the purpose of the project, and specify what the final design would be capable of. It was prepared during the proposal phase of the project, but still remains valid and achieves the objective of focusing time and energy in order to achieve the goal.

The main aim of this project will be to investigate and design a tracking camera solution, looking at existing methods and ascertaining whether GPS is a viable option. This will include the necessary research before undertaking the design and build of the system. The overall success of this project will be measured by the ability of the system to locate the target within the cameras FOV; once the system is functional there is the opportunity to develop it further. In working towards this goal there are several lesser milestones to overcome; some of these milestones are listed below:

1. The project must satisfy the requirements of the major project brief.
2. The project must be suitably complete within the allotted timescale.
3. The system must be accurate enough to maintain the target in the camera FOV.
4. The system must be user friendly, once installed it should operate with minimal user intervention.
5. The system must be rugged, as it will be used on instrumentation platforms out in Cardigan Bay.
6. The system will integrate with the existing electronics easily, whilst being transferrable.

1.4.2. Objectives

If there's any hope of achieving the main aim of the project, several key objectives will first need to be addressed, these are listed below:

1. Investigation of tracking technology.
2. Investigation into wireless data transmission.
3. Obtaining positional information for the object.
4. Transmission of the objects positional data back to the base (camera location).
5. Processing the data and calculating the difference between the two positions.
6. Build the system.
7. Processing the data and enabling the camera to adjust its position, to locate target.
8. Ascertain if tracking a stationary object is possible with the system.
9. Investigate whether tracking a slow moving object is possible with the system.
10. Investigate whether tracking a fast moving object is possible with the system
11. Highlight areas for future work and development.

1.4.3. Timescales

In order to achieve these objectives, and in turn the overall the success of the project, time management will be a crucial element. This is down to the complexity of some areas within the project, the scale, and the expected/ required performance of the finished product to

constitute a success. Along with these internal factors there will also be other academic time demands during the following academic year, without considering any other commitments.

A useful method of time/project management is using a Gantt chart, using this tool not only helps by making the author consider all the elements within the project, it also requires time estimates to be assigned for each task. With this information it can highlight any potential conflicts, or unreasonable timescales. A full Gantt chart showing major tasks and sub tasks can be viewed in Appendix 1, for ease of viewing the main tasks have been highlighted in Table 1. As this Gantt chart is a fluid document, there's likely to be updates throughout the project, possibly where tasks are completed ahead of schedule, or in other cases down to slippage.

Table 1 - Task Timescales

Major Tasks	Date
Research	01/08/17 – 25/12/17
Electronic Design	24/11/17 – 09/01/18
Program Design	05/12/17 – 09/02/18
Mechanical Design	07/12/17 – 12/01/18
Interim Viva	07/02/17 – 14/02/17
Electronics Prototype	10/01/18 – 15/02/18
Mechanical Build	08/12/17 – 06/03/18
Testing	15/02/18 – 08/04/18
Evaluation	08/04/18 – 15/04/18
Final Viva	10/04/18 – 27/04/18

2. Research & Development Methodology

With a reasonable technical overview of the project aims, and an insight into the features of the finished product, it is now time to outline the research and development methodology decided on for the project. To better understand what the research methodology entails, it's helpful to look at the definition of both words. 'Research can be defined as the investigation or experimentation aimed at the discovery and interpretation of facts or the collecting of information about a particular subject'. According to the Merriam-Webster dictionary.

Methodology is similarly defined as; "a body of methods, rules and postulates employed by a discipline: a particular procedure or set of procedures: the analysis of the principles or procedures of inquiry in a particular field." From the same source. [6]

Basically, a research methodology is important because it clarifies and defines the processes used for arriving at an outcome. This enables someone to work systematically through a series of steps to arrive at a conclusion. It enables others to follow that process also, which can be useful as it enables easier analysis if/when different outcomes are attained.

An easy way to illustrate all that needs to be considered when sourcing information is to use the Research Onion, developed by Saunders et al. (2007) a copy of this can be seen in Figure 4.

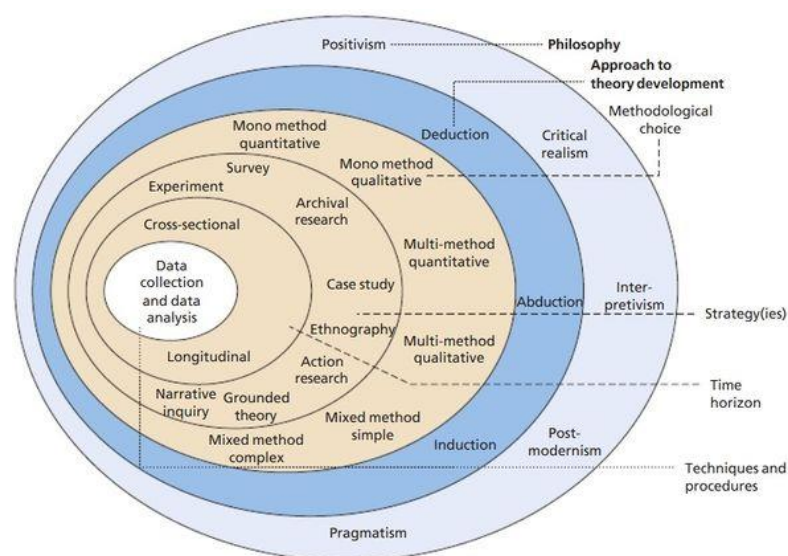


Figure 4 - Research Onion [7]

Understanding and using a research methodology has enabled work to be completed systematically, from a wider perspective narrowing down the processes along the way and thereby identifying clearly and clarifying the issues involved; so that at a course of action can be followed through to the completion of the project.

It has helped to consider carefully which is the most suited route of research to follow and why; assessing which methods best suit the proposed project and why, therefore allowing the most suitable method to be followed.

The following details on the method should allow others to follow the process if they so wish, or to highlight if another process could have produced better results.

2.1. Research and Development Conclusion

Using the different layers of the research onion a suitable method was adopted and followed:

2.1.1. Research Methodology

A positivistic philosophy was used as it aligns itself well with the technical nature of the project, and analysis is based on quantifiable results where the researcher has an independent role. The other philosophies can be far more subjective and aim to draw meaning from the results often involving the researcher within the study, which can influence results [8]. It was felt that this philosophy would not lend itself to the nature of the project.

2.1.2. Research Approaches

With the positivistic research philosophy decided upon, the deductive research methodology was a natural choice given how the two complement each other. This approach was also chosen as the aim of the project is to develop a tracking solution using existing technology. The technology concerned is mature and much literature has been produced on the various aspects of it. With the information available a theory or hypothesis can be put forward

regarding the expected results of the project, allowing it to be tested by altering variables and analysing performance accordingly [9].

2.1.3. Research Strategies

The choice for the method will be that of the mixed method. This will allow for some flexibility within the project and allow data to be recorded from experiments, testing the various components as well as observations of the performance as a whole. In this case some action research may be involved as the product is evaluated and developed.

2.1.4. Time Horizons

Due to the nature of the project a cross sectional horizon is appropriate. The product will either work or not. It is unlikely to degrade or change in terms of performance over time unless component failure is involved.

2.1.5. Data Collection

Primary and secondary data will be used as part of the research; the surrounding technology is fairly mature, so there should be plenty of information, and data from previous work surrounding them. Areas to look at will be published literature along with web articles and journals. When the system design begins it will be necessary to carry out tests on individual components, consult datasheets to ensure correct wiring and operation. To conclude there will be testing of the system as a whole in order to ascertain whether it's met the objectives.

3. Available Technology

3.1. Products on the Market

One of the positives regarding the selection of the tracking camera solution is due to the maturity of the associated technology; some of the tracking technologies such as RADAR have been in operation and development since the Second World War. At the lower end of the market is the availability of products catered more to the hobbyist or average consumer, this is helped by the increased popularity of social media, Instagram, YouTube etc, where people want to document and record more of their lives, including capturing good footage playing sports and other activities. Technologies such as Quadcopters and RC vehicles have become much more advanced, along with the increase in reasonably priced options this helps to appeal to a wider audience. Although these products are not aimed at the same market, and they may achieve the tracking aspect using a different method, it is reassuring that the goal is clearly achievable.

3.1.1. Soloshot

One of the camera systems on the market is the Soloshot; this product is aimed at people trying to record themselves in various sporting activities, where a cameraman may not be available. The product comes in two parts with the base unit with mounted camera and an armband tracker that the user wears. There is a calibration process to be completed which involves centring the camera FOV on an object, allowing the tracker a few minutes to acquire satellites, and then performing a 'walkaround' with the tracker, maintaining the aspect of the tracker so the GPS receiver has a constant view of the sky, to complete the process the tracker is placed on the base and button press sets the home position. Although the exact process the Soloshot uses to track is not explained in particular detail on their website, from the calibration process it appears that only the tracker has a GPS and the base gets its position during the calibration process, with this information it allows the base to receive the trackers position as it moves through space using a wireless link. The limitation this setup appears to have would be if the base was moved, the calibration process would have to be repeated. This would likely make it unsuitable for the desired application, where both objects may be moving. Available for £300.



Base

Pan: 360° at 80° per second continuously in both directions

Tilt: 150° of vertical tracking at 35° per second

Battery: Up to 8 Hours of internal battery rechargeable using supplied USB cord

Accessory Port: For adding features such as camera control and charging Tags

Feedback: Long range directional Green LED for tracking feedback

Security: K-Lock socket for locking camera to Base unit, Tool for secure attachment to attachment to tripod which may be locked to a fixed object using a standard bike lock.

Tag

Durable and lightweight

Range: 10 - 2,000 ft Range

Dimensions: 2.1oz. - 50x47x23mm

Durability: Waterproof (up to 100 ft.) and shock resistant

Battery: 4-Hour internal battery recharges by docking into Base accessory port

Mounts: Armband & Clip provided. Additional mounting accessories coming soon.

Multi Modes

- Single – One Base tracks one Tag. No interference with nearby SOLOSHOTs
- Multiple Bases to single Tag – Capture the action from multiple angles
- Single Base to multiple Tags – Camera records the closest, fastest moving, or whoever pressed the "call camera" button on their Tag
- Multiple Bases and multiple Tags – Capture multiple subjects with multiple cameras
- Barrel mode – For improved performance when filming surfers

Figure 5 - Soloshot data [10]

3.1.2. Pixio

Another product on the market is the Pixio, this has similar features to the Soloshot with some key differences, one being the fact that it can work indoors and out, but does have a lesser maximum range. With it being able to track indoors GPS is out of the question, from the items included this becomes clear. As well as a tracking base, and the user tag the Pixio includes three separate 'micro beacons' which are placed around the activity area, in a specific configuration. With these micro beacons in place and the base camera centred on beacon 1, the tag can now be switched on allowing the base to track it through the triangulated signal. One other feature that the Pixio offers is the ability to set the frame size with respect to the object, so as the calculated distance increases between the base and the tag, the zoom function of the camera is automatically adjusted, to maintain the object at the desired size within the FOV. Available for €679

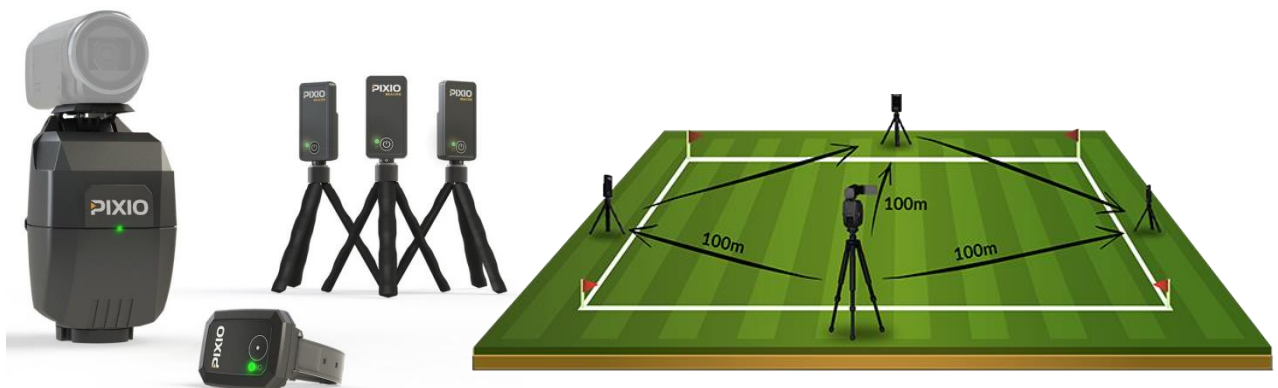


Figure 6 - Pixio Example

INDOOR and OUTDOOR Use PIXIO can track a watch with the same performance inside or outside	MOTOR NOISE Very silent motor. You can use a buetooth microphone (not provided) or any equivalent accessory to capture any distant voice
RANGE 330ft = 100 meters	TRACKS 1 to 16 WATCHES And 1 to 16 cameras can track the watches. But no more than 3 watches can be tracked at the same time by the robots. It means that if you have more than 3 robots, some of them will track the same watch
AUTOMATIC ZOOM With compatible cameras. Fixed otherwise.	AUTONOMY PIXIO 4h, WATCH 3h, Micro-BEACON 3h Li-Ion Batteries. All chargers included: WIRELESS CHARGER for the watch. Standard USB chargers for PIXIO and Micro-BEACONS. It is possible to increase the battery life of the beacons and the robot to 5-6 hours with 3000mAh power banks, and to 12-14 hours with 10000mAh power banks. Power banks are available in most supermarkets. People using power banks with their PIXIO also have 2 watches: one is charging while the other is used
REC control from the watch With compatible cameras	PIXIO robot and the Micro-BEACONS CAN BE PLUGGED IN A WALL SOCKET in order to film all day long in a conference room or an arena. It also allows to install PIXIO for months or years at the same place
Use PIXIO with standard camcorders, DSLRs, action cams... and with a special interface (not included) you can use a smartphone or a tablet to film (no auto zoom and no REC control in this case).	TRANSPORT Designed to be very easy to pack and to take with you everywhere. In any standard photo bag > 22x10x15cm (8.7x3.9x5.9in)
ROTATIONS PAN: Rotations 360° endless. 120°/s max (45mph at 30ft, 72km/h at 10m). No TILT rotations.	WEIGHT Watch tag 1.90z (50g.) Robot 1.2lbs (550g.)
CAN SUPPORT CAMERAS Up to 5lbs (2,5Kg)	WARRANTY
WHAT TRIPOD DO YOU NEED You need a tripod with a 3/8" screw. It is bigger than the usual 1/4" screw generally used for cameras. Do not use a tripod with a head, because of poor stability (except with high cost tripods!) and because it has a 1/4" screw. If you want to use such a tripod with a 1/4" screw, some small adaptors 1/4 - 3/8 exist.	

Figure 7 - Pixio data [11]

3.1.3. Pixy Cam

The Pixy cam operates in a different manner to the previous alternatives; it looks to be something that could be used as part of a project, rather than a complete product. In the examples available it's used in conjunction with an Arduino and attached to a Pan/Tilt servo. It's based on image tracking software so uses a fairly low resolution camera that's able to detect different colours, and objects of the desired colour. Different colours can be selected within the software as well. To use this effectively to capture decent quality images it's often paired with a better camera and the Pixy cam is used similar to a viewfinder. Available for £63



Technical specs

Processor: NXP LPC4330, 204 MHz, dual core

Image sensor: Omnivision OV9715, 1/4", 1280x800

Lens field-of-view: 75 degrees horizontal, 47 degrees vertical

Lens type: standard M12 (several different types available)

Power consumption: 140 mA typical

Power input: USB input (5V) or unregulated input (6V to 10V)

RAM: 264K bytes

Flash: 1M bytes

Available data outputs: UART serial, SPI, I2C, USB, digital, analog

Dimensions: 2.1" x 2.0" x 1.4

Weight: 27 grams

- Small, fast, easy-to-use, low-cost, readily-available vision system
- Learns to detect objects that you teach it
- Outputs what it detects 50 times per second
- Connects to Arduino with included cable. Also works with Raspberry Pi, BeagleBone and similar controllers
- All libraries for Arduino, Raspberry Pi, etc. are provided
- C/C++ and Python are supported
- Communicates via one of several interfaces: SPI, I2C, UART, USB or analog/digital output
- Configuration utility runs on Windows, MacOS and Linux
- All software/firmware is open-source GNU-licensed
- All hardware documentation including schematics, bill of materials, PCB layout, etc. are provided

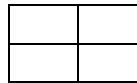
Figure 8 - PixyCam data [12], [13]

3.2. Tracking Methods

To satisfy the aim of this project doesn't require the development of any new technology, there's been a range of methods used to track an object going back to the Second World War, and probably further. The following section gives a brief overview of some of the methods:

3.2.1. RADAR

Radio Detection and Ranging. RADAR's can generally be split into two main categories, Primary and Secondary. Primary transmits RF energy usually in very short pulses, if this pulse hits an object some of it will be reflected back and received at the RADAR, from the time taken between the transmission and the reception the distance can be calculated based on electromagnetic waves travelling at the speed of light.



In order for the RADAR to continually follow the desired object the receiver horn is split into four quadrants, through processing the received signal and comparing the amount in each quadrant the RADAR is able to calculate offsets, these are then used to adjust both Azimuth and Elevation of the dish, this is a continual process as the RADAR tries to get an even amount of received RF in each quadrant, signifying it is aiming straight at the target [14]. The tracking process remains the same with secondary RADAR however it generally transmits a coded pulse, this could be something like two pulses with a $0.5\mu\text{s}$ delay. The object that is being tracked (if cooperative) will be fitted with a transponder; this will only transmit a reply pulse if the coded signal was correct. One of the advantages of secondary over primary is the increased distance it will work at, due to the RF energy travelling half the distance. Another advantage is the avoidance of cross lock, if two targets get very close or one passes by the other it is possible that a primary tracking RADAR may follow the wrong target.

3.2.2. Milimetric Wave RADAR

Another form of RADAR tracking is milimetric wave, this technology uses similar principles but operates at much higher frequencies typically +10 Ghz with a wavelength of 1 – 10mm. Some applications of this technology include scanners in airports, and missile seeker heads. There are some disadvantages of using such high frequencies, atmospheric conditions have a

large effect on the transmission, moisture in the air etc, so this is generally used for short range type applications [14], [15].

3.2.3. RSSI / RF

A similar method to RADAR that's used by hobbyists and remote control aircraft enthusiasts is RSSI – Received Signal Strength Indicator. A basic method to use this to track an object would be to have an array of three high gain directional antennas, one in the centre and two offset either side. This works by comparing the signal between the three antennas, and if one of the outer ones are receiving a higher signal level then the unit will rotate in order to get the maximum signal at the centre antenna.

3.2.4. IR Tracking

IR or infrared can be used in tracking applications both actively or passively, some common applications that use IR cameras include search and rescue helicopters and police helicopters which are looking for the heat signature generated by a body. Some CCTV cameras are also utilising IR technology with IR diodes used to illuminate the area for the camera, whilst not appearing to do so to human eyes. These applications mentioned although using IR would generally be using some form of image tracking to complement the IR aspect.

An active form of IR tracking that is widely used by the military is laser guidance; this has allowed considerable advances in the accuracy of weapons systems

“In World War II it could take 9,000 bombs to hit a target the size of an aircraft shelter. In Vietnam, 300. Today we can do it with one laser-guided munition from an F-117 [16].”

The testing of LGB's is fairly common at the Aberporth range, so their accuracy is well known (especially within the surface targets department). An LGB can be split into three sections consisting of the warhead, computer control group (CCG), and guidance canards (used to alter the flight path). When the bomb is released from the aircraft it's in the ballistic phase where it

continues on an unguided trajectory based on airspeed and release angle. Whilst this is taking place the pilot will have illuminated the target with an infrared laser designator (known as painting the target) some of this light is reflected back. Once the bomb has acquired the reflected light through the use of photodiodes, the transition phase of the flight begins. During this phase the bomb will try to align itself with the maximum received signal, this is done by comparing the received light at various points of the diode array, this information is then processed in the CCG and the commands sent to the canards. Once in the terminal guidance phase, where the bomb's flight path is aligned with the target, the same process carries on to maintain the flight path, when the detector is fully centred on reflected light the CCG commands the canards to a neutral position where the bomb returns to a ballistic flight towards the target [17].

3.2.5. Video Tracking

Video tracking is often used in high end CCTV systems with both static and PTZ style cameras. The processing required to achieve this is fairly intensive with various algorithms suiting different applications and environments. The basics of the system require some form of object recognition, or slightly less complex, motion detection. With the goal being to follow the desired object through each video frame. Several difficulties arise with this style of tracking and vary with the environment it is used in, changes in illumination, activity within the background and occlusion of the object to name a few, can all be detrimental to the system performance [18]–[20]. This is where the sophistication of the algorithm comes into play, whether it can cope with these issues and still maintain the track.

3.2.6. GPS Tracking

The GPS (Global Positioning System) network is widely used for navigation with lots of newer cars being fitted with 'satellite navigation', and the majority of Smartphone's having a GPS receiver. High end differential GPS receivers can also pinpoint positions down to

centimetre accuracy. GPS works by utilising satellites of known positions orbiting the earth, each of these are fitted with synchronized atomic clocks. The risk that these clocks aren't perfectly synchronized still remains so each satellite transmits a message including the time of the transmission, when this message is received the GPS receiver knows the transmission time, the time that message was received, and from this using the speed of light the distance can be calculated. As the range can't be guaranteed due to the potential synchronisation error, they are known as 'pseudo ranges'. In order to get an accurate position in space three coordinates are required, X, Y, Z along with the fourth variable, time. To calculate that position a process called trilateration is used, this works by narrowing down the area where the receiver could be, similar to some early navigation techniques, with each reference point the area becomes smaller. With one satellite fix it puts the receiver a set distance from the satellite anywhere on the surface of a sphere (the satellite will be at the centre). The second satellite allows that position to be narrowed down to anywhere on a circle. The third satellite will give another circle which intersects the first circle; the position has now been narrowed down to two points. Lastly the final satellite gives the exact 3D fix [21]–[23].

3.2.7. LIDAR

LIDAR – Light Detection and Ranging uses a similar process to that of IR tracking.

3.2.8. SONAR

SONAR – Sound Navigation and Ranging

3.3. Selected Tracking Technology

Based on the information available GPS was selected as the method for tracking, this was partly down to the fact that it would be less susceptible to adverse weather conditions and signal degradation being close to the water. It also offers lots of useful information within the sentences that could aid the tracking system. Another positive in GPS's favour is the accuracy of the technology and wide availability of reasonably priced receivers, especially with the popularity of quad copters and other drones using small GPS receivers for navigation.

4. Research GPS / GNSS

4.1. Satellite Network & Common GPS Terminology

The GPS satellite constellation is made up of 21 satellites; this figure was derived from the necessity to have at least four satellites in view twenty four hours per day. Using twenty one satellites evenly spaced with a 55° incline to the equator orbiting every twelve hours achieves this. [24]

Historically the GPS system was developed by the United States Department of Defence (DoD) for military applications in 1973, as the system was developed and implemented it also became available for civilian use on the instruction of the president and U.S congress. As a method of safeguarding the military applications and to prevent the technology being used against American interests there were a couple of methods included in the system that could reduce the accuracy of the system for civilian use, these are known as Selective Availability and Anti-spoofing.

Selective Availability works on the principle of ‘dithering’ the satellite clock frequency; this in turn introduces an error at the receiver which prevents it acquiring an instantaneous pseudo range. This error can be overcome through the use of two GPS receivers; this is known as differential GPS.

The second error that can be introduced is through reducing the length of the transmitted message from the satellite; this has the effect of reducing the accuracy of the satellites position in space, which introduces a similar error in the GPS receiver’s apparent position.

Anti-spoofing is another technique which is coined as a method of safeguarding the system from potential rogue signals which may lead to large errors in the calculated position. It works on the basis of either switching off one of the transmitted codes, or encrypting it so that only authorised users are able to decode the message. An Auxiliary Output Chip (AOC) is required to be installed in the receiver to decode the signal.

During the early days of GPS there were two separate systems, known as Standard Positioning Service (SPS) and Precise Positioning Service (PPS), these were based on the two signals being transmitted from the satellites, the L1 and L2 carriers. As the names indicate, one signal allowed a more accurate position to be obtained than the other, Selective Availability was also used in the SPS signal which could provide an error of approximately 100 metres in the final position. This process was deemed necessary by the US DoD in order to prevent potential enemies having the full accuracy of the system. This remained the case up until 2000, when President Clinton ordered the removal of SA saying:

"Worldwide transportation safety, scientific, and commercial interests could best be served by discontinuation of SA" [25]

That being said, the US still has the power to reduce the accuracy of the system in certain regions of the world, if required. The removal of SA has increased the accuracy of the SPS by about five times, although still not as accurate as the PPS system it is still a dramatic improvement. [26]

GPS Accuracy is an important factor when considering a GPS receiver, in most cases the receiver will be accurate to within a few metres; however manufacturers use different statistical methods to measure the accuracy. One of the reasons for this is due to the GPS receiver itself, and how the calculated position will move slightly over time, even if the receiver hasn't physically moved. This is partly down to the receiver constantly updating the tracked satellites, as the previous ones move beyond the line of site. If the GPS position is logged this produces a scatter type plot, with this data the accuracy can be calculated.

One of the common forms of expressing GPS accuracy is known as Circular Error Probability (CEP), as the name suggests this uses a circle around the known position with the receiver plot overlaid, if 50% of the points are within a 3m radius of that position the manufacturers could say that receiver has a 3m CEP. Another similar method of representing the GPS accuracy is known as R95, it uses the same process as CEP however this time 95% of the received points are within the circle, thereby indicating a higher consistency in the position over time. Spherical Error Probability is calculated with the same process as CEP, however this time looks at the altitude of the position as well, so rather than a circle it uses a sphere. The table in Figure 9 shows some of the other common accuracy measures.

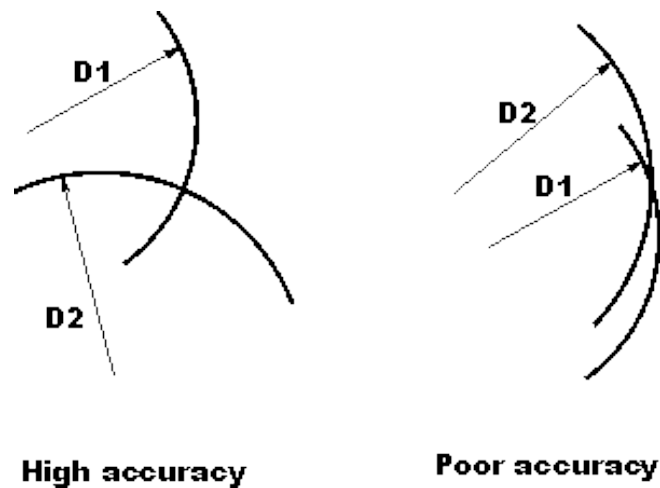
Dimensions	Accuracy measure	Probability (percent)	Typical usage (dimension)
1	rms	68	vertical
2	CEP	50	horizontal
2	rms	63–68	horizontal
2	R95	95	horizontal
2	2drms	95–98	horizontal
3	rms	61–68	3-D
3	SEP	50	3-D

Figure 9 - Accuracy Measurements [27]

Dilution of Precision (DOP) is a characteristic of obtaining a position through trilateration or triangulation, and refers to the geometry of the satellites and the intersecting circles formed from the Time of Flight (TOF) calculations. Hoffman states that: “The accuracy of the position determined using a single receiver essentially is affected by: Accuracy of each satellites position; Accuracy of pseudo range measurement; Geometry.

A measure for satellite geometry with respect to the observing site is a factor known as Geometric Dilution of Precision (GDOP).” [21]

In essence the greater the separation between the four satellites being used to obtain the position, the better the DOP figure and also the accuracy of the position. The picture in Figure 10 shows this well, with better spacing between the satellites the intersecting arcs cross closer to 90° thus forming a square where the actual position may be. The closer the satellites are together the intersecting lines cross closer to 180° than 90°, forming a diamond shape with a larger ambiguity.



[28]

Figure 10 - DOP Diagram

Where the GPS receiver has a choice of more than four satellites in view, it will constantly calculate the DOP figure between all available satellites, in order to get the highest accuracy possible/the lowest DOP figure. There are a few variations to the DOP, these are known as Vertical Dilution of Precision (VDOP), Horizontal Dilution of Precision (HDOP), Geometric Dilution of Precision (GDOP) and Position Dilution of Precision (PDOP), these focus on various elements of the geometry to give the most useful information to the user, e.g. If height is the main focus then VDOP would be more relevant than HDOP. [29]

Differential GPS (DGPS) is a method that can be used to improve the accuracy of the GPS position. It does this by receiving additional data from GPS stations around the globe (when in range), these GPS stations are fixed locations and have their positions accurately surveyed. With the known position along with the calculated position from the satellite network the receiver is able to determine the difference between the two, or the current error (this will vary throughout the day as atmospheric conditions change and satellites come in and out of view). With this information it's now able to send corrections to all GPS receivers in the area (as long as they accept DGPS), the GPS receives then apply this correction when calculating the position. [26]

Satellite Based Augmentation System (SBAS) is another method of improving the accuracy of positional data received using the GNSS; it works along similar principles to DGPS. It consists of reference stations across the different continents which receive the signal from the GNSS network, the positions are then sent to a control centre where the errors from the GNSS signal are calculated, with corrections being sent back up to a geostationary satellite; this has better coverage to transmit the corrections to SBAS enabled receivers within range. Various continents have their own groups of reference stations, the European Geostationary Navigation Overlay Service (EGNOS), and the Wide Area Augmentation System (WAAS) which serves the USA being two of them. The various networks all comply with the same standard, so an SBAS equipped receiver will be able to get corrected data in all areas across the globe, that form part of the greater SBAS network.

The EGNOS agency defines the performance of a satellite network by 4 key criteria, these are shown in Figure 11:

- **Accuracy** refers to the difference between the measured and the real position, speed or time of the receiver.
- **Integrity** refers to a system's capacity to provide confidence thresholds as well as alarms in the event that anomalies occur in the positioning data.
- **Continuity** refers to a navigation system's ability to function without interruption.
- **Availability** refers to the percentage of time during which the signal fulfils the accuracy, integrity and continuity criteria.

[30]

Figure 11 - Satellite Navigation Performance

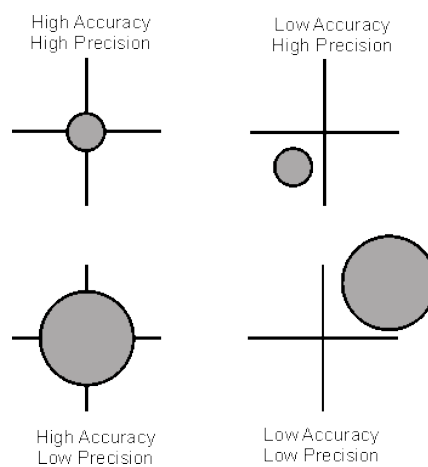


Figure 12 - GPS Terminology [28]

Real time Kinematic (RTK) uses a similar principle to DGPS in that it uses another receiver to offer corrections. In this setup it uses a master receiver at a known position, with the other receivers in the network receiving corrections from it. It also offers some advantages over other systems by using data from two or more of the satellite networks (GPS, Galileo, GLONASS, BeiDou), in order to do this it must be set up to receive the different frequencies, different size aerials etc. Along with the greater selection in satellites it also calculates its position using the phase of the carrier signal, rather than the pseudo random code being transmitted. This offers advantages due to the carrier frequency being much higher than the data frequency, with a higher frequency the wavelength is reduced, so any errors generated during the process will be on a lesser scale, centimetre accuracy is achievable. There are some inherent issues with this method that must be overcome to achieve this accuracy, one of them being able to determine if the signal has a delay of exactly one cycle, two or maybe more, this is known as inter ambiguity search.

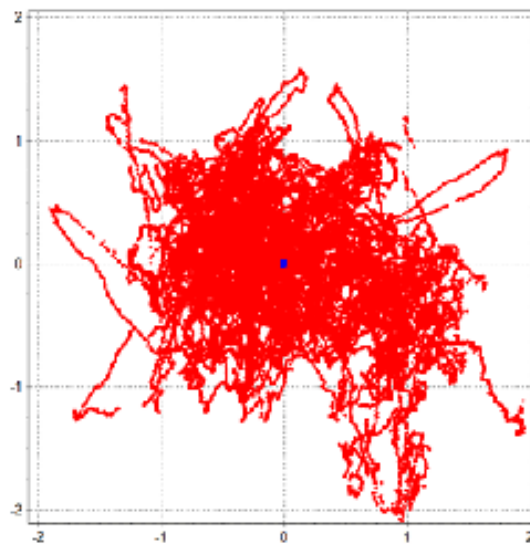


Figure 13 – 24hr scatter plot - RTK in blue, GPS in red

From the plot in Figure 13 the improved accuracy and reduced drift of RTK over GPS are clearly visible. [31]

Along with the accuracy of a GPS receiver, the speed it can acquire the satellite signal and determine the position is also critical, this is where the number of channels plays a roll, the greater the number of channels a GPS receiver has will improve the time it takes to get an

initial position once switched on, this is known as the Time To First Fix (TTFF). This is down to the amount of signals being transmitted from various satellites, as all the satellites transmit on the same frequency the receiver has to be able to distinguish the signals from each other, the message being transmitted by the satellites is a 1024 bit pseudo random code, using one channel or correlator it's able to generate a specific satellite code and check the received signal to see if it matches. If it doesn't match then the receiver will shift the code by 1 bit and try again, with a code being transmitted every millisecond it can completely check a code every second and then moves on to the next satellite code. With this process it can take up to thirty seconds to successfully identify a satellite.

Adding another channel can halve this time, as it's able to check a different code at the same time, the TTFF will keep halving as each additional channel is added. With more channels it also allows the receiver to track a few extra satellites, swapping between them to use the best four, the other channels are also able to start tracking new satellites as they come into view, streamlining the process to reduce signal drop outs. The process described is known as a cold start; where the receiver doesn't know its location or the time neither does it have valid ephemeris or almanac information. Once a receiver has been active for a few minutes it's able to update the almanac so it knows where in space the satellites are, and which ones it should be able to see. [32]

4.2. Transmitted Signals

There are a few different types of GPS receiver on the market, these can be categorised on the architecture and operation. Three common types include:

C/A code carrier receivers. These types of receiver use the course acquisition (C/A) code found in the L1 carrier, to get a pseudo range from the satellite. They use between 4 and 12 channels which allows information from up to 12 satellites to be collated, improving the

accuracy. As well as the C/A code these receivers also record the phase of the L2 carrier, using both pieces of information has the benefit of reducing any errors caused through ionospheric degradations in the signal. One drawback found when obtaining the carrier phase is the loss of the data included in the L2 signal, which is the Precise code (P-code)

C/A code Pseudorange. This is a basic type of GPS receiver that only utilises the C/A code. Typically they comprise of one to six channels, which reduces the accuracy when compared with the previous example. From earlier information it is known that four pieces of information are required to generate a 3D position, so a receiver with less than four channels doesn't sound ideal, however they can be used for static objects where they receiver sequentially poles separate satellites to build up the positional information.

P-code receivers. These are the most accurate of the three types and are generally used for high fidelity tasks such as surveying. These get their accuracy from the ability to use all the information transmitted on the L1 and L2 carriers, such as the P-code which requires a key to decode. This encryption is used to prevent anti-spoofing of the signal, something that was touched on earlier. The P-code has an increased accuracy when compared with the C/A code due to the increased 'frequency' transmitted, ten times faster than the C/A code, which allows a factor of ten increase in the accuracy of the pseudo range.

4.3. Receiver Construction

A basic GPS receiver consists of an antenna, signal amplifier, RF/IF, microprocessor and signal tracker, along with some memory to store data.

Antenna – in modern GPS receivers these generally use an Omni-directional microstrip style antenna, tuned to the required frequency, be that L1, L2 or both. It is required to provide an equal gain even with changes in the angle/orientation of the receiver which can be expected with moving objects (these could generate errors in the pseudo range). Some pre-amplification may also be incorporated as the received GPS signal is particularly small.

RF/IF – This part of the receiver reduces the received RF signal down to a lower frequency signal, known as the intermediate frequency. This is done by mixing the RF with a sine wave provided by a local oscillator, this provides a lower frequency while keeping the modulated data, therefore allowing components designed for lower frequencies to be used, improving accuracy and cost savings. This is a common process used in the majority of modern receivers, based on the development of the super heterodyne receiver.

Microprocessor – This includes a set of instructions used to operate the receiver along with performing the required computations in order to decode the incoming data, and calculate a position from them. Along with these tasks it usually offers some form of communication port that allows a user to alter settings within the receiver, in order to suit various applications.

Memory – As with all devices that may need to store data or settings, some form of memory is required. In a GPS receiver the data stored usually includes the GPS almanac or ephemeris. This includes information on the satellite constellation such as orbits, satellite health, and unique messages. With some approximate satellite positions it allows the receiver to work out its position around the globe much quicker than if the information wasn't available.

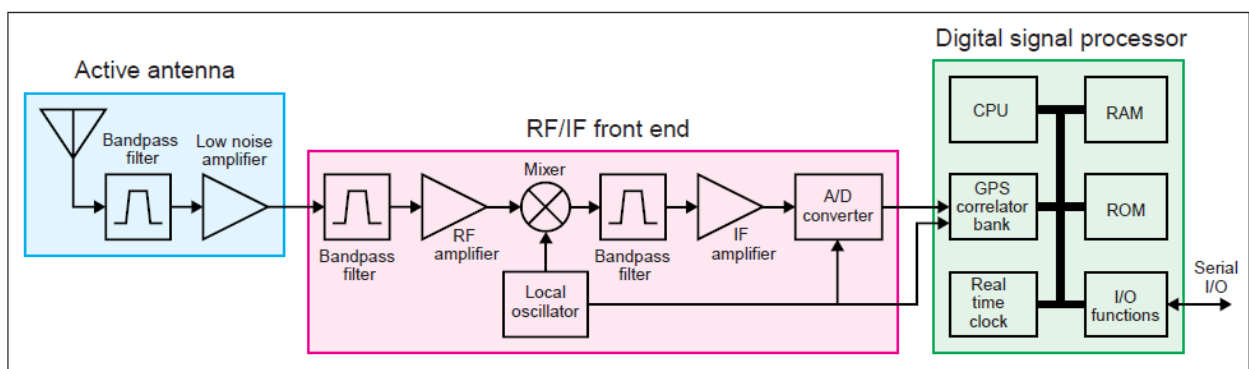


Figure 14 - GPS Receiver Block Diagram

[33]

4.4. GPS Data

The organisation that sets the standard for GPS data along with other electronics designed for use in the marine environment is known as the National Marine Electronics Association (NMEA), the standard was set for GPS in 1983, however the group was formed earlier in 1957 when a group of electronics manufacturers and retailers formed an alliance to provide a better service. The GPS standard was brought in to introduce some element of conformity between the different manufactures and software developers which meant various pieces of equipment and software could be used interchangeably by adhering to this standard. There have been a few iterations to the standard, but the current one governing GPS data is known as 0183 version 4.1 with NMEA 2000 governing network style devices.

The standard set out in 0183 details EIA 422 as the preferred output at 4800 baud, with 8 data bits, one stop bit and no parity, the maximum sentence length is 82 characters long, made up of ASCII characters with a carriage return and line feed denoting the end of the sentence. The various pieces of information included can vary between the different sentences used, but each field is separated by a comma for ease of finding the correct information. All sentences will start with a '\$' symbol followed by 'GP' for approved GPS sentences, a 'P' signifies a propriety sentence created by equipment manufacturers to include different forms of data. The other common sentence start is a 'GL' this signifies the GLONASS satellite network, which is the Russian equivalent. 'BD' Beidou, 'GA' Galileo.

Some of the common GPS sentences include:

GPGGA – Essential fix data, along with track accuracy.

GPRMC – Stated as the minimum requirement for Navigation.

The following few strings of GPS information provide an example of a common GPGGA sentence output from a GPS receiver:

```
$GPGGA,100611.00,5208.3897736,N,00434.2282631,W,2,09,0.9,135.5,M,52.3,M,4.0,0120*50
```

\$GPGGA,100610.70,5208.3897717,N,00434.2282646,W,2,09,0.9,135.5,M,52.3,M,4.1,0120*53

100610.70	5208.3897740	N	00434.2282640	W	2	09	0.9	135.5	M	52.3	M	3.7	0120*	51
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

A – Time – Greenwich Mean Time/ Zulu time (10:06:10.7)

B – Latitude – Decimal degrees (52° 08.389 minutes)

C – Indicating North or South of the equator

D – Longitude Decimal degrees (004° 34.228 minutes)

E – Indicating East or West of Greenwich

F – Indicating the GPS quality (0 = Invalid Fix, 1 = SPS Fix, 2 = DGPS Fix, 3 = PPS fix)

G – Satellites in view

H – Horizontal Dilution of Precision

I – Altitude (based on geoid)

J – Altitude Units

K – Geoidal Separation (difference between WGS84 earth ellipsoid)

L - Geoidal Separation Units

M - Age of differential information (seconds)

N – Differential Reference Station ID

O – Checksum

4.5. Serial Data Transmission

4.5.1. RS232

The Recommended Standard 232 (RS232) data protocol is an asynchronous serial transmission method; this allows bi-directional communication using three wires, one for transmitting, one for receiving, along with a common ground. The asynchronous part means that there's no associated clock signal, each bit is transmitted one after the other at a frequency defined at both the transmit side and the receive side. This frequency associated with digital data is known as the baud rate, this is the amount of bits transmitted per second. There is another method known as parallel transmission, this requires enough separate wires for the word being transmitted, it has some advantages over the serial method in that data can be transmitted at

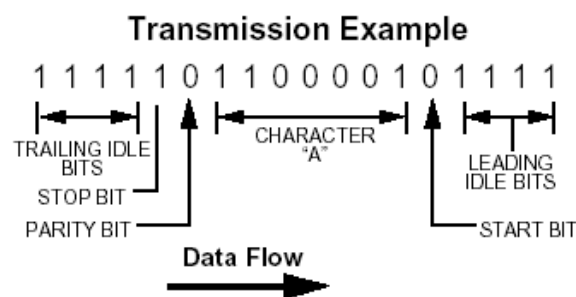
much higher rates. As the baud rate is the equivalent to frequency, the bit period can be calculated by one divided by baud. For 9600 baud $\frac{1}{9600} = 104.16\mu\text{s}$

It became popular in the 1960s as a method of transferring data between Data Terminal Equipment (DTE) such as a computer and Data Communication Equipment (DCE) like a modem, one of the leading factors in its popularity was the ability to transmit the data bit by bit over a standard phone line, a modem would be used at either end of the transmission line in order to convert it to and from a serial data stream.

Data can be transmitted a reasonable distance using RS232, approximately 50ft, this is down to the higher bi-polar voltage levels used, with $\pm 25\text{V}$ set as the maximum in the standard. This large voltage swing allows the signal to travel further before the cable resistance causes enough voltage drop to degrade the signal. In practice lower voltage levels are used with the common MAX232 IC generating -12V for a logic '1' and +12V for a logic '0'

Transmitting data requires a logic '0' to be transmitted first as the data line usually sits at -12V (logic 1) when inactive, once the start bit has been sent the data bits can then be sent, these vary between five to eight bits, with seven bits representing the ASCII character set. Once the data has been sent there's occasionally a parity bit used and then to complete the packet a stop bit, the stop bit is a logic '1' and can be distinguished from the other bits as it can extend more than one bit period, the next bit to follow this would be the start bit of the new packet, as the data changes from a logic '1' to a logic '0' it provides a rising edge, due to the inverse nature of the RS232 voltage levels.

UART (Universal Asynchronous Receiver/Transmitter)



[28]

Figure 15 – RS232 Packet Protocol

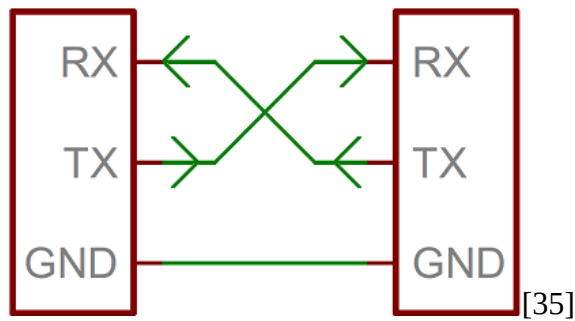


Figure 16 - Serial Wiring

4.5.2. TTL

Transistor Transistor Logic (TTL) is another method similar to RS232, and is used regularly for IC and MCU logic designs. So there's a large range of integrated circuits based on TTL, these are generally identified by a 74 or 54 at the start of the part number. The alternative logic design is known as Complementary Metal Oxide Semiconductor (CMOS).

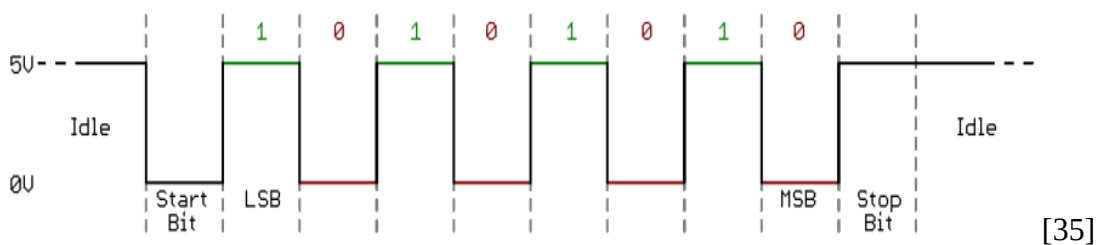
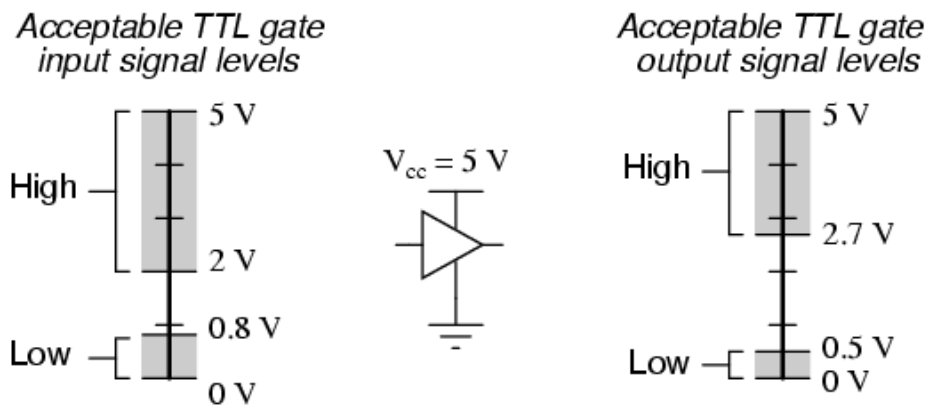


Figure 17 - TTL

TTL uses voltage levels between 0-5V with 5V representing a logic '1' and 0V a logic '0'. In contrast with RS232 the logic levels aren't inverted and it only uses positive voltages. These lower voltage levels used reduce its transmission range compared with RS232, due to signal degradation and noise, with the voltage dropping across length of cable to approximately 2V the receiving device may misinterpret the transmitted bit.

TTL is the main form of internal communications within microcontrollers and used for communicating with other basic IC's, so data being sent to the microcontroller will usually have to be in this form.



[36]

Figure 18 – TTL Voltage Range

4.6. Wireless Data Transmission

As the main platform and satellite platform are going to be at sea separated by approximately 1km of water the ability to transmit data between the two wirelessly is quite a high priority. There are instances where cables are used to send data across expanses of water, either overhead for short distances or along the bed of the river/sea these are known as submarine cables and can be used to connect countries at great distances, the UK and USA for example. For this application the cost would be prohibitive, along with the fact that the platforms are moved about, and one of the end goals of the project is for the system to be used on a moving target. Along with these reasons is the fact that the technology available to transmit data wirelessly is more than sufficient for this application.

4.6.1. Infrared

Data can be transmitted using infrared light which has a longer wavelength than visible light, making it undetectable to the human eye. In order to transmit data using this method the

transmitter and receiver usually have to be within line of site (LOS), an infrared LED or laser can be used to transmit the digital data by modulating the beam, which can then be seen by the receiver using a basic component such as an IR photodiode. A common use of this technology is in remote controls for common electrical items such as televisions, Hi-Fi systems etc. although it can be used outdoors, it's not particularly suited to longer distances and can experience interference and attenuation from the IR elements of sunlight. The power of the transmitter can be increased to overcome this issue, but this poses safety issues in public places as the human eye can't detect the light, so avoids the blink reflex, which can lead to damage to the retina. Another disadvantage of infrared is the directionality of the Tx/Rx, they have to be fairly well aligned for successful data transmission, although at shorter distances scattering also helps. [37], [38]

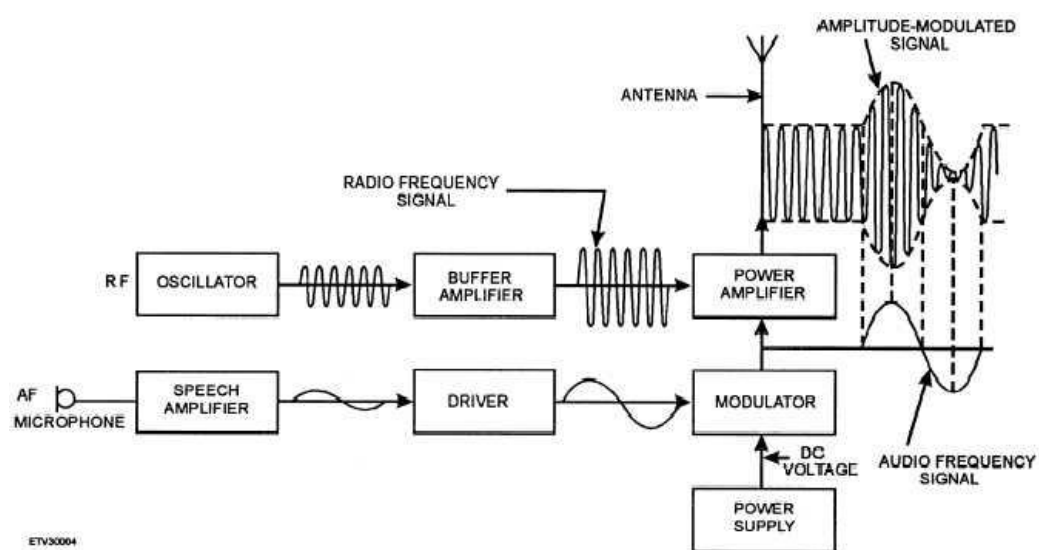
4.6.2. Radio Frequency (RF)

Data can be transmitted wirelessly using an RF carrier signal, in order to transmit this data through the atmosphere some form of aerial or antenna is used, which helps to propagate the electromagnetic energy. An aerial/antenna can be anything from a piece of wire, to a Yagi directional aerial (used for terrestrial television), or a parabolic reflector and feed horn. In order to transmit the data, either analogue or digital, it is modulated on to a higher frequency carrier signal. This is necessary both to convert the original baseband signal into a band pass signal at a unique frequency. Care is taken to avoid signals overlapping in terms of frequency, as this causes interference and potential corruption of the transmitted data. OFCOM manages the RF frequency spectrum in the UK.

There are various types of modulation used; these vary from earlier techniques such as amplitude modulation. This works as the name suggests by altering the amplitude of the carrier signal, with respect to the data. This along with frequency modulation are the two common methods for transmitting radio broadcasts, BBC1, 2 etc. Another method of modulation that offers some advantages over these techniques is known as Phase modulation, this technique offers better noise immunity for the transmitted signal, so is less susceptible to bit error, where

a '0' has changed to a '1' or vice versa. There are a few more advanced modulation techniques that are used in digital systems; these generally use a mixture of the three basic types.

Some important considerations when looking at RF transmission networks include the output power of the transmitter, the higher the power generally equates to further transmission ranges, and better noise immunity, generally at the expense of a higher current draw. Receiver sensitivity is also an important factor, as this determines how small a signal can be when it arrives at the destination, and still be able to be separated from the ambient noise and understood. [39]



[40]

Figure 19 - Modulation

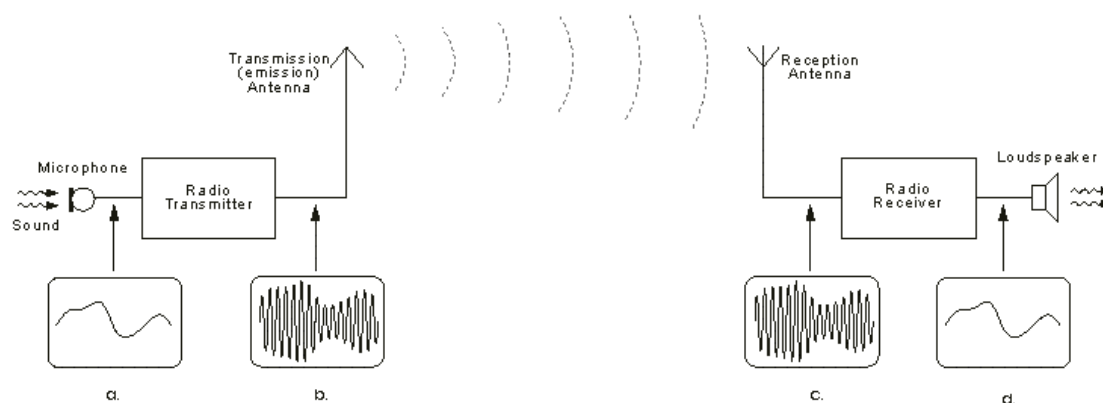


Figure 20 - Radio Transmission [41]

4.6.3. Microwave link

A microwave link uses the same principles as RF transmission, however the frequencies are generally higher as the name suggests. It's described as a link as the transmitter and receiver have to be aligned accurately using parabolic dishes, this means LOS is critical and it is generally point-to-point, unless more antennas are used. This produces both advantages and disadvantages for the system, with the aligned dishes a higher bandwidth is achievable, this is ideal in fixed locations where a fibre optic cable would be impracticable to install.

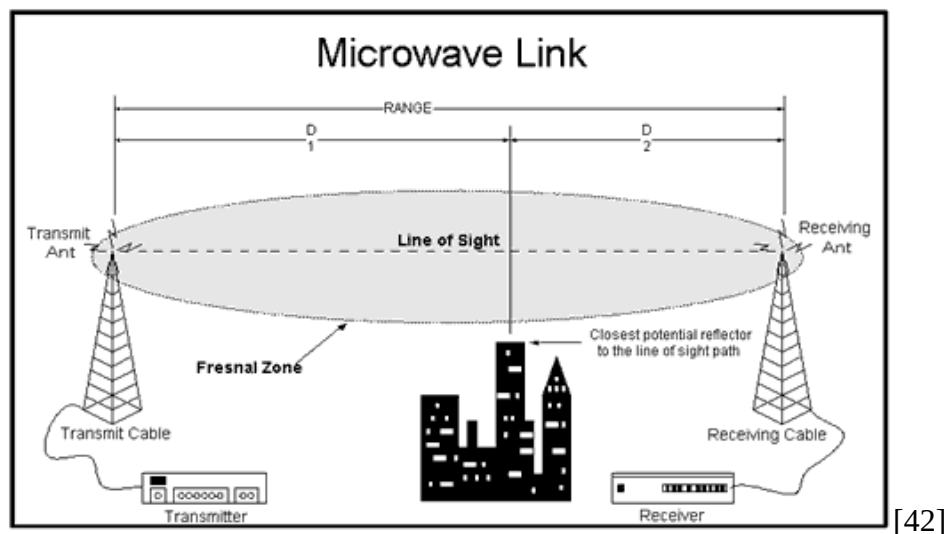
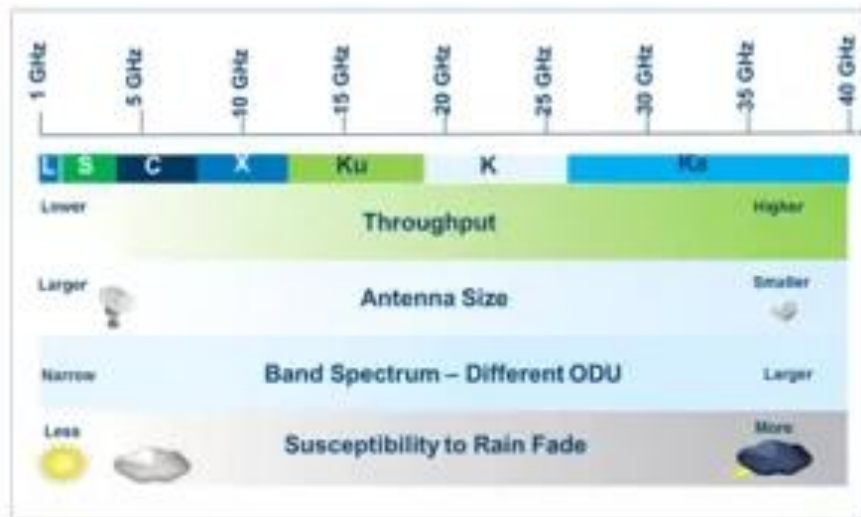


Figure 21 - Microwave link Diagram

Portable units are available, but care must be taken when aligning them to achieve the best possible results. The distances achievable depend on the common factors, transmitter power, receiver sensitivity, gain of the antenna, frequencies used.

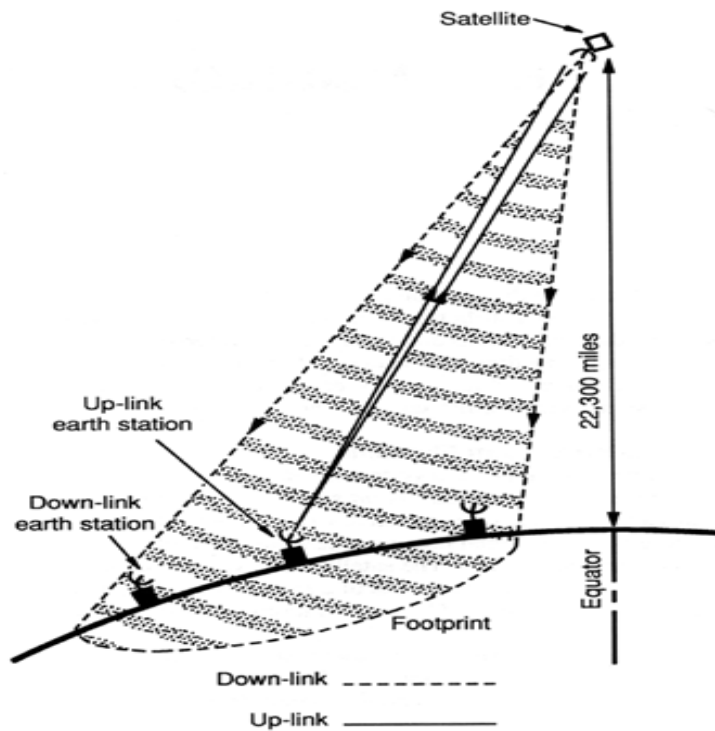


[43]

Figure 22 – Microwave Frequency Bands

4.6.4. Satellite

Satellite data transmission uses similar methods to those discussed with RF transmission, one difference being the data is transmitted to a satellite first, which then retransmits the data allowing the receiver to pick it up. One advantage this offers over basic RF transmission is the increased range it offers, due to bouncing the data off the satellite more of the globe can be covered including exceptionally remote locations.



[44]

Figure 23 - Satellite

Three geostationary satellites can effectively cover the entire globe; however there are a lot more in use today. Due to their position roughly 22,236 miles above the earth's surface; they follow the earth's rotation at the same speed, which means they remain in a fixed position relative to the earth. Due to the distance away from the earth it can take 0.22 seconds for the data to get their travelling at the speed of light, and the same again for the return journey, this can cause some problems for things like voice communications. There are a great many satellites that are used for other tasks, and follow two other orbits, the Low Earth Orbit ranges from 100-1000 miles above the earth, and the Medium Earth Orbit from 6,300-12,500 miles, these can also orbit the earth at varying speeds. [45]

Similar to OFCOM regulating the frequency spectrum in the UK, there's also an agency that regulates the frequencies in space, with the vast amount of satellites used all sending data for various purposes this is necessary to avoid interference. The International Telecommunication Union is responsible for this. [46]

UHF-Band	S-DAB-Band	L-Band	S-Band	C-Band	Ku-Band	Ka-Band
235 MHz to 400 MHz	1.452 GHz to 1.492 GHz	1.518 GHz to 1.675 GHz	1.97 GHz to 2.69 GHz	3.4 GHz to 7.025 GHz	10.7 GHz to 14.5 GHz	17.3 GHz to 30 GHz
Military mobile services	Television and radio broadcasting	Civilian mobile services	Television and radio broadcasting to mobiles	Television, radio and data Internet connection	Television, radio and data Internet connection	IP applications, radio and data Internet connection

[46]

Although satellite communications offer lots of advantages, there are some downsides one of these being cost. Due to the high cost of designing building and placing the satellite in space, these costs need to be recovered. Although consumers don't directly pay for each GPS message they receive, if you want to use other services such as a satellite phone, they'll have to pay a premium which is likely to be more than a standard phone contract. Likewise if you want to add satellite communication on a new product there are modules available to achieve this, they allow you to send data via the iridium satellite network, however you will be paying for each bit of information that's transmitted.

4.7. Distance & Bearing

In order to calculate the range and bearing between the two GPS receivers, it'll be necessary to convert the positions into a suitable format and use an element of spherical geometry known as the Haversine formula. The Haversine will give a great circle distance between two points on the globe; although the earth is not a perfect sphere this method has proved to be accurate enough for the projects purpose, from some initial research online. There's a separate calculation that will be used for the bearing.



Figure 24 - Great Circle Arc [47]

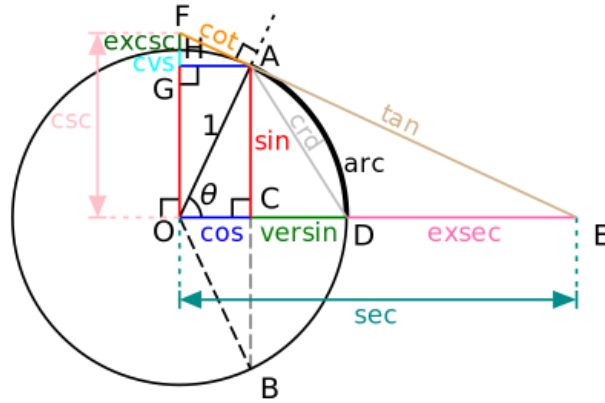


Figure 25 - Additional Trig Functions [48]

The term Haversine is an abbreviation from “half versed sine” where [48]:

$$\text{haversin}(\phi) = \text{versin}(\phi)/2$$

The Haversine equation can be seen below, using point A and point B.

λ = Longitude

ϕ = Latitude

R = Earth's radius (6,371km)

$$a = \sin^2\left(\phi_B - \left(\frac{\phi_A}{2}\right)\right) + \cos\phi_A \times \cos\phi_B \times \sin^2\left(\lambda_B - \left(\frac{\lambda_A}{2}\right)\right)$$

$$c = 2 \times \text{atan2}(\sqrt{a}, \sqrt{1-a})$$

$$\text{Distance} = R \times c$$

The equation for the bearing can be seen below, using the same Greek letters.

$$= \text{atan2}(\sin \Delta\lambda \times \cos \phi_B, \cos \phi_A \times \sin \phi_2 - \sin \phi_A \times \cos \phi_B \times \cos \Delta\lambda)$$

As atan2 will return a radians value, this will need to be converted to a suitable compass bearing of 0 - 360°. [49]

5. Market Research

Although there are a few similar products available on the market, they don't quite meet the requirements for this application. One of the main reasons being the setting for the equipment, which makes any calibration or setup procedure fairly difficult. There are some nice features on some of the products, especially the Soloshot which offers a smooth track of the object, maintaining it clearly within the FOV; this is something that will hopefully be replicated in the final design.

Referring to the basic system diagram constructed as part of the proposal, it's necessary to research the market comparing various products to suit the specific application.

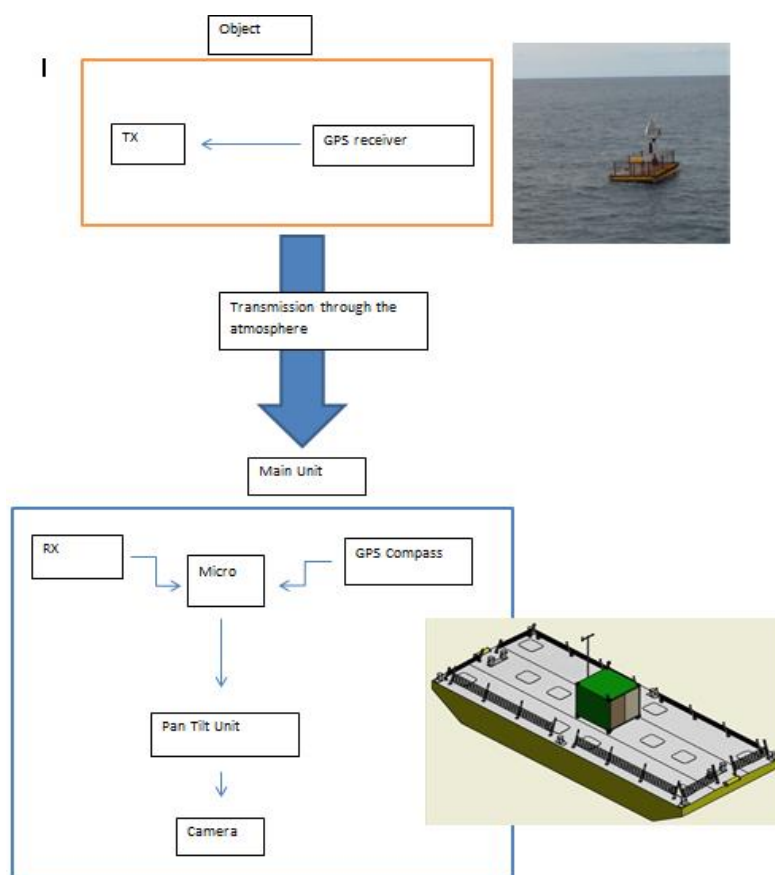


Figure 26 - Basic Block Diagram

5.1. Remote GPS Receiver

One of the key requirements of this project is a reasonably accurate and reliable GPS receiver, this is necessary if there is to be any chance of success, if the GPS receiver on the remote side is misrepresenting the position by 20m then there's no chance the system will be able to track accurately. On the other hand it doesn't need to be accurate to the standard of surveying equipment or even the sub metre accuracy offered by the GPS compass. The smallest object that would have the remote GPS pod attached to would be a 5m pontoon, there are other pontoons and along with USV's, but they are all larger than 5m. Taking this into account a GPS receiver with a 5m or better accuracy should be suitable.

Table 2 - GPS Receiver Comparison

GPS	Sensitivity (dBm)	Tracking chan (view)	Accuracy	Overall channels	Updates	Data	Details	Voltage	Price
SA-920	-159	20	3m	/	1Hz	RS232	GPS L1	5V	£95
GPS-622	-161	14	2.5m cep	65	10Hz	TTL	GPS L1	5V	£30
L86-M33	-165	33	<2.5m cep	99	< 10Hz	TTL	GPS GLONASS QZSS	3.3V	£10
Flora	-165	22	<3m	66	< 10Hz		WAAS	3-4V	£40
746	-165	22		66	< 10Hz	TTL	GPS L1	5V	£27
LS20032	/	22	2.5m	66	< 10Hz	RS232	GPS GALILEO BEIDOU QZSS SBAS	5V	
SA-320	-143	12	<3m	/	1Hz	RS232	GPS L1	5V	£90
Featherwing	-165	22	<3m	66	10Hz	TTL	GPS L1	3.3V	£40
GlobalSat MR350	/	48	<5m	48	/	RS232	GPS L1	5V	£40
GM-1315LA	-157	/	2.5m	50	2Hz	TTL	GPS L1	3-3.6V	
NEO-6M	-162	/	/	50	5Hz	TTL	GPS		
963-GYSFFMAXC	-146	33	1.4m	99	/	TTL	GLONASS	3.3V	£16
Hemisphere	-142	27	0.6m 2drms	/	< 20Hz	RS232	GPS	7-32V	£1000
NAVILOCK 62571	-167	/	2m cep	72	< 18Hz	LVTTL	GPS GLONASS SBAS	5V	£55
GP-20U7	-162	22	2.5m	56	1Hz	TTL	GPS L1	3.3V	
Ocean Vision		22	<2.5m cep		< 5Hz				

The table above shows a selection of suitable GPS receivers, based on key parameters. From this list one GPS receiver was purchased for testing. The performance of this would be compared to two other GPS receivers that were available from previous projects.

5.1.1. Hemisphere

The Hemisphere A101 smart antenna was left from a previous task, which allowed it to be tested along with the other receivers. Having equipment like this available at work is a good advantage, as it wouldn't be cost effective to perform this type of test on a personal budget. At approximately £1000 it's by far the most expensive receiver on the list, but also quotes the best performance with sub metre accurate horizontal positioning when valid SBAS data is available. The full specification can be seen in Figure 27.

GPS Sensor Specifications		Environmental	
Receiver Type:	L1 GPS	Operating Temperature:	-40°C to +70°C (-40°F to +158°F)
Channels:	12 L1CA GPS	Storage Temperature:	-40°C to +85°C (-40°F to +185°F)
	12 L1P GPS	Humidity:	95% non-condensing
	3 SBAS or 3 additional L1CA GPS	Shock and Vibration:	Mechanical Shock: EP455 Section 5.41.1 Operational Vibration: EP455 Section 5.15.1 Random
GPS Sensitivity	-142 dBm	EMC:	CE (ISO 14982 Emissions and Immunity), FCC Part 15, Subpart B, CISPR 22
SBAS Tracking	3-channel, parallel tracking	Enclosure:	IP67
Update Rate:	10 Hz standard, 20Hz optional (with subscription)	Power	
Horizontal Accuracy:	RMS(67%) 2DRMS (95%)	Input Voltage:	7 - 36 VDC with reverse polarity operation
RTK ^{1,2}	10 mm+1 ppm 20 mm+2 ppm	Power Consumption:	< 3 W @ 12 VDC typical
SBAS (WAAS) ¹	0.3 m 0.6 m	Current Consumption:	249 mA @ 12 VDC typical
Autonomous, no SA ¹	1.2 m 2.5 m	Power Isolation:	No
Pitch/Roll Accuracy	1° using tilt sensor	Reverse Polarity Protection:	Yes
Timing (1PPS)		Antenna Voltage:	Internal Antenna
Accuracy:	20 ns	Mechanical	
Cold Start:	< 60 s typical (no almanac or RTC)	Dimensions:	10.4 H x 14.5 D (cm) 4.1 H x 5.7 D (in)
Warm Start:	< 30 s typical (almanac and RTC)	Weight:	< 558 g (< 19.7 oz)
Hot Start:	< 10 s typical (almanac, RTC and position)	Status Indicators (LED):	Power, GPS Lock
Maximum Speed:	1,850 kph (999kts)	Power/Data Connector:	12-pin male (metal)
Maximum Altitude	18,288 m (60,000 ft)	Antenna Mounting:	1-14 UNS-2A female, 5/8-11 UNC-2B adapter, and mag-mount available
Communications			
Serial Ports:	2 full-duplex RS-232, CAN		
Baud Rates:	4800 - 115200		
Data I/O Protocol:	NMEA 0183, NMEA 2000 ² , Hemisphere GNSS binary		
Correction I/O Protocol:	Hemisphere GNSS proprietary, RTCM v2.3 (DGPS), RTCM v3 (RTK), CMR (RTK), CMR +(RTK) ⁴		
Timing Output:	1 PPS CMOS, active high, rising edge sync, 10 kΩ, 10 pF load		
Event Marker Input:	CMOS, active low, falling edge sync, 10 kΩ, 10 pF load		

Figure 27 - A101 Datasheet

5.1.2. GlobalSat

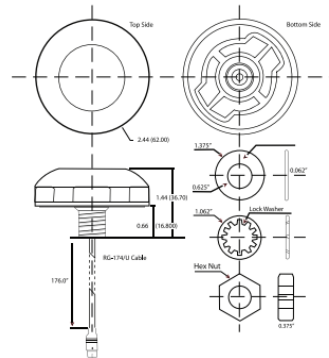
The MR-350 was selected from the list as it met the required specification, at a reasonable price of £40. There were a couple of other receivers in Table 2 that could have been good choices, however although not included in the table, the MR-350 is based around the SIRF

Star IV receiver. From some of the research conducted this has been mentioned frequently online being one of the newer chips, and offering better than quoted performance. Based on this information it was selected as part of the test pool, to see if the data specifications were on the conservative side.

MR-350PS4

GPS Receiver

- SiRF Star IV Chipset
- 48-Channel All-In-View Tracking
- NMEA 0183 GPS Protocol
- WAAS/ EGNOS Support
- 2.44" x 0.82"(Exposed Housing)
- USB or RS232 Interface Cable Sets Available
- IPX7 Rated Water Resistant Design



Performance Specifications

General.....	L1 (1575.42MHz) frequency C/A code 48 channel all-in-view-tracking receiver
Accuracy.....	5 meters 2D RMS (WAAS enabled) 10 meters, 2D RMS, (WAAS disabled)
Acquisition.....	Reacquisition: 0.1 sec, average hot start: 1 sec., average warm start: 35 sec., average cold start: 35 sec., average

Protocol

```
PPS output.....1uS(microsecond) pulse every second at 2.85v with 3D GPS Fix
GPS Protocol.....Default: NMEA0183 (Secondary: SIRF binary)
GPS Output Data.....SIRF binary >> position, velocity, altitude,
                        status and control NMEA0183 MEA0183 V2.2 protocol
                        Software command setting
GPS transfer rate.....(Default: 4800,n,8,1 for NMEA )
Connection.....Requires Optional Cable Set
                        USB: #BR305-USB8
                        RS232: #BR305-RS232
```

Electrical Characteristics

Prime Power.....4.5V - 6.5V DC Input (USB or PS/2)
Power Consumption.....80mA

Environmental Specifications

Operation Temperature.....-40°~ 185°F (-40°~ 85°C)

Physical Characteristics

Enclosure.....	Durable Polycarbonate
Housing Dimensions.....	2.44"x0.82" (exposed housing) (62mm x 21mm)
Cable Length.....	177" (terminates to PS/2) (4.496mm)
Weight.....	4.4oz(123.74 grams)

PACKAGE CONTENTS:



PS/2 Mini DIN 6-Pin Male Connector

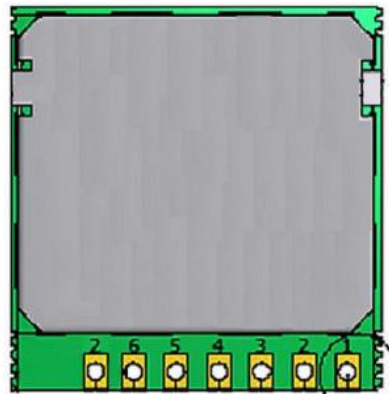
Color	Function	Pin
Black	GND	1
Red	VCC	2
Yellow	PPS	3
White	RX	4
Green	TX	5
----	N/C	6

Figure 28 - MR-350 Datasheet

5.1.3. GPS-622R

The 622R from RF solutions was another receiver that was available from a previous task; it differs slightly from the other two as it comes as a bare chip, with no enclosure. For £30 it shows good specifications on the datasheet, the main point for consideration will be the TTL output rather than RS232 which will have to be considered when testing.

Pin Number	Signal Name	Description
1	RXD	UART input, 3V LVTTTL for SUP500R, SUP500RB
2	TXD	UART output, 3V LVTTTL for SUP500R, SUP500RB UART output, RS232 level for SUP500RR
3	GND	System ground
4	VDD	Main 3.0V ~ 5.5V supply input
5	VBAT	Backup supply voltage for RTC and SRAM, 1.5V ~ 5.5V for
6	P1PS	1 pulse per second time mark output
7	PSE_SEL	Search Engine Mode select



1.2 Features

- 65 Channel GPS L1 C/A Code
- Perform 8 million time-frequency hypothesis testing per second
- 65 Channel GPS L1 C/A Code
- Perform 8 million time-frequency hypothesis testing per second
- Open sky hot start 1 sec
- Open sky cold start 29 sec
- Signal detection better than -161dBm
- Multipath detection and suppression
- Accuracy 2.5m CEP
- Maximum update rate 10Hz
- Tracking current ~28Ma
- Supports external active antenna
- RoHS compliance

Figure 29 - 622R Specification

Parameter	Specification
Receiver Type	65 Channels GPS L1 frequency, C/A Code
Time-To-First-Fix	Cold Start (Autonomous) 29s (Average, under open sky) Warm Start (Autonomous) 29s (Average, under open sky) Hot Start (Autonomous) 29s (Average, under open sky)
Sensitivity	Tracking & Navigation -161 dBm Reacquisition -158 dBm Cold Start (Autonomous) -148 dBm
Accuracy	Autonomous 2.5 m CEP Velocity 0.1 m/sec (without aid) Time 300 ns
Max Update Rate	Supports 1 / 2 / 4 / 5 / 8 / 10 Hz update rate (1Hz default)
Velocity Accuracy	0.1m/s
Heading Accuracy	0.5 degrees
Dynamics	B 4 G (39.2 m/sec)
Operational Limits	Velocity 515 m/s (1000 knots) Altitude <18000 meters (COCOM limit, either may be exceeded but not both)
Serial Interface	LVTTTL level
Datum	Default WGS-84 User definable
Input Voltage	3.3V -5.5V DC +/-10%
Input Current	~23 mA tracking
Dimension	22L x 22W x H (mm)
Weight	25g

Figure 30 -622R Datasheet

5.1.4. Selected GPS

With three GPS receivers highlighted for testing, two being evenly matched on paper and another that should perform considerably better. The test procedure and results will be available in section 6.

5.2. GPS Compass

A GPS compass is not entirely required as part of the design, a reasonably accurate GPS receiver would likely suffice. However there is a GPS compass fitted to the main instrumentation platforms with spare output channels available, along with this the fact that they're also high spec pieces of equipment offering features such as sub metre accurate GPS positions, compass bearings, along with pitch and roll data. With these features available it makes sense to utilise them from the projects perspective. The compass in question is the Hemisphere Vector V103:

Table 3 - GPS Compass

Receiver Type	Vector GNSS L1 Compass
Channels	540
GPS sensitivity	-142dBm
Update Rate	Up to 20Hz
Communications	RS 232, RS422, NMEA 0183, NMEA 200
Voltage	9 – 36VDC
IP Rating	IP69K
Operating Temperature	-30°C to +70°C

GNSS Sensor Specifications

Receiver Type: Vector GNSS L1 Compass
 Signals Received: GPS and GLONASS
 Channels: 540
 GPS Sensitivity: -142 dBm
 SBAS Tracking: 2-channel, parallel tracking
 Update Rate: 20 Hz standard

Positioning Accuracy

RMS:	Horizontal	Vertical
Single Point ¹ :	1.2 m	2.5 m
SBAS (WAAS) ² :	0.3 m	0.6 m
Code Differential GPS ¹ :	0.3 m	0.6 m
Heading Accuracy:	0.30°	
Pitch/Roll Accuracy:	1°	
Heave Accuracy:	30 cm ³	
Timing (1PPS) Accuracy:	20 ns	
Rate of Turn:	90°/s maximum	
Compass Safe		
Distance:	75 cm (with enclosure) ⁴	
Cold Start:	60 s (no almanac or RTC)	
Warm Start:	20 s typical (almanac and RTC)	
Hot Start:	1 s typical (almanac, RTC and position)	
Heading Fix:	10 s typical (valid position)	
Maximum Speed:	1,850 mph (999 kts)	
Maximum Altitude:	18,288 m (60,000 ft)	
Differential Options:	SBAS Beacon, External RTCM	

Beacon Sensor Specifications (V113 version)

Channels: 2-channel, parallel tracking
 Frequency Range: 283.5 to 325 kHz
 Operating Modes: Manual, Automatic, and Database
 Compliance: IEC 61108-4 beacon standard

Communications

Serial Ports: 1 full-duplex RS232; 1 full-duplex RS422 and 1 half-duplex RS422 (Tx only)
 Baud Rates: 4800 - 115200 (V103) and 4800 - 38400 (V113)
 Correction I/O
 Protocol: RTCM v2.3 (DGPS), RTCM SC-104, L-Dif ⁵
 Data I/O Protocol: NMEA 0183, NMEA 2000, Hemisphere Crescent binary ⁵
 Timing Output: 1 PPS (CMOS, active high, rising edge sync, 10 kΩ, 10 pF load)
 Heading Warning I/O: Open relay system indicates invalid heading

Power

Input Voltage: 9 to 36 VDC
 Power Consumption: 4.3 W nominal (GPS L1 + GLONASS L1)
 4.6 W nominal (GPS L1 + GLONASS L1 + Beacon)
 Current Consumption: 0.36 A nominal (GPS L1 + GLONASS L1)
 0.38 A nominal (GPS L1 + GLONASS L1 + Beacon)
 Power Isolation: Yes
 Reverse Polarity Protection: Yes

Environmental

Operating Temperature: -30°C to +70°C (-22°F to +158°F)
 Storage Temperature: -40°C to +85°C (-40°F to +185°F)
 Humidity: 95% non-condensing
 Vibration: IEC 60945 Section 8.7
 EMC: CE (IEC 60945 Emissions and Immunity)
 FCC Part 15, Subpart B CISPR22
 IP Rating: IPX6

IMO Wheelmark

Certification: Yes (does not include the V103 Non-IMO and V113 Non-IMO models). ⁵

Mechanical

Dimensions: 66.3 L x 20.9 W x 14.6 H (cm) 26.1 L x 8.3 W x 5.8 H (in)
 Weight:

<u>V103</u>	<u>V113</u>
2.1 kg (4.6 lb)	2.4 kg (5.4 lb)

 Power
 Status Indications (LED): 18-pin, environmentally sealed
 Power/Data Connector:

Aiding Devices

Gyro: Provides smooth heading, fast heading reacquisition and reliable 1° per minute heading for periods up to 3 minutes when loss of GNSS has occurred ⁴
 Provide pitch and roll data and assist in fast start-up and reacquisition of heading solution
 Tilt Sensors:



Figure 31 - Hemisphere Compass Specification

5.3. Wireless data link

Another key component in this project is the data link, this is needed in order to send the remote GPS data wirelessly back to the main unit. The data will need to be transmitted reliably as any errors in the information being sent will be detrimental to the system performance, without receiving the latest position the bearing will either be calculated using stale positional data and introduce errors or a bearing won't be able to be calculated at all. Transceivers will be used to form the data link adding flexibility in the design and testing as they can be used interchangeably. The data link must be reliable up to 2.5km, this figure was selected as the system is primarily designed for use with a camera, and anything further than this viewed at sea level won't provide the best footage. The majority of tasks will be shorter than 1km range.

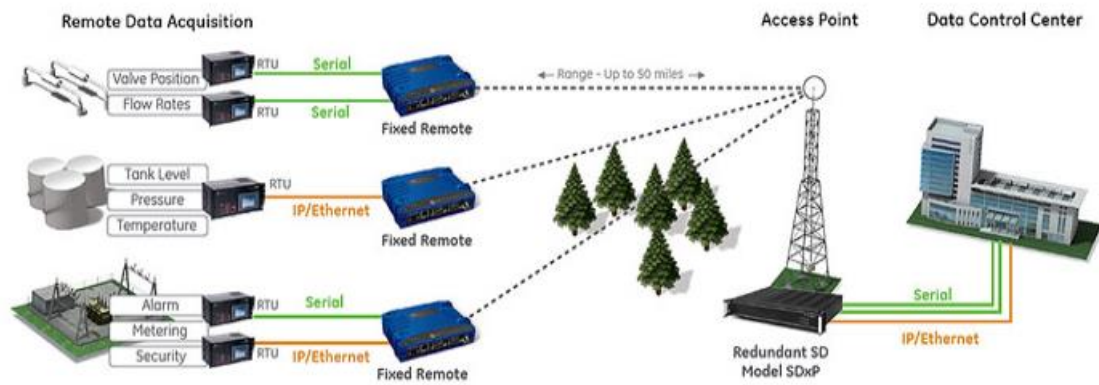
5.3.1. GE Grid Solutions

This company operates in the energy sector, with a range of products for the control, transmission, distribution and monitoring of the equipment along the way. "Grid solutions, a GE and Alstom joint venture, is serving customers globally with more than 20,000 employees in approximately 80 countries. Grid Solutions equips 90% of power utilities worldwide to bring power reliably and efficiently from the point of generation to end power consumers". www.ge.com



The MDS SD Series of data modems is one item of monitoring equipment they use. It operates in licensed frequency bands which allows higher powers to be used, which in turn offers higher transmission ranges. It offers both Ethernet inputs along with standard serial data, such as RS232 and RS485.

SD Series Application Advantages



SD Series Application Advantages

- Operational temperature range from -40°C to 70°C
- CSA Class I, Div. 2 groups A,B,C,D for Hazardous Locations
- IEEE1613*, IEC 61850-3 and EN61000 for electric substation environments

Application Flexibility

- Supports two serial ports and an IP/Ethernet port simultaneously
- Broad coverage flexibility over distances up to 50 miles
- Supports Ethernet Bridging, IP to serial and serial to serial communications
- Low power consumption with sleep mode for solar and battery powered applications
- Fast-serial features with embedded terminal server functions for serial to IP/ Ethernet encapsulation
- Extend communication paths using single radio store and forward

Reliable & Scalable

- Exclusive, non-shared licensed band operation
- High performance Media Access Control for asynchronous polling and exception reporting
- Collision detection and avoidance insures data arrives at destination without lost messages
- High receive sensitivity for long distance communications
- Compatible with multiple industry protocols including Modbus, Modbus TCP, and DNP3

Secure

- AES 128-bit data encryption
- Password protected access
- VLAN data segregation

* Requires an external DC to DC converter having floating DC inputs (neither side grounded)

Figure 32 - MDS Modem

Figure 32 shows an example communication setup using three remote SD modems and one master, from the MDS website

5.3.2. Adeunis

Adeunis has a good reputation in the design and manufacture of connected objects and wireless solutions, along with the integration of the equipment into larger systems; they've grown the business and reputation over their 20 years in business.

The ARF 868MR is one option from their wireless range, and meets the requirements for the data link. It uses a 25mW transmitter in the 863 – 870MHz range giving up to 4km operating distance. It utilises serial data communications, either RS232 or RS485 with various operating modes. Initially the transparent mode would be the most suitable, which operates similar to a cable in that anything coming in on the data lines gets transmitted as RF and vice versa. Due to the power output and frequency range this device has been certified for use without any additional licences. IP53 -67 available



Table 4 - Adeunis Specifications

Name	Range	Data Type	Voltage	Cost
ARF 868MR	4km	RS232 or 485	4.5V - 36V	£175

Highlights

- Range of up to 4km
- High transmission reliability
- RS232/RS485 or USB serial port
- RF rate from 2.4 to 57.6 kbps
- Multi-mode communication: Transparent, addressed, repeater

Technical specifications

- HF Power: 25mW
- +500 channels @14dBm
- External power supply
- Throughput: 1.2-115.2kbps
- Dimensions: 135 x 75 x 35mm (integrated antenna)
- Box: IP41
- Option: IP53 and IP67

Reference

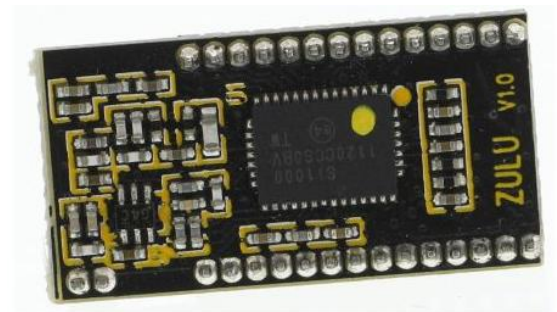
- **ARF7942AA** : ARF868 MIDDLE RANGE 25MW RADIO MODEM INT. ANTENNA
- **ARF7942BA** : ARF868 MIDDLE RANGE 25MW RADIO MODEM EXT. ANTENNA

Figure 33- Adeunis Specification [47]

5.3.3. RF Solutions

RF Solutions as the name suggests specialise in radio modules and remote control systems, the business has been growing substantially since 1991 and now they're one of the leaders of the RF industry. "We are now the largest supplier of RF Remote Controls and RF Telemetry systems, in the UK. We are also one of very few RF module design houses in the EU. From initial design through to the final production inspection. We believe quality brings success. We pride ourselves in supplying the highest quality product combined with the latest technology." www.rfsolutions.co.uk

The Zulu M868 radio modem is built around a 8051 microcontroller using an EZRadioPRO Transceiver for the RF. It has an RF output of +20dBm giving a 2km range. It has four channels available between 868.4 MHz to 869.8 MHz ISM band. UART communications buffered to RS232 levels. The unit is available as a small PCB without an aerial, so an enclosure and aerial would be required.



Name	Range	Data Type	Voltage	Cost
Zulu M868	2km	RS232	2.2V-3.6V	£19.43

TECHNICAL INFORMATION:

PART	ZULU-M868
TYPE	Radio Modem Module
FREQUENCY	868MHz
VCC	2.2 to 3.6V
MODULATION	FM
DATA RATE	UP TO 115Kbps
O/P	+20dBm
SENSITIVITY	-121dBm
PACKAGE	DIP
APPLICATION	Remote Networking, USB/RS232 Cable Replacement, Remote Data Log, Meter Readings

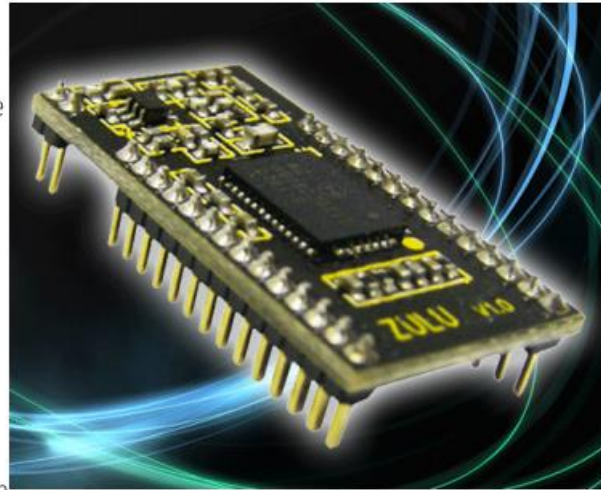
DESCRIPTION:

Radio Modem Module DIP Package

The ZULU Modem module is a highly integrated RF modem and intelligent controller with simple interface to achieve a wireless serial data link for data (upto 38Kbps) over 2km range. Range may be further extended with suitable antenna. The user interface is standard RS232 style control operating at low voltage. All RF operation is automatically controlled (with error checking etc) so the Zulu can be treated as a simple Communications device. Possible applications include one-to-one and multinode wireless links in applications including car and building security, EPOS, inventory tracking, remote industrial process monitoring and computer networking. Because of their small size and low power requirements this module is ideal for use in portable, battery-powered applications such as hand-held terminals.

Features

- Intelligent RF Modem Module
- Serial Data Interface with Handshake
- Host Data Rates up to 38,400 Baud
- RF Data Rates to 115Kbps
- Range up to 2Km
- Minimal external components
- Direct Led Drive Shows Data Flow
- 8 User Selectable Channels
- Secure Data Protocol
- Ultra Low Power 2.4 - 3.6V Operation
- CE Compliant for Licence Free Use
- 868MHz multi channel operation
- 100mW Transmit Power (+20dBm)
- Receiver Sensitivity -121dBm

**Applications**

- Remote networking
- USB/RS232 cable replacement
- Remote data log
- Meter reading

Figure 34 - Zulu M68 data [51]

5.3.4. LORA Gamma 868

The Gamma868 Transceiver is another offering from RF Solutions and can operate as a modem or bidirectional switch, at 868Mhz. Serial data can be input and then transmitted using Orthogonal Frequency Division

Multiplexing (OFDM), this along with other algorithms can achieve a 16km maximum range.



- Low voltage
- No External components
- Spread spectrum Technology
- 20dBm Transmit power
- -137dBm Receiver sensitivity

Name	Range	Data Type	Voltage	Cost
Gamma 868	16km	TTL	5V or 12V	£36

TECHNICAL INFORMATION:

PART	GAMMA-868
TYPE	TRX
FREQUENCY	868MHz
VCC	1.8-3.6V
MODULATION	FM
DATA RATE	UP TO 9.6Kbps
O/P	+13dBm
SENSITIVITY	-121dBm
PACKAGE	SMT
APPLICATION	Remote Control, Remote Networking, Remote Switching, Remote Traffic Lights

DESCRIPTION:

The GAMMA-T telemetry module provides a reliable transceiver based industrial remote switch with up to 16km range. This is achieved using internal OFDM, spread spectrum and extensive algorithm enhancements. When the inputs of the transmitter are activated the outputs of the receiver are activated. Two or more modules may be combined to provide a simple or complex network of radio switches.

Features

- Range up to 16Km
- 8 Switch inputs
- 8 Digital outputs
- 4 acknowledged channels
- Spread spectrum technology
- No external components
- Low Rate Serial Comms
- 38.4K Host serial data comms
- Low voltage 1.8—3.6V
- 'R' Version 3.6—15V
- 869.5 / 915MHz Versions
- +20dBm TX / -137dBm RX
- 868MHz CE / 915Mhz FCC compliant
- SIL version with SMAF connector

**Applications**

- Remote Control
- Remote Networking
- Remote Switching
- Remote Sensors

5.3.5. Digi XBee-PRO XSC

The XBee offers up to 14km transmission range using only a dipole antenna, operating in the 902 to 928MHz frequency range, maximum power of 250mW



Name	Range	Data Type	Voltage	Cost
Digi Xbee	14km	TTL	2.4-3.6V	£114

5.3.6. Selected Data Link

Based on the transceiver options highlighted, the Gamma Lora transceiver was selected, partly down to being at the lower end in terms of price, but it also offered the greatest transmission range, and the option to run at either 5 or 12V could be useful depending on the other component selections.

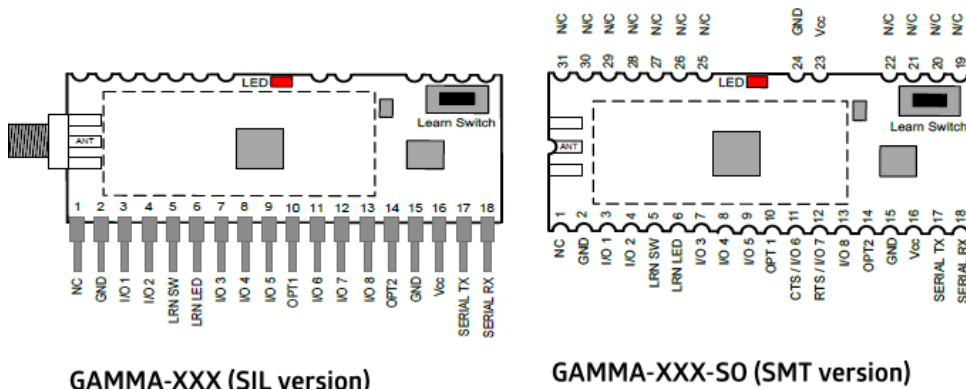


Figure 35 - Gamma Lora Pinout

5.4. Microcontroller

With the required components selected, some suitable microcontrollers can be highlighted that will meet the key requirements. There are still a couple of unknown variables such as program ROM that will only be ironed out once the software development has been completed, however a base specification can be established.

5.4.1. MCU Requirements

A PIC Microcontroller was selected for this project, partly down to the fact that the university had the programmers for this type of MCU, and suitable compilers that would allow the code to be written.

A basic summary of the features that would be required, along with the number of pins for the MCU, this can be seen in Table 5 below.

Table 5 - MCU Requirements

I/O	Data Type	Pins	Freq	Memory
GPS	TTL	2	1Hz	79 bytes
Lora Transceiver	TTL	2	1Hz	79 bytes
LCD Screen	Digital	7	/	/
Terminal	TTL	2	/	/
Start Button		1	/	/
Power	/	2	/	/
Motor	PWM	1	/	/

With the basic requirements of the MCU set, a suitable clock speed and memory size had to be calculated.

If on average it takes 30 instructions in order to take one reading. The clock needs to pulse 4 times for each instruction due to the Quadrature architecture.

$$9600^{-1} = 104\mu\text{s}$$

160 characters in both GPS strings every second

Each ASCII character needs 8 bits to represent, including start/stop gives 10

$160 \times 10 = 1600$ bits per second

30 instructions per reading $\times$ 160 characters = 48K

$48K \times 4 = 192000$ so 192kHz

From previous tasks using the PIC MCU a minimum program size of 16Kb was specified. As the program isn't required to store vast amounts of data, only enough variables to carry out the calculations so 512 Bytes was specified as an initial requirement.

Requirement	Minimum
Pins	17
UART	3
Supply	5V
LCD	1
RAM	≥ 512
Clock Speed	$>192\text{kHz}$
Program	$\geq 16\text{kB}$

With the MCU requirements specified they were entered into the Microchip search function, a selection of the PIC's that matched the specification can be seen in Table 6. Three UARTS were a problem though, the maximum available were two. However from using the CCS complier it had been discovered that it could use up to four software serial ports, so the serial monitor displaying the data could be connected to that.

Table 6 - MCU Options

MCU	PIC18F23K22	PIC18F24K22	PIC18F26K22
Pins	28	28	28
UART	2	2	2
Supply	2.3V -5.5V	2.3V -5.5V	2.3V -5.5V
RAM	512B	768B	3896B
Program Memory	8KB	16KB	65KB
Instructions	4096	8192	32768
Speed	64 Mhz	64 Mhz	64 Mhz
Cost	£1.62	£1.77	£2.23

The PIC18F24K22 was selected from the options, as it met the requirements for a reasonable price.

5.5. Additional components

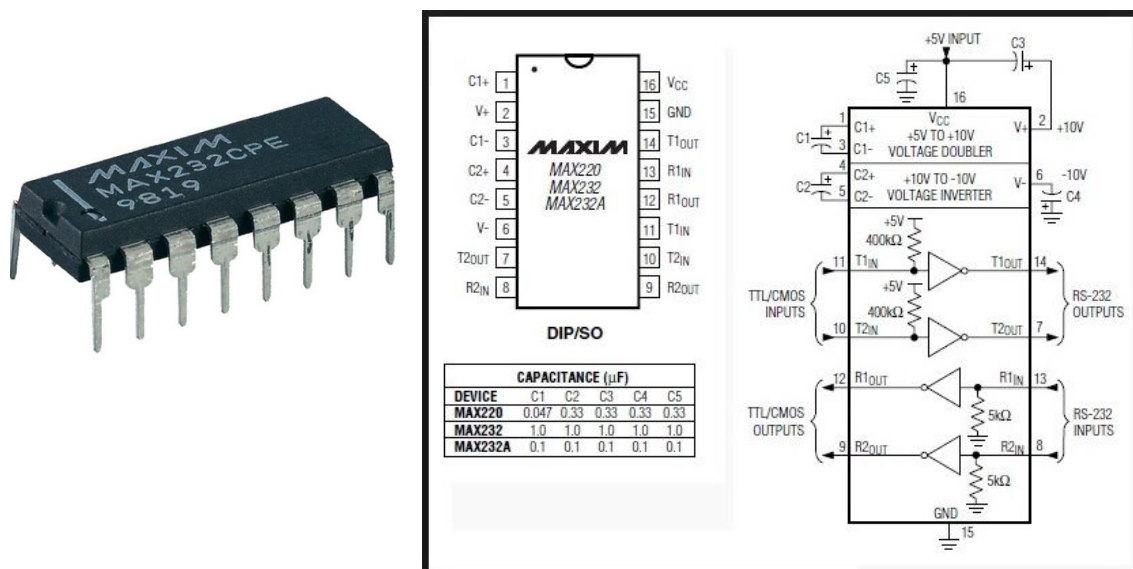


Figure 36 - MAX232

[52]

The Max232 IC is a useful component when dealing with serial data, as it's often required to convert between the various types. The Max232 is designed to convert voltage levels from the TTL standard to RS232 or vice versa. In order to achieve this some additional 1 μF capacitors are required externally to the IC, these are used as part of the charge pump circuit which alters the voltage levels. Standard TTL runs from 0-5V with 5V being the logic high. RS232 operates from -12V - +12V. There are similar IC's that allow conversion to the other data types, RS422 and RS485.

6. Design & Testing

This section details the process undertaken to develop the system design from the basic block diagram seen in the introduction. Although the major components were considered early on, as the design has developed and components selected, an updated system diagram and operation sequence has been produced. Along with these high level diagrams, the system has also been broken down into the constituent parts and detailed in electrical schematics.

6.1. System diagram

Figure 37 shows the basic blocks that make up the system, on the left hand side is the remote unit which will transmit the data via the transceiver. It shows the power connections using the black arrows, and the flow of data using the grey. On the right is the main unit which is built around the PIC microcontroller. The power connections have been omitted from this section to avoid it appearing cluttered; it does show the data directions though.

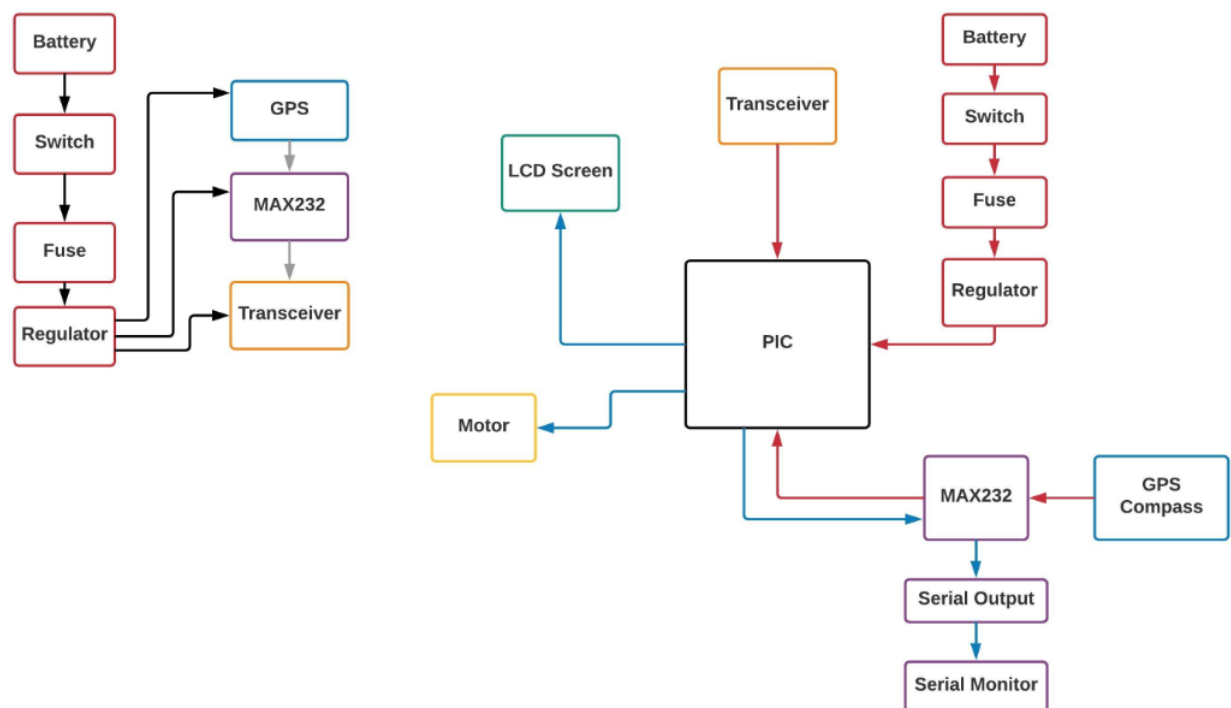


Figure 37 - Basic Block Diagram

6.2. Operational flow chart

A basic high level diagram of the system operation was created, as it would help capture the requirements of operation prior to starting the software. This will be expanded on later in the software section, once the coding and testing has begun.

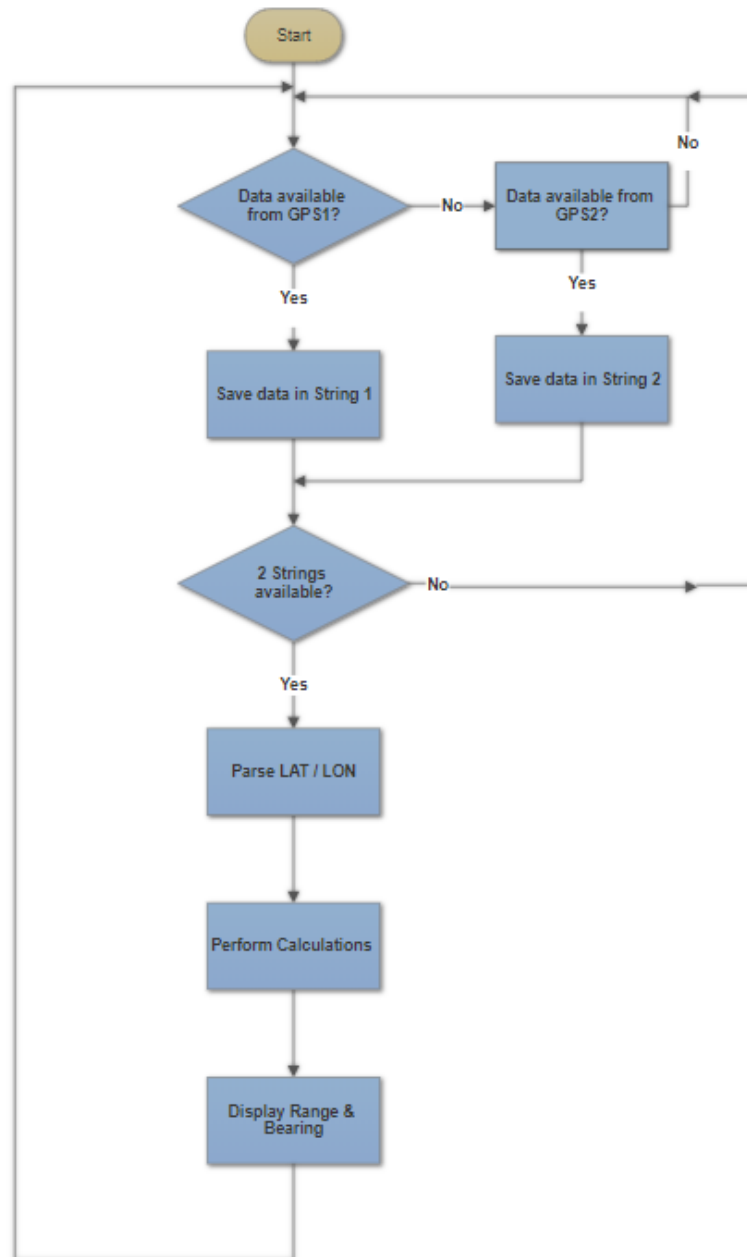


Figure 38 - High Level Operation

6.3. Risk Assessment

Prior to undertaking any manufacture or testing activities, a basic risk assessment was created to ensure everything was done safely. The risk matrix was taken from a company template for risk assessments, with the contents in Figure 39 created purely for this project.

Likelihood of Event	Severity					Severity		Likelihood	
		C	Cr	Se	M	N	C	F	
	F	VH	VH	H	M	L	Cr	Cr	Frequent (Not surprised, will occur several times)
	P	VH	VH	H	M	L	Cr	P	Probable (Occurs repeatedly/an incident to be expected)
	O	H	H	M	L	T	Se	O	Occasional (Infrequent, but could occur some time)
	R	M	M	L	T	T	M	R	Remote (Unlikely though conceivable)
	I	L	L	T	T	T	N	I	Improbable (Could happen but probably never)

Task	Hazard	Who Might Be Harmed?	Likelihood	Severity	Risk Rating	Control Measures	Likelihood	Severity	Risk Rating
Manual Handling	Muscular-Skeletal Injury Muscle strain Crushing injury	Student	O	Se	M	- Manual handling training - Use of lifting aids - Seek assistance - Adhere to HSE guidelines - Correct PPE	R	Se	L
Soldering	Fumes Burns	Student	O	M	L	- Fume extraction - Competency - Suitable PPE	O	N	T
Electronic Manufacture	Sharp tools Power tools Electric shock Burns	Student	R	Se	L	- Competency - Use of machine guards - Correct PPE - Equipment PAT Tested - PUWER	R	M	T
Mechanical manufacture	Power Tools Guillotine Sheet Bending	Student / Colleagues	R	Se	L	- Competency - Use of machine guards - Correct PPE - Equipment PAT Tested - PUWER	R	M	T
Driving	Other Road Users Unsafe Load	Student / Public	R	Cr	H	- Valid driving licence - Take breaks if tired - Care when loading equipment - Fasten items securely, when used for testing	R	Se	L
Testing	RF hazard Moving parts Electric shock	Student	R	Se	L	- RADHAZ Assessment - PAT tested equipment - Ensure equipment isolated, when approaching.	R	M	T

Figure 39 - Risk Assessment

6.4. Gamma Lora

This section details the setup and testing of the Gamma Lora, which was selected from the range of RF transceivers. The following figures are some key excerpts from the datasheet showing the wiring and settings available.

Mode selection

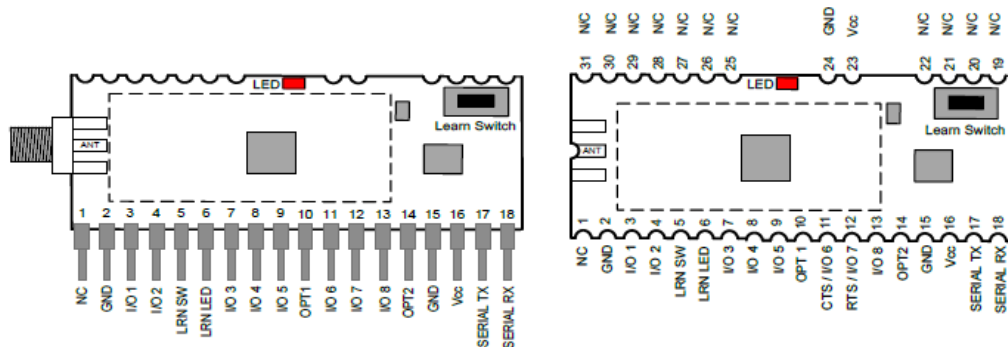
Using the OPT option links, a GAMMA module can be configured to be a

- Telemetry Transmitter, Receiver or Transceiver,
- Serial Data Modem

For telemetry operation, two or more GAMMA modules are required to be paired together. The outputs on the GAMMA receiving will then follow the inputs on the GAMMA transmitting.

Serial data communication does not require any pairing.

	OPT1 (pin10)	OPT2 (pin14)	Inputs	Outputs
Transmitter mode Operates as a transmitter. All I/O lines are dedicated as digital inputs (open/closed contact switch) and will map directly to all 8 outputs on paired receiver(s).	NC	NC	8	-
Receiver mode Operates as a receiver with digital switching outputs.	NC	GND	-	8
Telemetry transceiver Operates as a transceiver with digital switching inputs and outputs on the same board.	GND	NC	4	4
Serial MODEM Mode Operates as a serial modem sending and receiving serial data.	NC	GND	-	-



GAMMA-XXX (SIL version)

GAMMA-XXX-SO (SMT version)

Figure 40 - Gamma Pinout & Mode

Configuring a GAMMA module modem:

In Serial Data modem mode the GAMMA module is a transparent link, passing serial data received on the TX pin to all other GAMMA modules which in turn send the data received to their connected host via the receive pin.

In order to change the configuration settings the GAMMA module must be placed into config/Learn Mode.

Data is then processed internally by the module instead of being transmitted via RF.

Config/learn mode

Press and hold the 'LEARN' button (or activate the 'LEARN' input) on a GAMMA module for two seconds or until the learn LED begins to flash. This places the module in config mode.

Please Note: When in Config/learn mode modules will always communicate at a default baud rate of 9600kbps it does not matter what baud rate is set with #B command.

Default LVTTL Comms RS232:

Data bits: 8
Parity: None
Stop bits: 1
Flow control: Hardware CTS/RTS if enabled
Buffer size: 250bytes
Timeout: 2 bytes (time dependent on baud rate)
Data bytes: 11 bytes

GAMMA module factory defaults:

Local address: 7F7F7F
Destination address: 7F7F7F
Handshaking: OFF
LoRa™ Mode: 5
Host baud rate: 9600kbps
O/P power: +20dBm

Configuration commands:

Command	Description	Options / example packet														
#C	Set LORA™ mode and power output GAMMA can be set to operate in different LORA™ modes, trading off range with speed of operation. With a lower LORA mode the data packet is much shorter but the maximum range achievable is also shorter. In mode 6 the GAMMA has been tested to 16km	#C<LORA MODE 1-6 (SF6-12)><O/P POWER 1-15(-1 - +20dBm)> Where: SF6 = Short range / high speed SF12 = Long range / low speed Power 1 = +5dBm Power 15 = +20dBm Output power is set in 1dbm increments from +5 to +20. ASCII example: #C 006 015 GAMMA set to longest range and max. power. Please Note: all option values are byte decimal values. <table><tr><th>LORA MODE</th><th>Packet length</th></tr><tr><td>001</td><td>55ms</td></tr><tr><td>002</td><td>90ms</td></tr><tr><td>003</td><td>180ms</td></tr><tr><td>004</td><td>360ms</td></tr><tr><td>005</td><td>720ms</td></tr><tr><td>006</td><td>1.02 sec</td></tr></table>	LORA MODE	Packet length	001	55ms	002	90ms	003	180ms	004	360ms	005	720ms	006	1.02 sec
LORA MODE	Packet length															
001	55ms															
002	90ms															
003	180ms															
004	360ms															
005	720ms															
006	1.02 sec															

Command	Description	Options / example packet																		
#A	Sets the send to and local address: Pre-configured factory defaults: L_ADD = 7F7F7F D_ADD= 7F7F7F	#A<L_ADD1><L_ADD2><L_ADD3><D_ADD1><D_ADD2><D_ADD3> Where: L_ADD are local address bytes 1 3 D_ADD destination address bytes 1-3 Example: #A 125 125 125 126 126 126 Sets the Local address to 125 125 125 Sets the Destination address to 126 126 126 Please note the Address must be sent as byte values. Example: <table><tr><td>Command</td><td>#</td><td>A</td><td>7D</td><td>7D</td><td>7D</td><td>7E</td><td>7E</td><td>7E</td></tr><tr><td>ASCII Value</td><td>035</td><td>065</td><td>125</td><td>125</td><td>125</td><td>126</td><td>126</td><td>126</td></tr></table>	Command	#	A	7D	7D	7D	7E	7E	7E	ASCII Value	035	065	125	125	125	126	126	126
Command	#	A	7D	7D	7D	7E	7E	7E												
ASCII Value	035	065	125	125	125	126	126	126												
#H	Turn on handshaking CTS / RTS enable or disable command	#H 001 Enables handshaking - set 0 to disable																		
#B	Set serial baud rate	#B <000-004> Where: 000 = 9600(default) 001 = 19200 002 = 28800 003 = 38400 004= 56000 Example: Set the Baud to 38K4: #B 003																		
#?	Get local settings Returns all configured settings	#? Returns a single packet containing 11 bytes as follows: <L_ADD1><L_ADD2><L_ADD3> <D_ADD1><D_ADD2><D_ADD3> <NULL Value> <LORA Mode> <RF Power> <Handshaking> <Baud rate>																		
#Q	Reset device	All changes on the GAMMA are carried out in real time and saved after each change. However none become active until the module is reset either using this command or by power cycling.																		

Figure 41 - Lora Programming Settings

6.4.1. Lora Test Procedure

- Establish communications with a PC.
- Set Parameters.
- Send data across the link.
- Send NMEA format GPS data.
- Test output power and frequency.
- Range test.

In order to program the Lora modems a basic interface circuit was built using a MAX232 IC that would allow the TTL device to be connected up to a computer serial port, this was

necessary as a PC terminal was required to show the Hexadecimal messages from the device, in order to configure the properties. It would also aid in the testing of the data link, as a method of viewing the transmitted and received data. The completed circuit connected up with the Lora transceiver can be seen in Figure 42. In order to configure it as a modem, OPT2 had to be connected to ground, and the Pinout from Figure 40 was used for the other connections. The various parameters that could be adjusted along with the default manufacturers' settings can be seen in Figure 41.

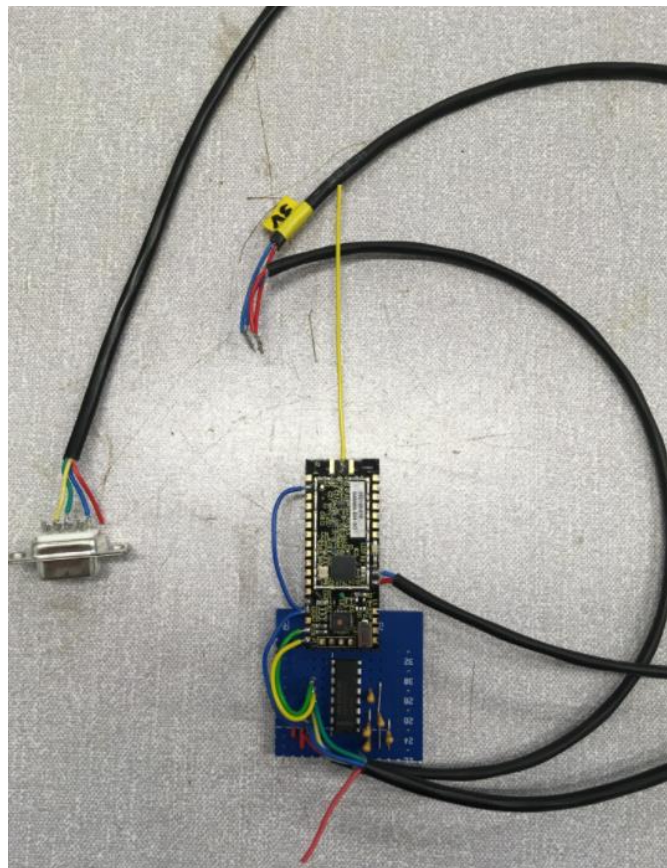


Figure 42 – Lora with Interface Circuit

In order to send commands to the Lora, a new terminal was downloaded based on the manufacturers' recommendations; this allowed macros to be set within the program, which is something hyper terminal doesn't allow. It also allowed the messages to be displayed as either ASCII or hexadecimal. A few Macros were set following the format shown in the datasheet, Figure 41. The terminal showing a typical received message along with the macros set can be seen in Figure 43 and Figure 44.

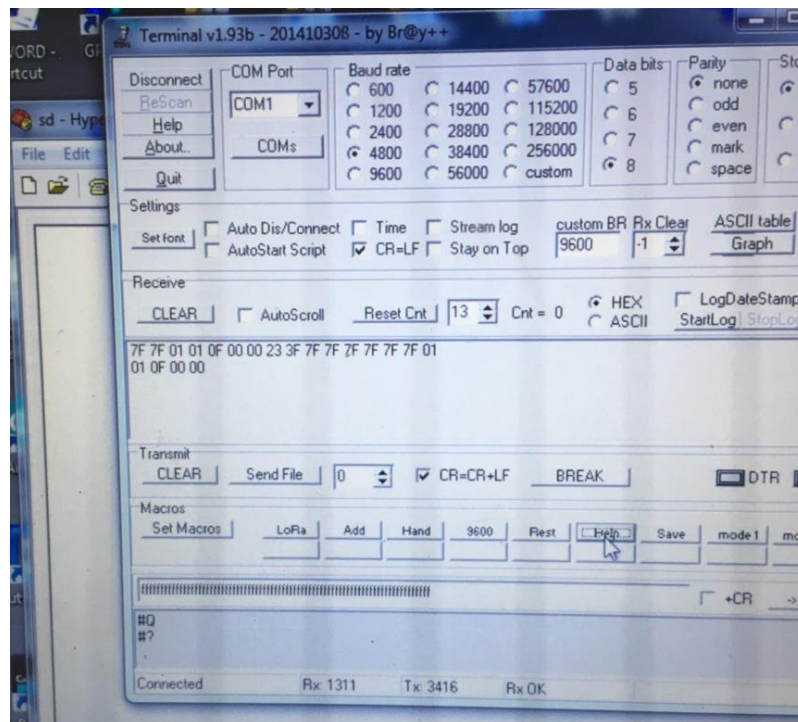


Figure 43 - Initial Lora Setup

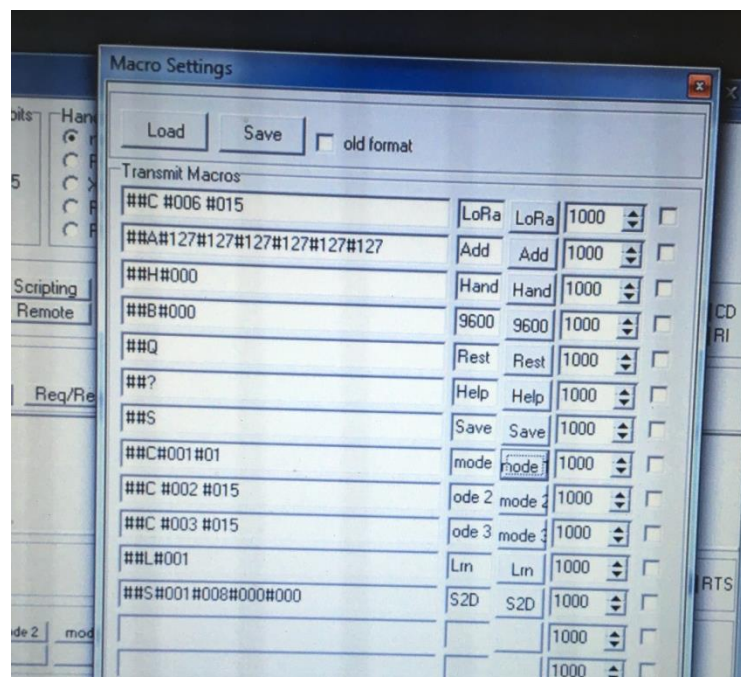


Figure 44 - Setting Macros

With both Lora modems setup along with an interface circuit, some initial tests were carried out using two PC's and sending characters and sentences across the data link. This worked ok, in that the characters would be displayed on the other terminal, however there was quite a delay observed, a sentence could be written, then walk across the room and watch it start to appear on the other terminal. This would not be suitable for the application, and clearly showed some settings needed to be modified. The different modes available to the Lora are shown in Figure 45, which allowed the user to adjust between speed of operation and maximum transmission distance between 6 individual modes. As default the Loras' had been set at mode 6 which was quoted as being tested at 16km, in this setting it had a packet length of 1.02 sec. As this had proved too slow during the initial test, the settings were changed to the opposite end of the spectrum, mode 1 which stated a packet length of 55ms. With both Loras' reprogrammed the test was repeated, with a much quicker response. This looked more suited to transmitting GPS data at 1Hz.

Command	Description	Options / example packet														
#C	Set LORA™ mode and power output GAMMA can be set to operate in different LORA™ modes, trading off range with speed of operation. With a lower LORA mode the data packet is much shorter but the maximum range achievable is also shorter. In mode 6 the GAMMA has been tested to 16km	#C<LORA MODE 1-6 (SF6-12)><O/P POWER 1-15(-1 - +20dBm)> Where: SF6 = Short range / high speed SF12 = Long range / low speed Power 1 = +5dBm Power 15 = +20dBm Output power is set in 1dbm increments from +5 to +20. ASCII example: #C 006 015 GAMMA set to longest range and max. power. Please Note: all option values are byte decimal values. <table><tr><th>LORA MODE</th><th>Packet length</th></tr><tr><td>001</td><td>55ms</td></tr><tr><td>002</td><td>90ms</td></tr><tr><td>003</td><td>180ms</td></tr><tr><td>004</td><td>360ms</td></tr><tr><td>005</td><td>720ms</td></tr><tr><td>006</td><td>1.02 sec</td></tr></table>	LORA MODE	Packet length	001	55ms	002	90ms	003	180ms	004	360ms	005	720ms	006	1.02 sec
LORA MODE	Packet length															
001	55ms															
002	90ms															
003	180ms															
004	360ms															
005	720ms															
006	1.02 sec															

Figure 45 - Lora Mode

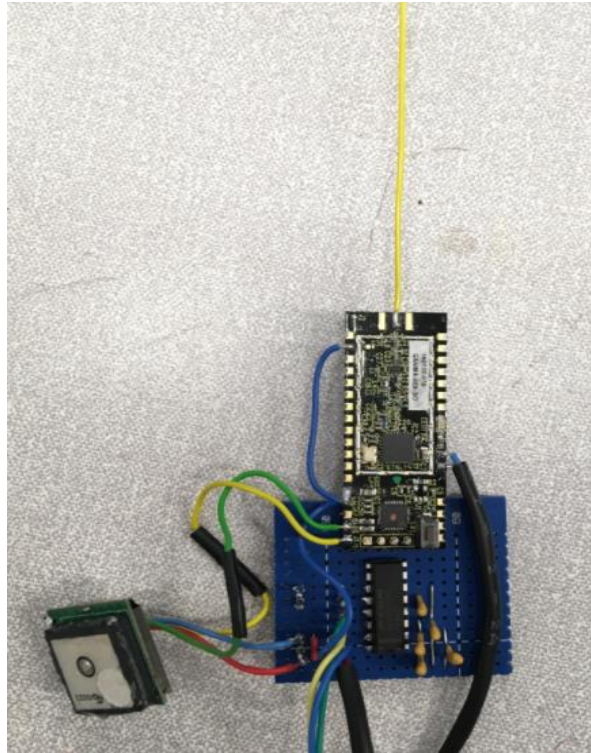


Figure 46 - Lora & GPS

The next stage of testing required sending actual GPS data, in order to do this a 5V GPS receiver was used with a TTL output, this was connected directly to the Lora Rx pin bypassing the MAX232, as this would now have to be placed outside a USB connector was added to provide 5V from a USB Power bank. An aerial was made using a length of solid core wire, this would act as a basic $\frac{1}{4}$ wave isotropic aerial, and although not adding any gain it would help the signal to propagate through the air more effectively. This was done using the calculation below:

$$C = f\lambda$$

Where C is the speed of light, F is frequency and λ is the wavelength.

$$3 \times 10^8 = 868 \times 10^6 \times \lambda$$

$$\lambda = \frac{3 \times 10^8}{868 \times 10^6} = 0.3456\text{m}$$

$$\frac{1}{4} \lambda = 0.086\text{m}$$

To back up the calculated length an online wavelength calculator was also used, which matched the 8.6cm $\frac{1}{4}$ wavelength at the Lora's operating frequency.

Figure 47 - Wavelength Calculator [53]

6.4.1.1. Radiation Hazard

Although the transceivers have a low output power, allowing them to be used without a licence, a basic Radiation Hazard (RadHaz) assessment was carried out using an online tool as a precaution. The output power from the datasheet was quoted as being able to be set between 5– 20 dBm, for the assessment the max power of 20 dBm was used, which equates to 100mW as shown below.

$$P_{dBm} = 10 \log_{10}(P_{mW})$$

$$P_{mW} = 10^{\frac{P_{dBm}}{10}}$$

This was entered into the tool along with the gain and frequency of the Gamma Lora, and returned a safe working distance of 2cm in an uncontrolled environment. With such a low distance this should prove fairly easy to mitigate any risk. The details can be seen in Figure 48.

Amateur Radio RF Safety Calculator

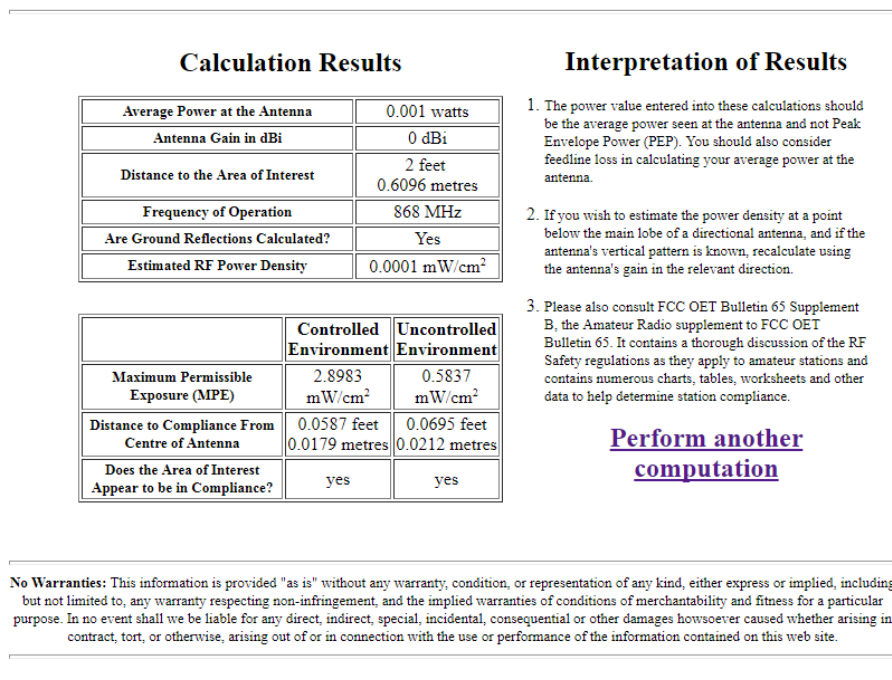


Figure 48 - Radiation Safety Distance

In order to prove that the Gamma Lora had been set to the maximum power prior to carrying out any more function and range tests of the data link, they were connected up to a spectrum analyser which would show the actual frequency they were transmitting at, along with the output power. A 30dB attenuator was used to protect the input of the spectrum analyser and a RG58 cable with an N-type on one end and an SMA connector on the other was used to connect to the Lora (an SMA connector was substituted for the wire aerial). Figure 49 and Figure 50 show the setup, with the peak frequency centred on 869.5 MHz which is slightly off the quoted 868 MHz, the power shows at -11.83dBm which taking into account the 30dBm attenuator gives approximately 18dBm, this showed that the Lora was setup correctly, but some loss could be being introduced in the connectors and cable, a rule of thumb is 0.5dBm each connecting surface.

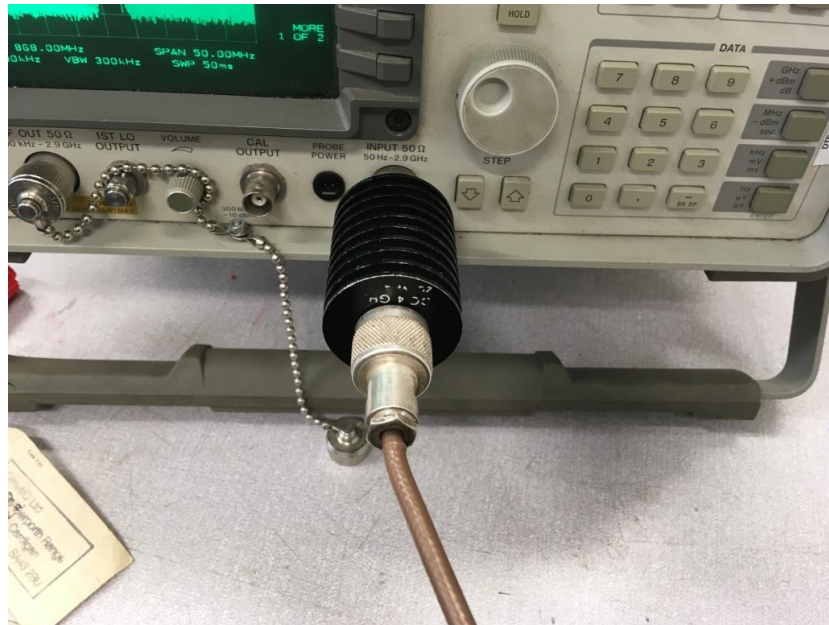


Figure 49 - 30dB Attenuator

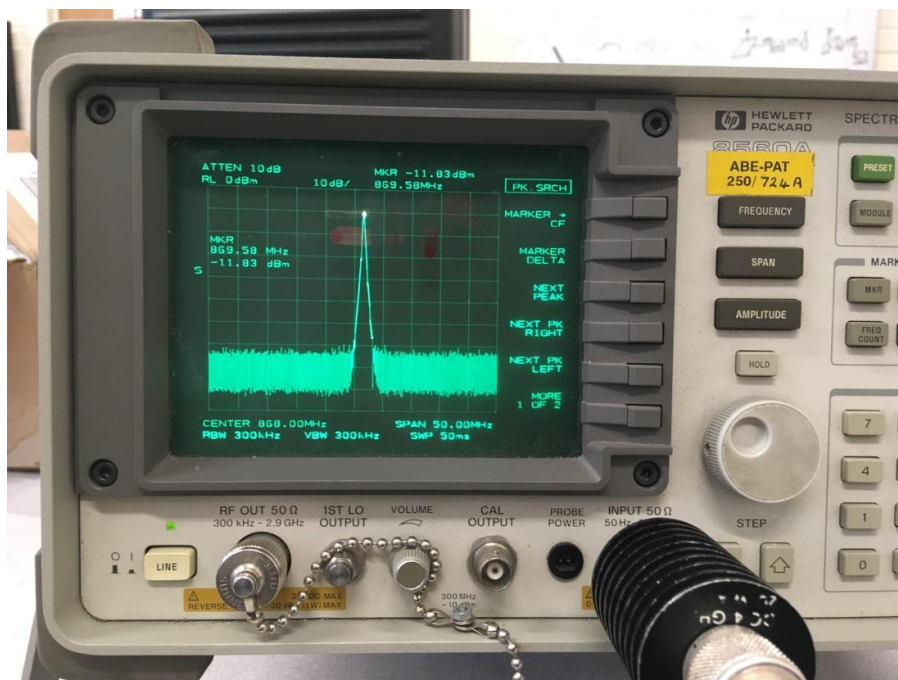


Figure 50 - Spectrum Analyser

The frequency spectrum is fairly good, with no energy lost in sidebands or any spikes from harmonics. The fundamental has a sharp point with a steep roll off, showing the tuning for that frequency, rather than a wide frequency band.

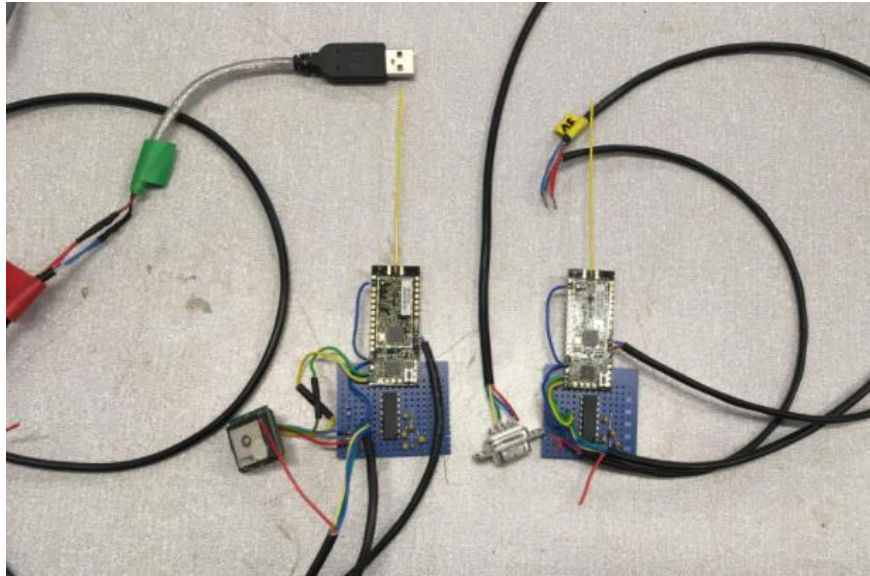


Figure 51 - Wireless Data Link

6.4.1.2. Range Test

A GPS receiver was connected up to the transmitter which was left in a fixed location, the receiver then travelled away from the transmitter in a vehicle, maintaining a rough line of site; the transceivers had been set to mode 1, which displayed the 1Hz GPS data tidily on the screen. The achieved distance before the data stopped being received was approximately 4km, the specifications hadn't quoted a maximum distance in mode 1, however mode 6 was quoted at 16km. 4km will still be suitable for this application as the 5m pontoons are usually within 2km of the main platform. One of the issues in carrying out a representative range test in this area is maintaining a clear line of site, whilst taking advantage of public roads to make testing easier, Figure 52 doesn't show it clearly, but the terrain in this area is fairly hilly. Another potential issue is the fact that this data link will be used at a fairly low height over the water when the system is complete (approximately 2.5m), this can introduce additional issues such as signal multipathing. Ideally a range test would have been carried out at sea, however there weren't any activities planned where this could have been incorporated, and it wasn't practical in terms of time and cost to go out solely for this activity.

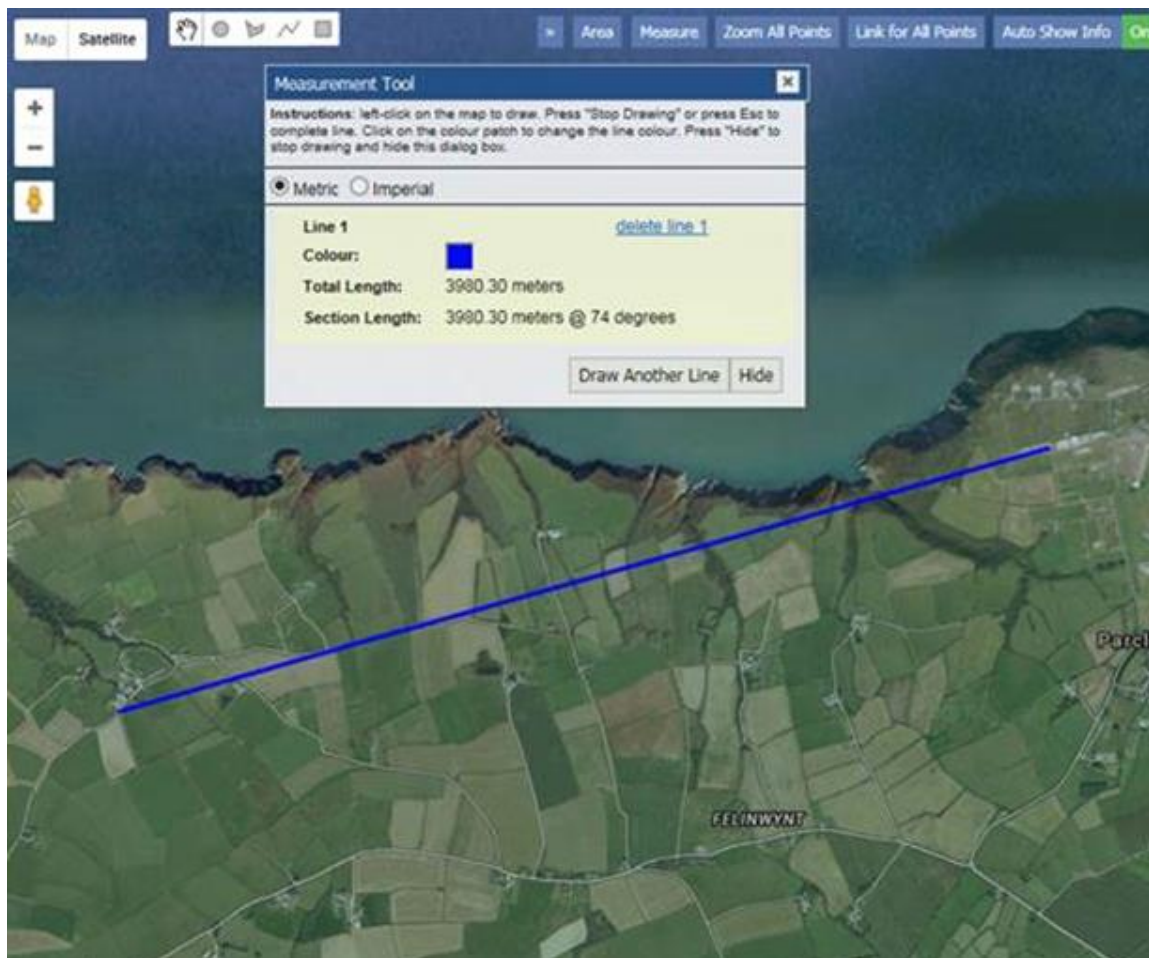


Figure 52 - Lora Range Test [39]

6.4.2. Lora Test Conclusion

For completeness following the range test, the other Lora modes were tested with a GPS receiver connected up to the input of one modem, the following figures show the output from the data link.

```

$GPGGA,162200.987,5208.1184,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-41
$GPGGA,162201.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-41
$GPGGA,162202.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-42
$GPGGA,162203.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-43
$GPGGA,162204.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-44
$GPGGA,162205.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-45
$GPGGA,162206.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-46
$GPGGA,162207.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-47
$GPGGA,162208.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-48
$GPGGA,162209.987,5208.1185,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-49
$GPGGA,162210.987,5208.1186,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-42
$GPGGA,162211.987,5208.1186,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-43
$GPGGA,162212.987,5208.1186,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-40
$GPGGA,162213.987,5208.1186,N,00433.5118,W,1.06,1.2,105.2,M,54.6,M,0000-41
$GPGGA,162214.987,5208.1186,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-49
$GPGGA,162215.987,5208.1186,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-48
$GPGGA,162216.987,5208.1186,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-4B
$GPGGA,162217.987,5208.1187,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-4B
$GPGGA,162218.987,5208.1187,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-44
$GPGGA,162219.987,5208.1187,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-45
$GPGGA,162220.987,5208.1186,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-4E
$GPGGA,162221.987,5208.1186,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-4F
$GPGGA,162222.987,5208.1187,N,00433.5117,W,1.06,1.2,105.2,M,54.6,M,0000-4D

```

Figure 53 - Mode 2

Mode 2 also proved suitable to transmit 1Hz data, with the time (\$GPGGA,162222.987) incrementing by one second each transmission. The data is also coming through tidily, with one line used per sentence. Mode 3 in Figure 54 also proved suitable, which indicated it may be worth carrying out an additional range test using this setting. Another consideration was to alter the GPS data rate, as it may be necessary to transmit data at a higher frequency when developing the tracking element of the system.

```

$GPGGA,162554.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4A
$GPGGA,162555.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4B
$GPGGA,162556.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-48
$GPGGA,162557.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-49
$GPGGA,162558.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-46
$GPGGA,162559.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-47
$GPGGA,162600.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-48
$GPGGA,162601.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-49
$GPGGA,162602.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4A
$GPGGA,162603.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4B
$GPGGA,162604.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4C
$GPGGA,162605.987,5208.1180,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4D
$GPGGA,162606.987,5208.1179,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-48
$GPGGA,162607.987,5208.1179,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-49
$GPGGA,162608.987,5208.1179,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-46
$GPGGA,162609.987,5208.1179,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-47
$GPGGA,162610.987,5208.1179,N,00433.5110,W,1.07,1.1,105.1,M,54.6,M,0000-4F
$GPGGA,162611.987,5208.1179,N,00433.5109,W,1.07,1.1,105.1,M,54.6,M,0000-46
$GPGGA,162612.987,5208.1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-46
$GPGGA,162613.987,5208.1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-47
$GPGGA,162614.987,5208.1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-40
$GPGGA,162615.987,5208.1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-41

```

Figure 54 - Mode 3

```

$GPGGA,162617.987,5208,1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-43
$GPGGA,162618.987,5208,1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-4C
$GPGGA,162619.987,5208,1179,N,00433.5109,W,1.07,1.1,105.2,M,54.6,M,0000-4D
$GPGGA,163057.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-4E
$GPGGA,163059.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-4F
$GPGGA,163101.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-4A
$GPGGA,163103.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-4E
$GPGGA,163105.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-48
$GPGGA,163107.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-4A
$GPGGA,163109.988,5208,1177,N,00433.5086,W,1.08,1.0,106.6,M,54.6,M,0000-44
$GPGGA,163111.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4F
$GPGGA,163113.988,5208,1177,N,00433.5087,W,1.07,1.0,106.6,M,54.6,M,0000-41
$GPGGA,163115.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4B
$GPGGA,163117.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-49
$GPGGA,163119.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-47
$GPGGA,163121.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4C
$GPGGA,163123.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4E
$GPGGA,163125.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-49
$GPGGA,163127.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4B
$GPGGA,163129.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-45
$GPGGA,163131.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4C
$GPGGA,163133.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4E

```

Figure 55 - Mode 4

Figure 55 shows the Lora modems operating in mode 4, this is where the performance starts to degrade, although the sentences are still being displayed tidily, from looking at the time again it can be seen that only 1 message every 2 seconds is being displayed, this must be down to the duration of the buffer in this mode, where it's waiting for more data but missing the next sentence.

```

$GPGGA,163119.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-47
$GPGGA,163121.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4C
$GPGGA,163123.988,5208,1177,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4E
$GPGGA,163125.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-49
$GPGGA,163127.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4B
$GPGGA,163129.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-45
$GPGGA,163131.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4C
$GPGGA,163133.988,5208,1176,N,00433.5087,W,1.08,1.0,106.5,M,54.6,M,0000-4E
$GPGGA,163135.988,5208,1176,N,00433.5088,W,1.08,1.0,106.5,M,54.6,M,0000-47
$GPGGA,163137.988,5208,1176,N,00433.5088,W,1.08,1.0,106.5,M,54.6,M,0000-45
$GPGGA,163139.988,5208,1176,N,00433.5088,W,1.08,1.0,106.5,M,54.6,M,0000-4B
$GPGGA,163141.988,5208,1176,N,00433.5088,W,1.08,1.0,106.5,M,54.6,M,0000-44
$GPGGA,163143.988,5208,1176,N,00433.5088,W,1.08,1.0,106.5,M,54.6,M,0000-46
$GPGGA,163341.988,5208,1176,N,00433.5088,W,1.08,1.0,106.3,M,54.6,M,0000-40
176,N,00433.5088,W,1.08,1.0,106.3,M,54.6,M,0000-45
$GPGGA,163347.988,5208,1176,N,00433.5088,W,1.08,1.0,106.3,M,54.6,M,0000-46
6,N,00433.5088,W,1.08,1.0,106.3,M,54.6,M,0000-40
$GPGGA,163353.988,5208,1176,N,00433.5088,W,1.07,1.1,106.3,M,54.6,M,0000-4D
1177,N,00433.5088,W,1.07,1.1,106.3,M,54.6,M,0000-49
$GPGGA,163359.988,5208,1177,N,00433.5089,W,1.07,1.1,106.3,M,54.6,M,0000-47
08,1177,N,00433.5089,W,1.07,1.1,106.3,M,54.6,M,0000-4E
$GPGGA,163405.988,5208,1177,N,00433.5089,W,1.07,1.1,106.3,M,54.6,M,0000-49
08,1177,N,00433.5089,W,1.07,1.1,106.4,M,54.6,M,0000-43

```

Figure 56 - Mode 5

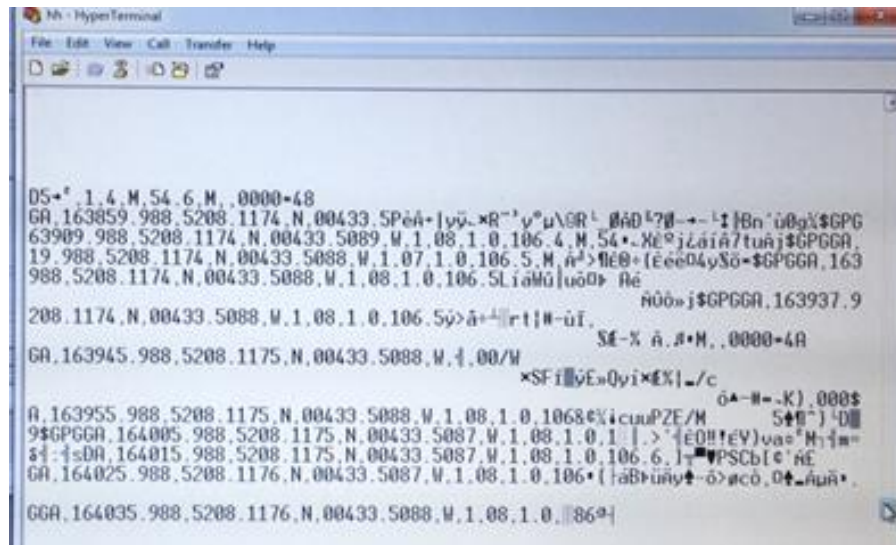


Figure 57 - Mode 6

Figure 56 and Figure 57 show mode 5 and 6 respectively, where the performance degrades even further, along with the formatting on the terminal display.

6.5. GPS

6.5.1. GPS Test

- Setup procedure
- Time To First Fix (TTFF)
- Positional accuracy
- Precision

In order to prove whether the available GPS receivers meet the manufactures claims in terms of accuracy a test basic test procedure has been devised, it will also allow a comparison of the precision of the selected receivers. The site at Aberporth has a dedicated surveying team that get utilised in the deployment of some equipment along with providing accurate positional data ready for various activities, a consequence of this is that there's a few surveyed trig positions on site with highly accurate positional data. This will allow each receiver to be placed at the same location and log the GPS position for a period of time. Ideally they would be left for 24 hours which could show any trend or degradation in performance when using

specific satellites; however this would be problematic in the time it took to get data for the selected receivers, along with the amount of data being produced with 1Hz logging:

$$60 \times 60 \times 24 = 86,400$$

A period of 1 hour was selected instead, and each receiver would be tested at the same time on consecutive days, to ensure fairness in terms of the visible satellites. With the data collected each set of data will be plotted in Excel against the known position, this will allow some form of analysis to take place, possibly a CEP plot to see if the figure matches the receiver specification, or merely some visual annotations such as varying diameter circles around the nominal position. These plots will also show the precision of the receivers, or how closely the positions are grouped.

There are a few different formats for Latitude and Longitude positions, the format used in NMEA messages is known as Degrees Decimal Minutes, and looks like this:

5208.3897740,N,00434.2282640,W

Breaking this down is 52° 08.3897740 minutes of Latitude, and 004° 34.2282640 minutes of Longitude. It is known that lines of latitude remain constant from the equator to both poles, and lines of longitude get smaller as they near the poles due to the shape of the earth. From this fact conventional navigation using charts always referred to 1 minute of latitude to get distances, as it is equal to 1 Nautical mile. It's known that 1Nm is equal to 6076.12 Feet, so the distance for each decimal place can be calculated:

1.0	6076.12 Feet
0.1	607.612 Feet
0.01	60.7612 Feet
0.001	6.07612 Feet
0.0001	0.60712 Feet
0.00001	0.06076 Feet

These calculations were checked with the Aberporth Survey department, who also provided some figures for Longitude in the Aberporth area.

Long

0.1 = 328.91 feet
0.01 = 32.89 feet
0.001 = 3.29 feet
0.0001 = 0.33 feet

Decimal degrees

0.1 degrees = 36480 feet
0.01 degrees = 3648 feet
0.001 degrees = 364.8 feet
0.0001 degrees = 36.4 feet
0.00001 degrees = 3.64 feet
0.000001 degrees = 0.364 feet
0.0000001 degrees = 0.0364 feet

The other common format that will be required later is known as Decimal degrees, in order to convert Decimal Minutes into Decimal degrees, the minutes part is divided by 60 and added onto the original value for degrees.

$$08.38977 / 60 = 0.13983$$

$$0.13983 + 52 = 52.13983$$

In this format a negative number will indicate either south of the equator or west of the Greenwich meridian.

6.5.1.1. Hemisphere

In order to program the GPS receiver, the RS232 connections were wired to a D-type connector, as per the datasheet. It was then connected to a PC running hyper terminal with the default baud rate of 9600 used. In order to configure the output strings, proprietary messages were typed in the terminal window, followed by enter.

\$JOFF – Turns all messages off.

\$JASC, GPGLA,1 – Set port-A to output GPGLA messages at 1Hz.

\$JSAVE – Saved the current configuration.

With the GPS setup, it was placed on the survey stud, and left logging the data for over an hour, as per the earlier procedure. The data plot can be seen in Figure 58, logged from 12:00 – 13:00.

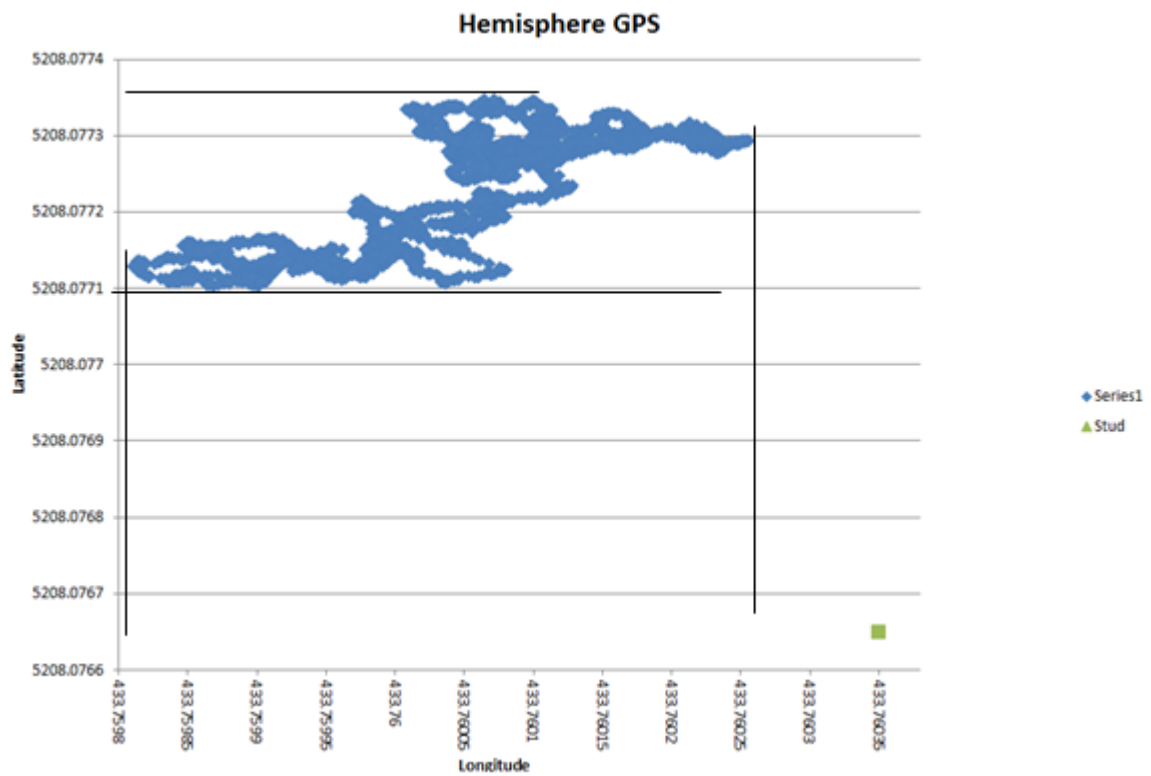


Figure 58 – Hemisphere 1 Hour Plot

$$0.07735 - 0.0771 = 0.00025$$

$$0.00025 \times 6076 = 1.52 \text{ Feet spread in Latitude}$$

$$0.76025 - 0.7598 = 0.00045$$

$$0.00045 \times 3289 = 1.48 \text{ Feet spread in Longitude}$$

(3289 comes from multiplying the survey team figure by 10)

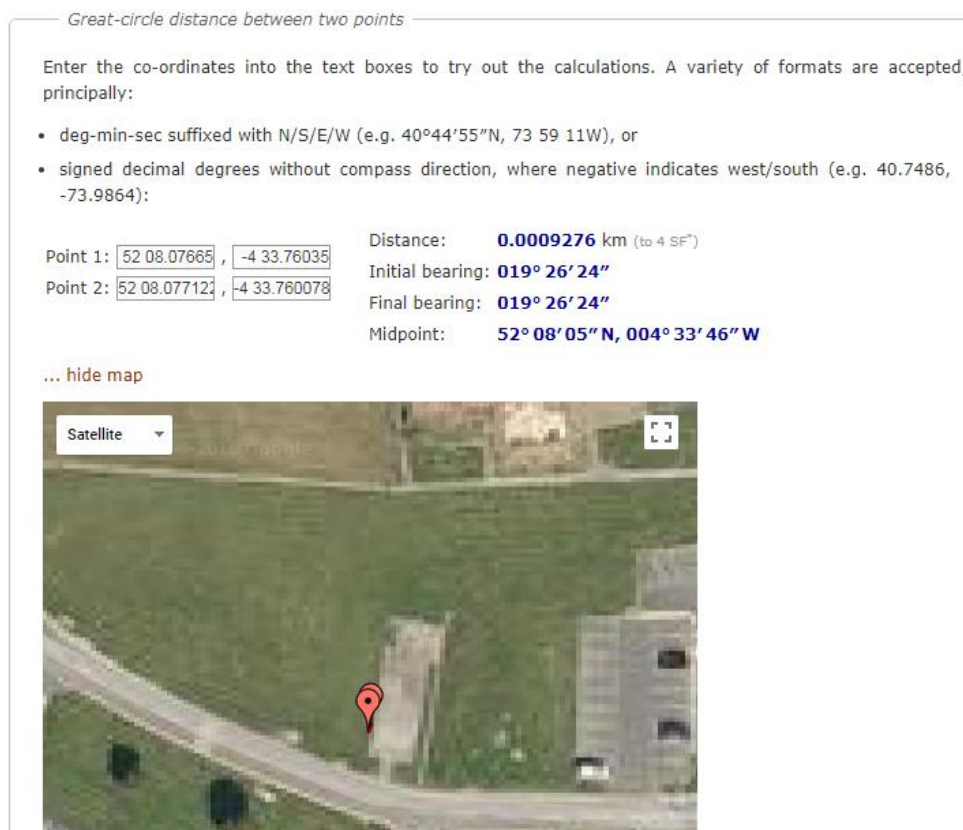


Figure 59 - Hemisphere Accuracy

Hemisphere nearest point to trig stud = 0.928m

Figure 60 shows the TTFF of the Hemisphere GPS receiver after a long time without switch on, at least months. Rather than setting the parameters beforehand, as this would have required switching on which may have altered the results, some maths has to be performed to find the correct TTFF: there were two strings set to output at 10Hz, 4712 lines of data before a valid time and position locked.

$$4712 / 2 = 2356$$

$$2356 / 10 = 235.6 \text{ seconds}$$

$$3.55 \text{ minutes}$$

The calculations tie up with the total time the terminal was connected, in Figure 61.

Figure 60 - Hemisphere Very Cold Start





The TTFF figure from the hemisphere during the cold start was considerably worse than the 60 seconds quoted in the datasheet; however this could be down to the long length of time since the last switch on. The hot start value was considerably better, and much closer to the quoted value of 10 seconds.

To configure the GlobaSat parameters a specific piece of software was downloaded, SIRFDemo allowed direct configuration of the SirfStar chip within the receiver. The connection on the receiver was changed to a DB9 connector to allow it to be connected to the PC COM port. With this setup the default baud rate was selected on the software, and the connect icon clicked. It started streaming out data straight away, in order to configure the messages; the receiver was changed to Sirf Protocol, which changed the data from ASCII to another format. Changing back to NMEA allowed the different strings to be configured, along with the baud rate. There were several other configurable parameters, however these were left for the time being.

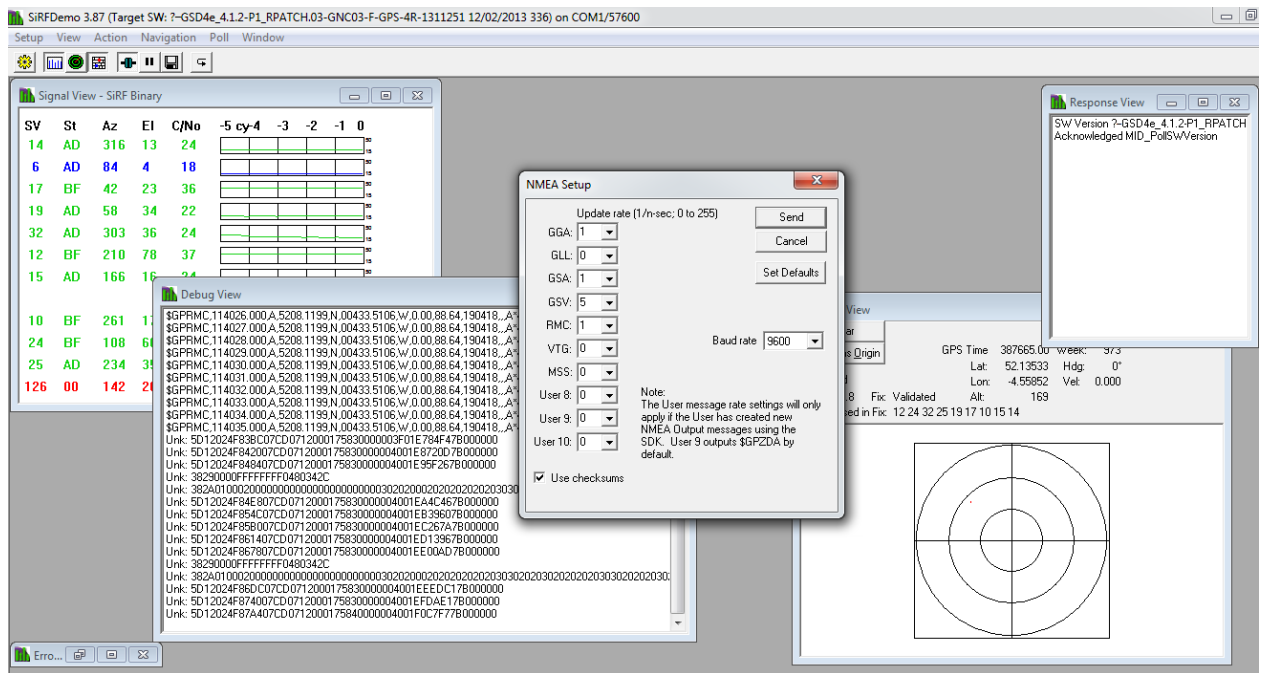


Figure 63 - SirfDemo Software

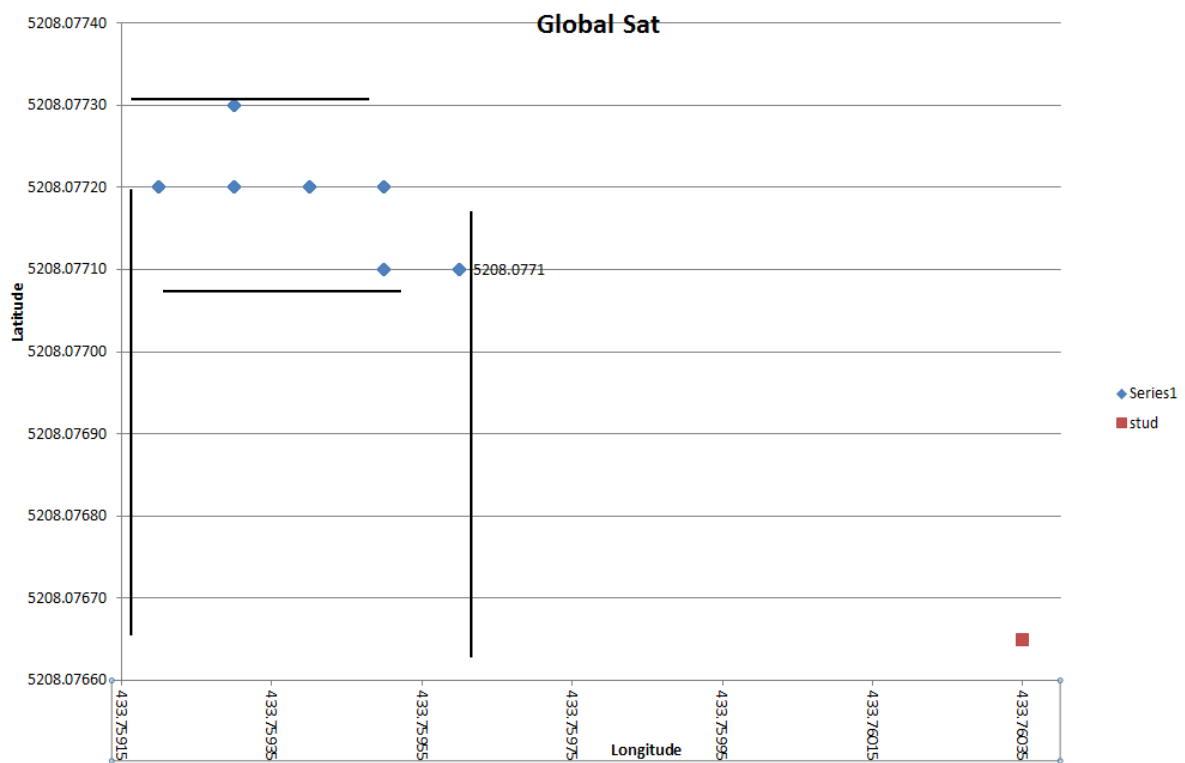


Figure 64 - GlobalSat 1 hour GPS Plot

$$0.0773 - 0.0771 = 0.0002$$

$$0.0002 \times 6076 = 1.22 \text{ Feet spread in Latitude}$$

$$0.7596 - 0.7592 = 0.0004$$

$$0.0004 \times 3289 = 1.32 \text{ Feet spread in Longitude}$$

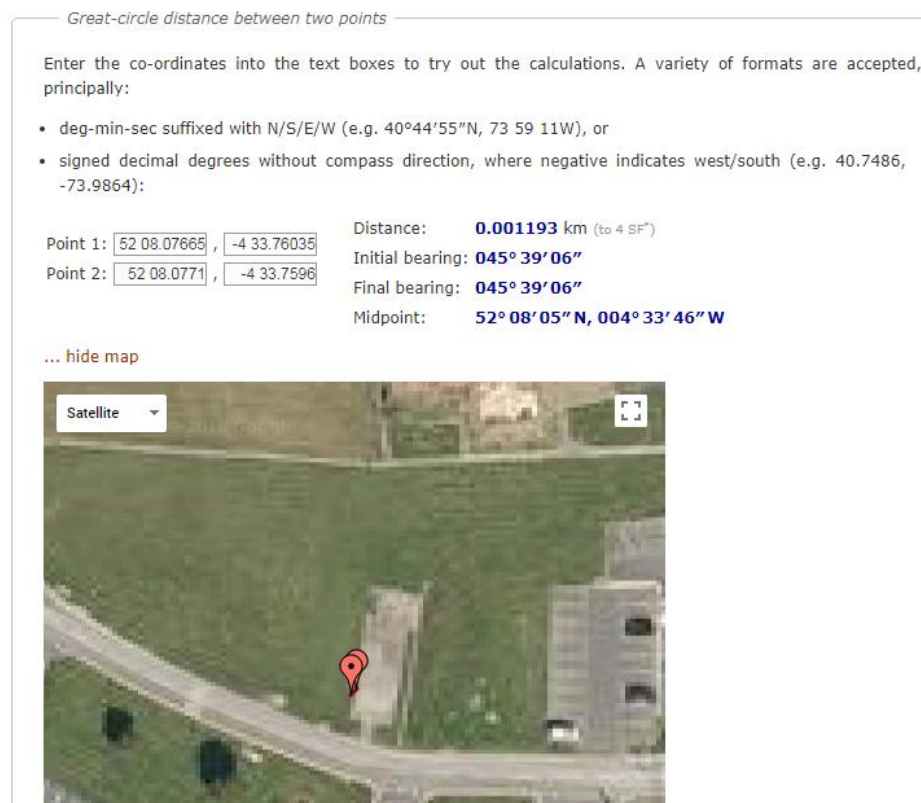
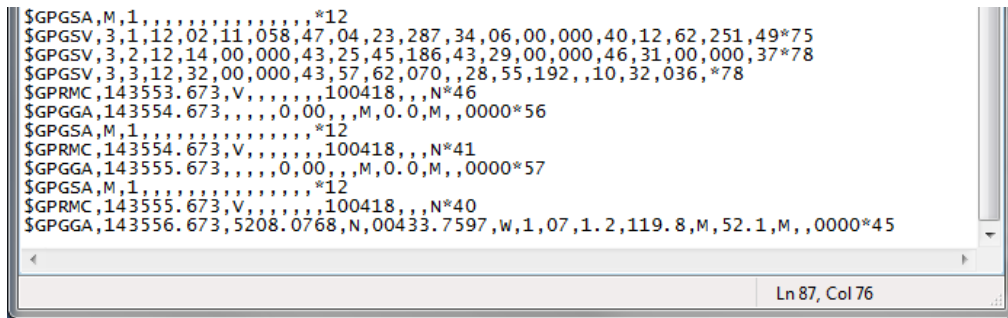


Figure 65 - GlobalSat Accuracy

GlobalSat nearest point to trig stud = 1.19m

```
$PSRF150,1*3E
$PSRFTXT,Version: GSD4e_4.1.2-P1_RPATCH.03-GNC03*0C
$PSRFTXT,Version2: F-GPS-4R-1311251*6C
$PSRFTXT,SBAS: Enabled*3F
$PSRFTXT,TOW: 0*25
$PSRFTXT,WK: 1662*66
$PSRFTXT,POS: 6378137.0 0.0 0.0*34
$PSRFTXT,CLK: 96248*2C
$PSRFTXT,CHNL: 12*73
$PSRFTXT,Baud rate: 4800*65
$GPGGA,,0.00,,M,0.0,M,0.000*48
$GPGSA,M,1,,,,,,,,,,,,,*12
$GPRMC,V,,,,,,,,,N*53
$GPGGA,,0.00,,M,0.0,M,0.000*48
$GPGSA,M,1,,,,,,,,,,,,,*12
$GPRMC,V,,,,,,,,,N*53
$GPGGA,,0.00,,M,0.0,M,0.000*48
```



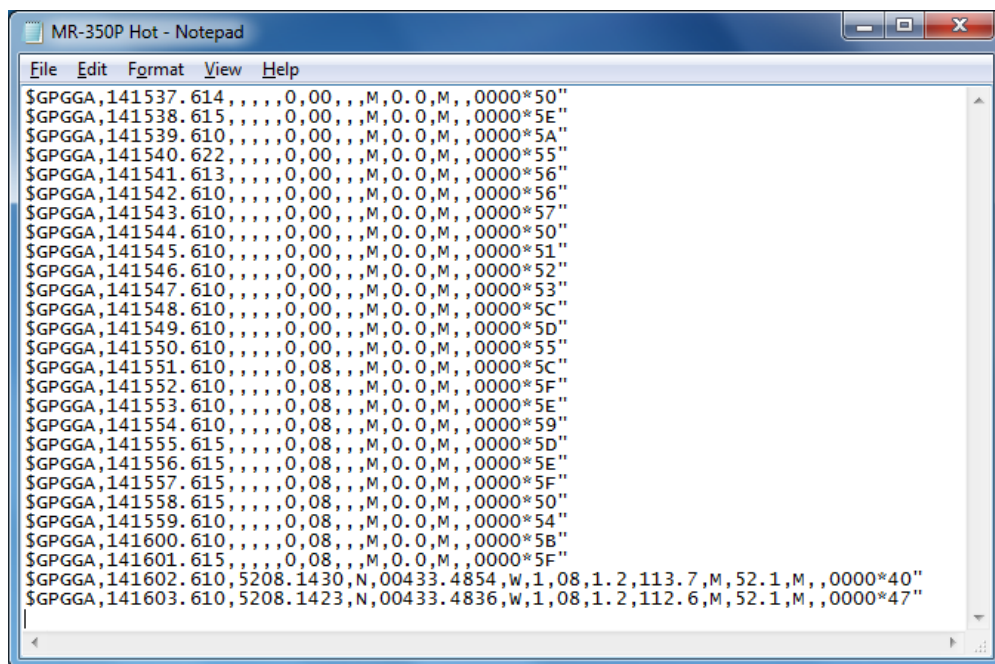
```

$GPGSA,M,1,,,,,,,,,,,,,*12
$GPGSV,3,1,12,02,11,058,47,04,23,287,34,06,00,000,40,12,62,251,49*75
$GPGSV,3,2,12,14,00,000,43,25,45,186,43,29,00,000,46,31,00,000,37*78
$GPGSV,3,3,12,32,00,000,43,57,62,070,,28,55,192,,10,32,036,*78
$GPRMC,143553.673,V,,,,,,,,,100418,,N*46
$GPWGA,143554.673,,,,,0,00,,M,0.0,M,,0000*56
$GPGSA,M,1,,,,,,,,,,,,,*12
$GPRMC,143554.673,V,,,,,,,,,100418,,N*41
$GPWGA,143555.673,,,,,0,00,,M,0.0,M,,0000*57
$GPGSA,M,1,,,,,,,,,,,,,*12
$GPRMC,143555.673,V,,,,,,,,,100418,,N*40
$GPWGA,143556.673,5208.0768,N,00433.7597,W,1,07,1.2,119.8,M,52.1,M,,0000*45

```

Figure 66 - GlobalSat Cold Start

From Figure 66 it can be seen that the GlobalSat took approximately 77 seconds to achieve a position lock, the bottom right shows 87 lines of data minus the 10 lines of settings data the GPS output. Figure 67 shows the results from a hot start, with a TTFF of 25 seconds.



```

$GPWGA,141537.614,,,,,0,00,,M,0.0,M,,0000*50"
$GPWGA,141538.615,,,,,0,00,,M,0.0,M,,0000*5E"
$GPWGA,141539.610,,,,,0,00,,M,0.0,M,,0000*5A"
$GPWGA,141540.622,,,,,0,00,,M,0.0,M,,0000*55"
$GPWGA,141541.613,,,,,0,00,,M,0.0,M,,0000*56"
$GPWGA,141542.610,,,,,0,00,,M,0.0,M,,0000*56"
$GPWGA,141543.610,,,,,0,00,,M,0.0,M,,0000*57"
$GPWGA,141544.610,,,,,0,00,,M,0.0,M,,0000*50"
$GPWGA,141545.610,,,,,0,00,,M,0.0,M,,0000*51"
$GPWGA,141546.610,,,,,0,00,,M,0.0,M,,0000*52"
$GPWGA,141547.610,,,,,0,00,,M,0.0,M,,0000*53"
$GPWGA,141548.610,,,,,0,00,,M,0.0,M,,0000*5C"
$GPWGA,141549.610,,,,,0,00,,M,0.0,M,,0000*5D"
$GPWGA,141550.610,,,,,0,00,,M,0.0,M,,0000*55"
$GPWGA,141551.610,,,,,0,08,,M,0.0,M,,0000*5C"
$GPWGA,141552.610,,,,,0,08,,M,0.0,M,,0000*5F"
$GPWGA,141553.610,,,,,0,08,,M,0.0,M,,0000*5E"
$GPWGA,141554.610,,,,,0,08,,M,0.0,M,,0000*59"
$GPWGA,141555.615,,,,,0,08,,M,0.0,M,,0000*5D"
$GPWGA,141556.615,,,,,0,08,,M,0.0,M,,0000*5E"
$GPWGA,141557.615,,,,,0,08,,M,0.0,M,,0000*5F"
$GPWGA,141558.615,,,,,0,08,,M,0.0,M,,0000*50"
$GPWGA,141559.610,,,,,0,08,,M,0.0,M,,0000*54"
$GPWGA,141600.610,,,,,0,08,,M,0.0,M,,0000*5B"
$GPWGA,141601.615,,,,,0,08,,M,0.0,M,,0000*5F"
$GPWGA,141602.610,5208.1430,N,00433.4854,W,1,08,1.2,113.7,M,52.1,M,,0000*40"
$GPWGA,141603.610,5208.1423,N,00433.4836,W,1,08,1.2,112.6,M,52.1,M,,0000*47"

```

Figure 67 - GlobalSat Hot Start

6.5.1.3. 622R

Prior to setting the 622R parameters a RS232 converter circuit that was built earlier got reused, as the GPS outputs TTL data rather than RS232. Once this was done, it was configured using Sky Traq software that came with the receiver. This allowed several parameters to be configured such as; NMEA strings and updates, Baud rate, mode of operation (Pedestrian or vehicle).

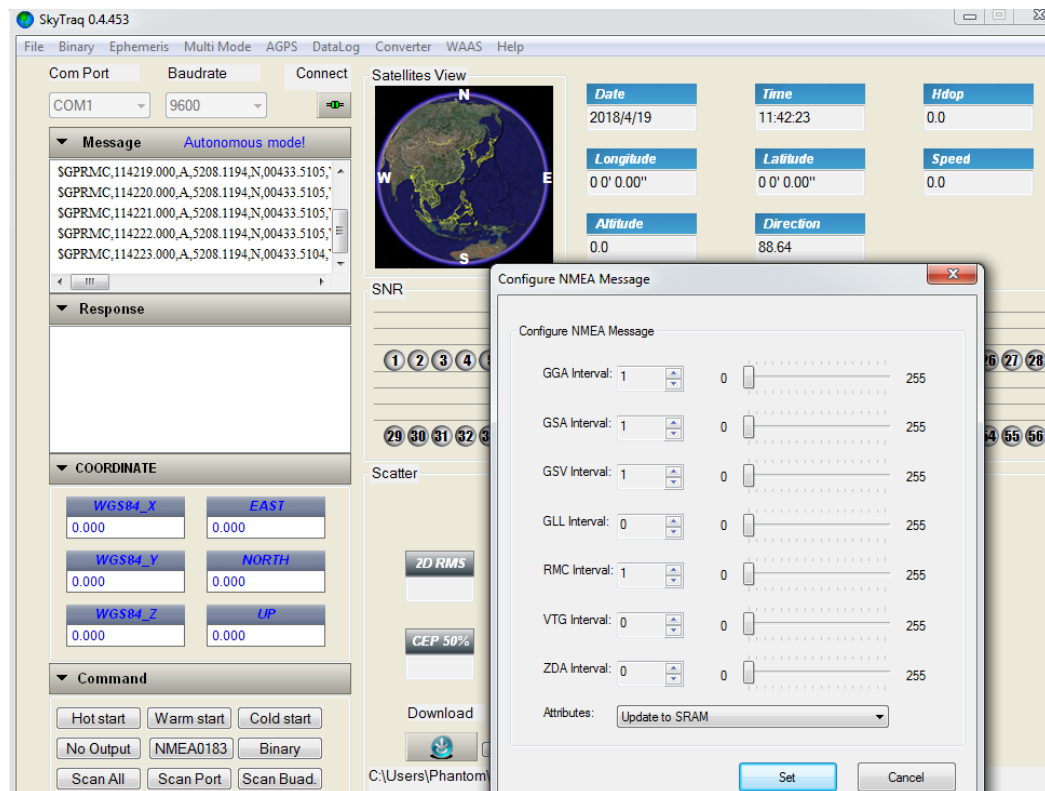


Figure 68 - SkyTraq Software

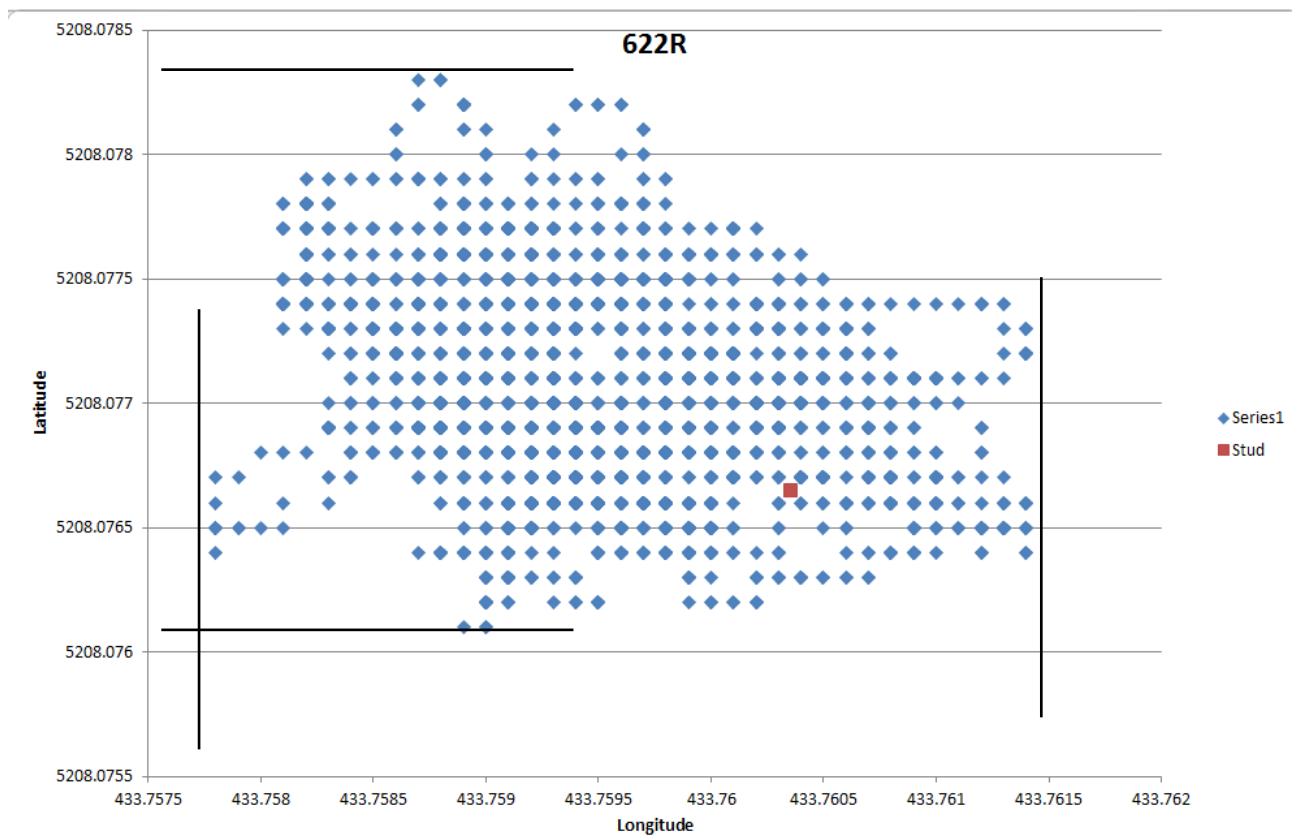


Figure 69 - 622R 1 hour GPS Plot

$$0.0783 - 0.0761 = 0.0022$$

$$0.0022 \times 6076 = 13.37 \text{ Feet spread in Latitude}$$

$$0.7614 - 0.7578 = 0.0036$$

$$0.0046 \times 3289 = 11.84 \text{ Feet spread in Longitude}$$

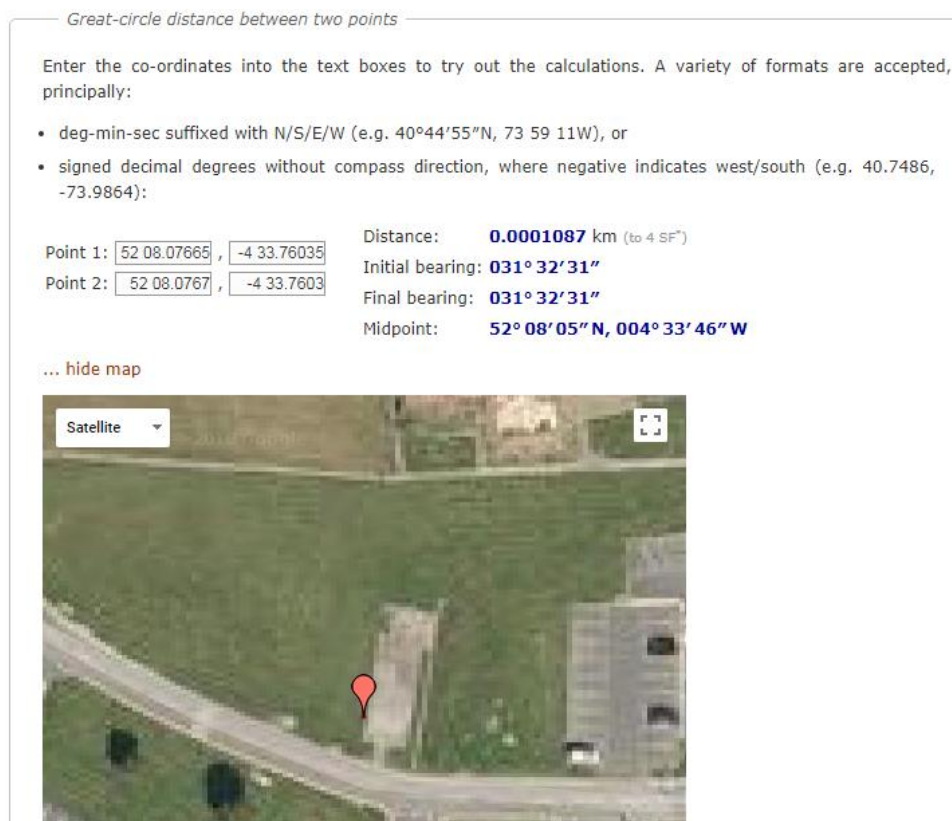


Figure 70 - 622R Distance

622R nearest point to the trig stud = 0.1m, although looking at the plot Figure 69 there's such a spread of positions that this accuracy can't be trusted, and it's where this method of analysis shows issues.

The logged data in Figure 71 shows the initial switch on of the 622R receiver, it's sending NMEA messages out at 1Hz using the internal clock, however a valid time isn't given until 11:28:52, when it has found a satellite, 23 seconds after switch on. Figure 72 shows when the receiver has acquired three satellites, and it's able to provide a valid GPS position at 11:29:34. This gives a Time to First Fix (TTFF) of 65 Seconds. The hot start was slightly better at 40 seconds, as can be seen in Figure 73. Both of these figures were fairly decent, although they didn't meet the 25 second average quoted by the manufacturer.

Figure 71 - 622R Cold Start

Figure 72 - 622R Cold TTFF

```

File Edit Format View Help
$GPGLL,11.5949,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6C
$GPGLL,11.5950,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*64
$GPGLL,11.5951,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*65
$GPGLL,11.5952,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*66
$GPGLL,11.5953,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*67
$GPGLL,11.5954,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*60
$GPGLL,11.5955,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*61
$GPGLL,11.5956,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*62
$GPGLL,11.5957,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*63
$GPGLL,11.5958,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6C
$GPGLL,14.2552,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*68
$GPGLL,14.2553,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*69
$GPGLL,14.2554,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6E
$GPGLL,14.2555,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6F
$GPGLL,14.2556,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6C
$GPGLL,14.2557,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6D
$GPGLL,14.2558,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*62
$GPGLL,14.2559,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*63
$GPGLL,14.2600,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6C
$GPGLL,14.2601,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6D
$GPGLL,14.2602,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6E
$GPGLL,14.2603,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6F
$GPGLL,14.2604,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*68
$GPGLL,14.2605,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*69
$GPGLL,14.2606,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6A
$GPGLL,14.2607,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6B
$GPGLL,14.2608,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*64
$GPGLL,14.2609,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*65
$GPGLL,14.2610,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6D
$GPGLL,14.2611,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6C
$GPGLL,14.2612,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6F
$GPGLL,14.2613,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6E
$GPGLL,14.2614,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*69
$GPGLL,14.2615,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*68
$GPGLL,14.2616,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6B
$GPGLL,14.2617,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6A
$GPGLL,14.2618,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*65
$GPGLL,14.2619,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*64
$GPGLL,14.2620,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6E
$GPGLL,14.2621,0.00,0.0000,0.0000,N,0.0000,0.0000,E,0.00,0.0,0.0,M,0.0,M,0.0000*6F
$GPGLL,14.2622,680,5208.0525,N,00433.5426,W,1,03,3.7,0.0,M,54.6,M,0.0000*4D
$GPGLL,14.2623,680,5208.0526,N,00433.5427,W,1,03,3.2,0.0,M,54.6,M,0.0000*4B

```

Figure 73 - 622R Hot Start

6.5.2. GPS test Conclusion

From all the tests carried out on the three GPS receivers, the main figures have been collated in Table 7 it can be seen that two of the receivers performed comparably on the whole, with the other showing considerably worse performance. The Hemisphere was expected to perform better than the other two, although this hasn't been quite so definitive it has shown the greatest accuracy with the nearest position being 3.05ft away from the trig stud. The GlobalSat was only slightly worse at 3.9ft which is impressive for the price, it also shows a tighter spread of results than the Hemisphere, so it could be said that it has a slightly higher precision. The drawback of the GlobalSat as shown in the excel plots, although the final data shows it had a tighter spread, the fact that the position was only given to 4 decimal places might have had an effect on this, as it only shows 6 distinct points on the plot. The output from the hemisphere giving greater resolution, you can see a lot of small fluctuations in the position.

The 622R shows the worst spread of positions by far, as seen from the excel plot. This has thrown a slight anomaly into the results, as using the closest position from the 3600 data points collected to give accuracy for each receiver has shown the 622R to be the best, which could be

misleading and is why the distance has been highlighted in red. Even with the best TTFF values of the three, it can't outweigh the poor positional results.

From all the data gathered the MR-350P was selected to be used as the remote GPS receiver, although it didn't quite meet the accuracy of the hemisphere, the difference wasn't enough to offset the huge disparity in terms of cost. It also performed better than the original project requirement for positional accuracy, and better than the datasheet stated.

Table 7 – GPS Test Summary

GPS	Lat Spread (ft)	Lon Spread (ft)	Distance (ft)	TTFF Warm	TTFF Cold
Hemisphere	1.52	1.48	3.05	18sec	235sec
MR-350P	1.22	1.32	3.9	25sec	77sec
622R	13.37	11.84	0.32	40sec	65sec

6.5.2.1. Improvements

Prior to conducting these tests it was mentioned that a longer time frame would give a better overall view of the three receivers, but wasn't acted on due to the timescales and processing of all the data. Another aim was to give a CEP figure for each receiver; this would undoubtedly provide a truer value in terms of accuracy for each receiver compared with the conclusions drawn here. This wasn't possible in the end, as the amount of work to devise a method to calculate this figure in excel would have been fairly time consuming for one who wasn't particularly experienced using the program, for this reason it was omitted. Another possible improvement would have been using the average figure from the 3600 points, and calculating the distance to the trig stud using that. This would have probably been advantageous to the receivers giving a tight spread of results, compared with the 622R. One of the reasons this wasn't used in the first place is due to the fact that GPS positions sometimes appear to jump about, so a position that was clearly wrong would alter the average value considerably. This error could be from a number of factors in the method the receiver uses to calculate the position. Some of these were mentioned in the research section such as dilution of precision, signal attenuation or multipathing, as the receiver swaps between tracked satellites etc. lastly

another test that should have been carried out was a moving test, following a set course such as a narrow footpath, the results could then have been overlaid on a satellite image, which may have given some additional data to base the GPS selection on.

6.6. Hemisphere Compass

6.6.1. Compass Test Procedure

- Configuring parameters
- Setting output data messages
- Accuracy compared with surveyed datum
- Precision

In order to configure the GPS compass it was necessary to solder a 9 way D-type connector onto the port-A wires from the wiring diagram, as this was the main port and supported RS232. This allowed it to be connected up to a laptop with a DB9 serial connector running hyper terminal. From the user manual it was found that the compass was set to a default baud rate of 19200, with a few common strings set at 1Hz. The Pinout can be seen in Figure 74.

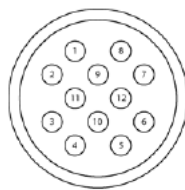


Figure 2-9: Power/data cable pin assignment Table 2-1:

Power/data cable pinout

Pin	Function	Wire Color
1	Port C, RS-232 female DB9 pin 2, device out	White
2	Port C, RS-232 female DB9 pin 3, device in	Green
3	N/C	N/C
4	N/C	N/C
5	Power input	Red
6	N/C	N/C
7	Signal ground	Yellow
8	Port A, RS-232 female DB9 pin 3, device in	Brown
9	Port A, RS-232 female DB9 pin 2, device out	Blue
10	Power ground	Black
11	CH_GND	Drain
12	N/C	N/C

Figure 74 - Compass Pinout

With communications established with the compass, the settings could be altered through typing set messages from the datasheet:

\$JBAUD,9600 – Set the port-A baud rate to 9600, the terminal then required reconfiguring.

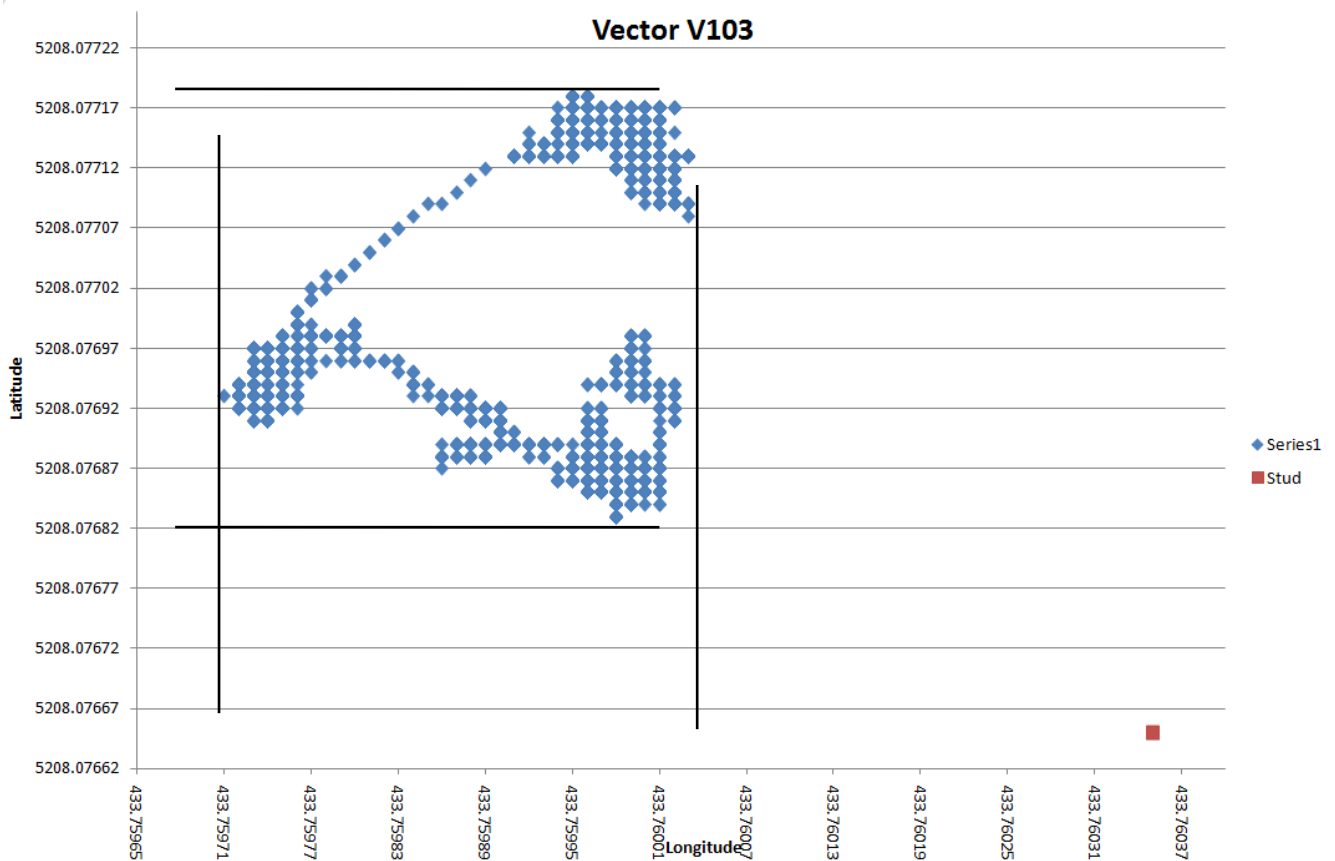
\$JASC, GPRMC,1 – Set port-A to output GPRMC messages at 1Hz.

\$JASC,PASHR,1 – Set port-A to output PASHR messages (heading, pitch and roll) 1Hz.

\$JSAVE – Saved the current configuration.

There were a range of other settings that could be altered, but they were left as standard to begin with.

In order to test the compass's performance in terms of accuracy, precision the GPS test procedure was replicated, with an hour's worth of data and a known position, this allowed another plot to be created in excel.



$$0.077185 - 0.07682 = 0.000365$$

$$0.000365 \times 6076 = 2.217 \text{ Feet spread in Latitude}$$

$$0.76004 - 0.7592 = 0.00084$$

$$0.00084 \times 3289 = 2.76 \text{ Feet spread in Longitude}$$

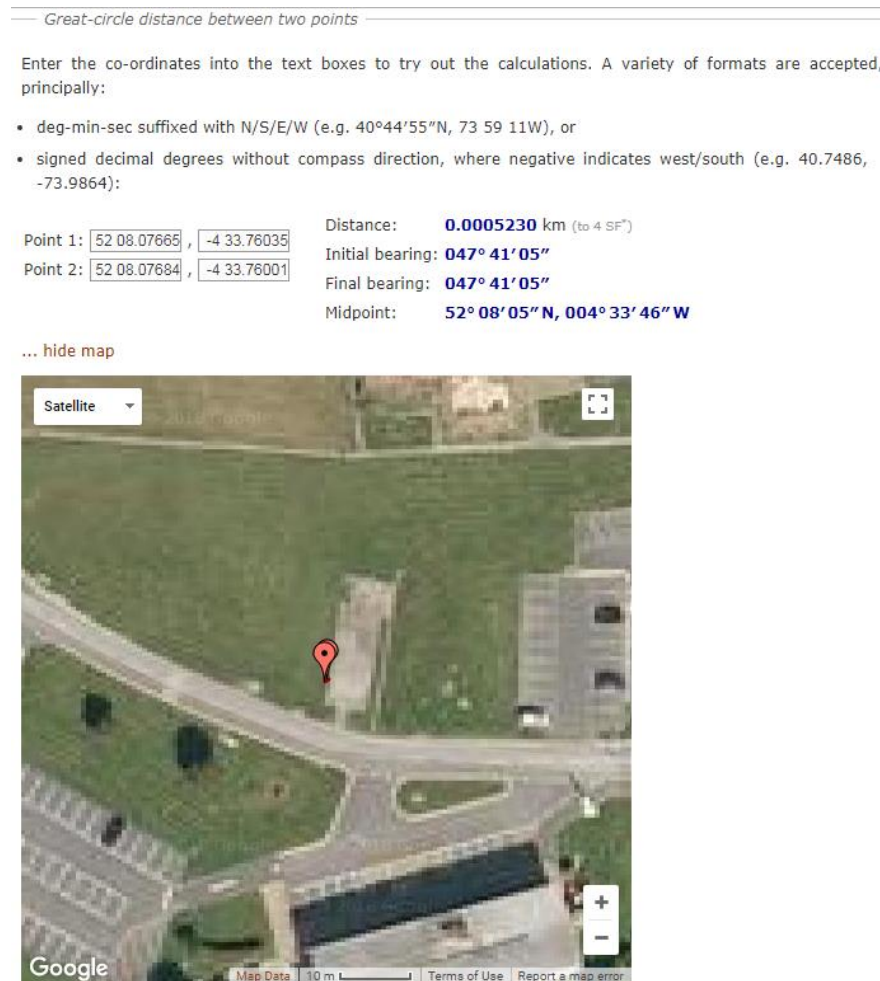


Figure 75 - Compass distance from trig stud

GPS	Lat Spread (ft)	Lon Spread (ft)	Distance (ft)
Compass	2.22	2.76	1.71

6.7. Schematic Designs

6.7.1. Main Unit

The main circuit centres on the PIC18F24K22; this takes two serial inputs from a GPS compass and Lora data modem. The GPS compass data is converted to TTL using the MAX232 shown in Figure 76. With the data from the modem being TTL already, no processing is necessary. The circuit also includes a 20x4 LCD display that offers some

information to the operator without having to connect the serial data lead to a PC. There is that option if a PC with a terminal view is available, as more data is displayed compared with the LCD. This output from the PIC uses the MAX232, to convert TTL to RS232 for connection to a PC. The circuit also includes a basic regulator circuit, to give a steady 5V for all the necessary components.

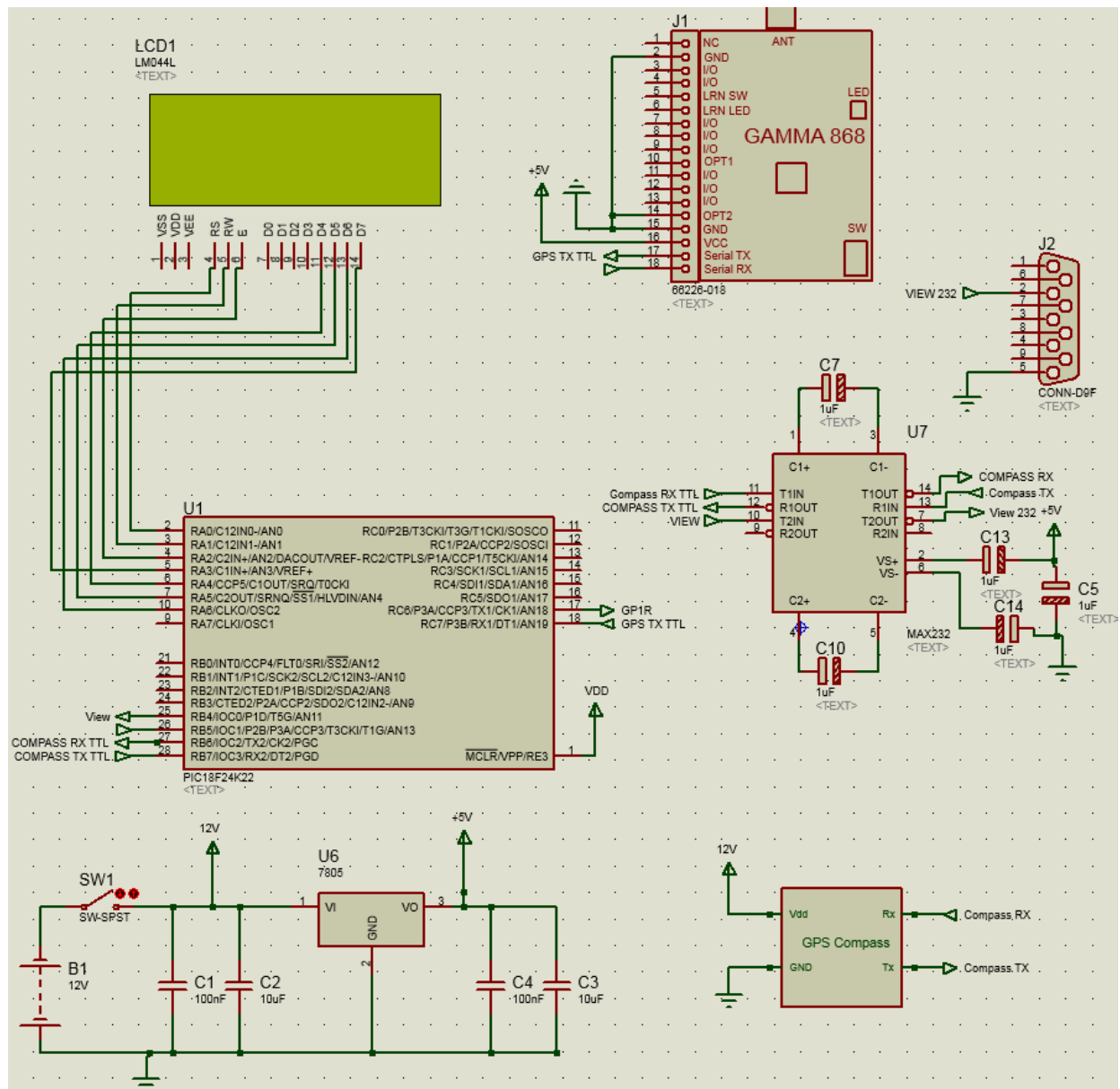


Figure 76 - Main Circuit Schematic

6.7.2. Remote Unit

There isn't a great deal of complexity in the electronic circuit for the remote GPS receiver, the main parts being a basic voltage regulator circuit that drops the 12V coming from the battery to 5V which is required by all the components. The RS232 data from the GPS is converted to TTL using the MAX232 converter, before being transmitted through the atmosphere using the Gamma Lora transceiver.

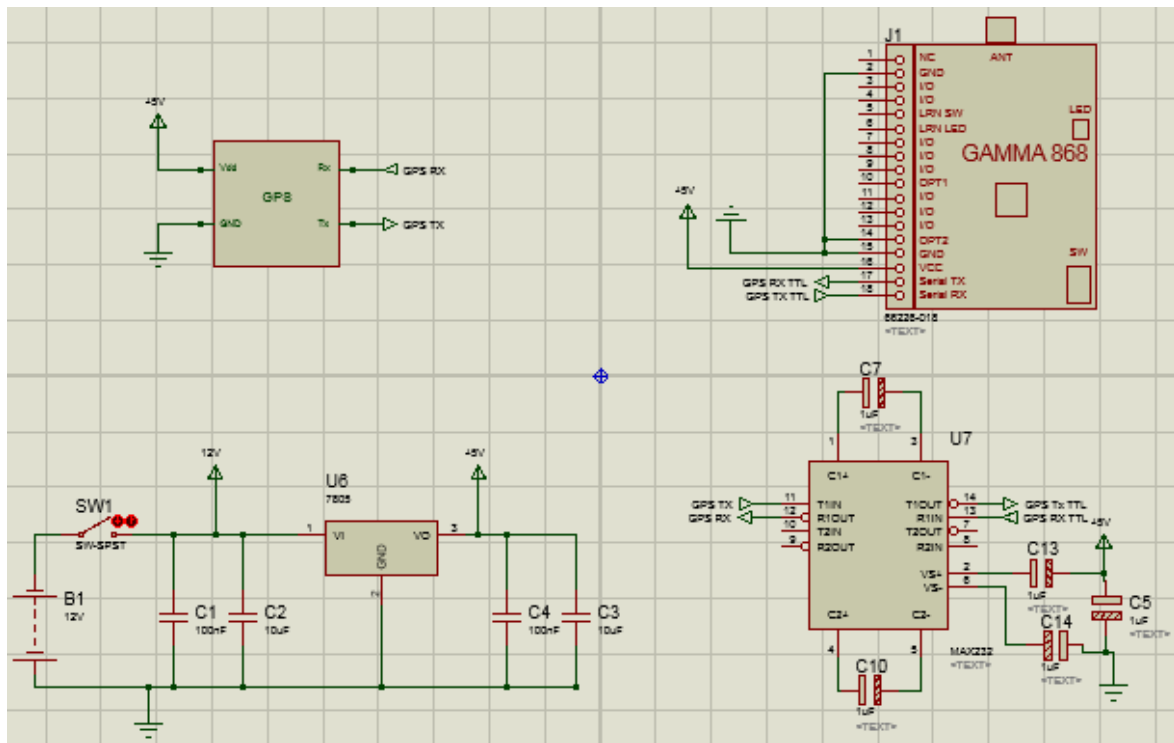


Figure 77 - Remote Schematic

6.8. PCB Design

6.8.1. Main Unit

The circuit for the main board was redrawn in Easy PC, as this allowed the transfer to a PCB design. The PIC that was being used wasn't available however, so a new component had to be drawn. The connectors on the board are for the LCD, two GPS sources and an output for the serial monitor. Figure 78 and Figure 79 show the schematic design.

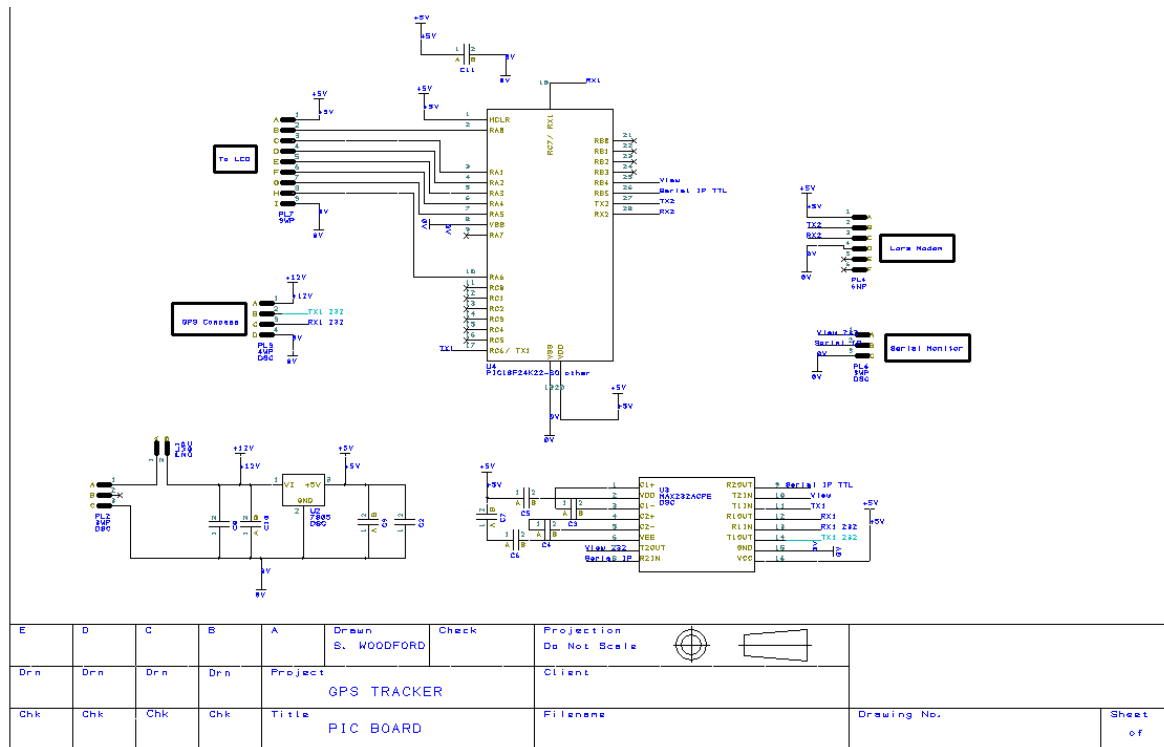


Figure 78 - Main Board Easy Pc

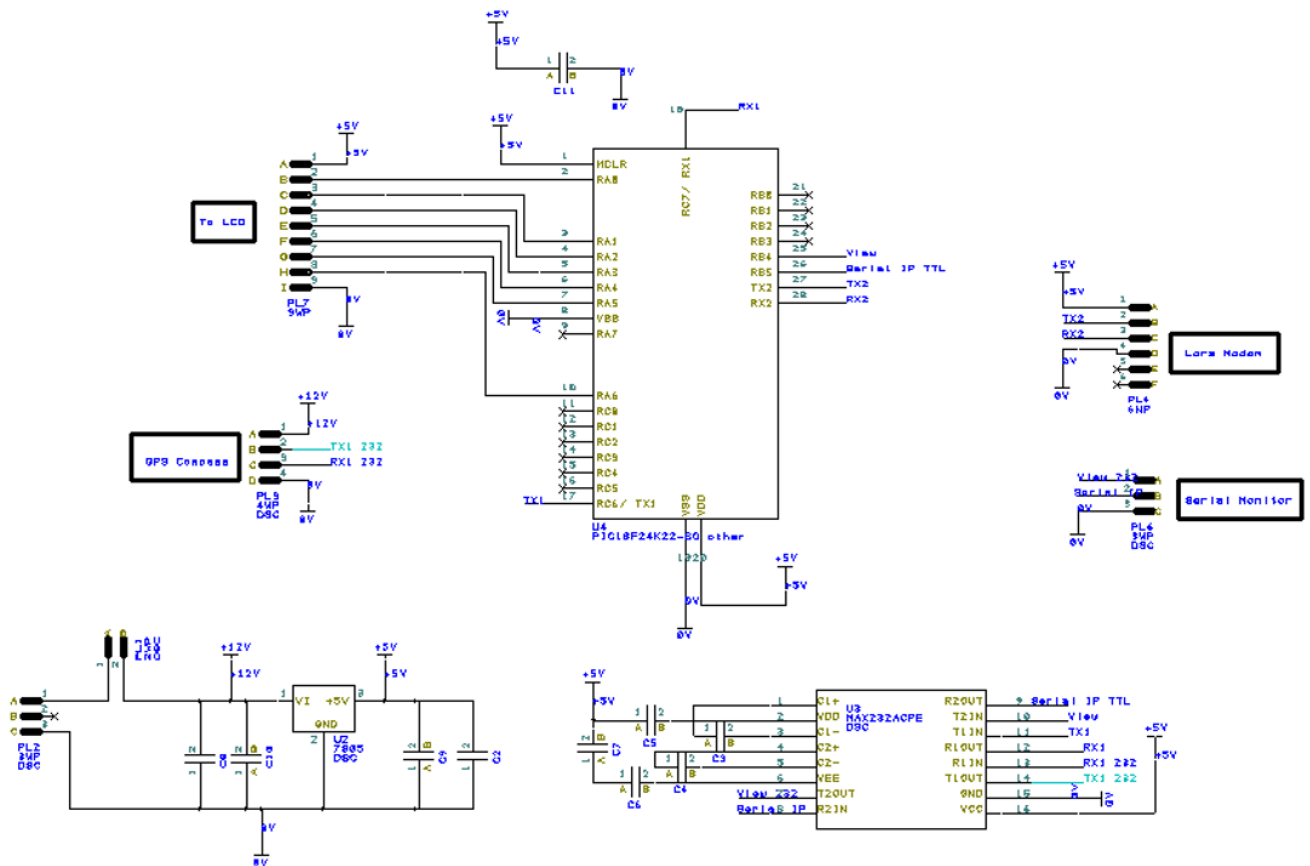


Figure 79 – Magnified Schematic

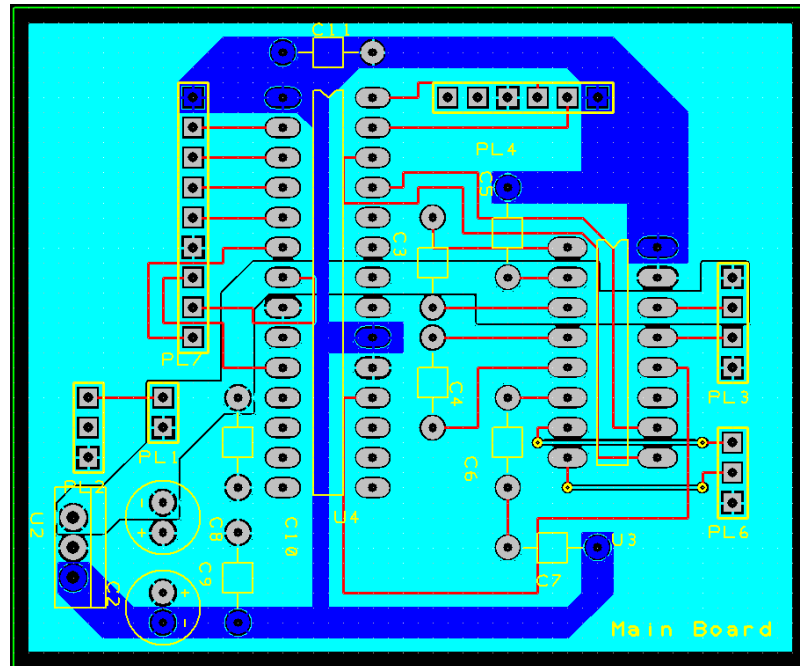


Figure 80 –PCB All layers

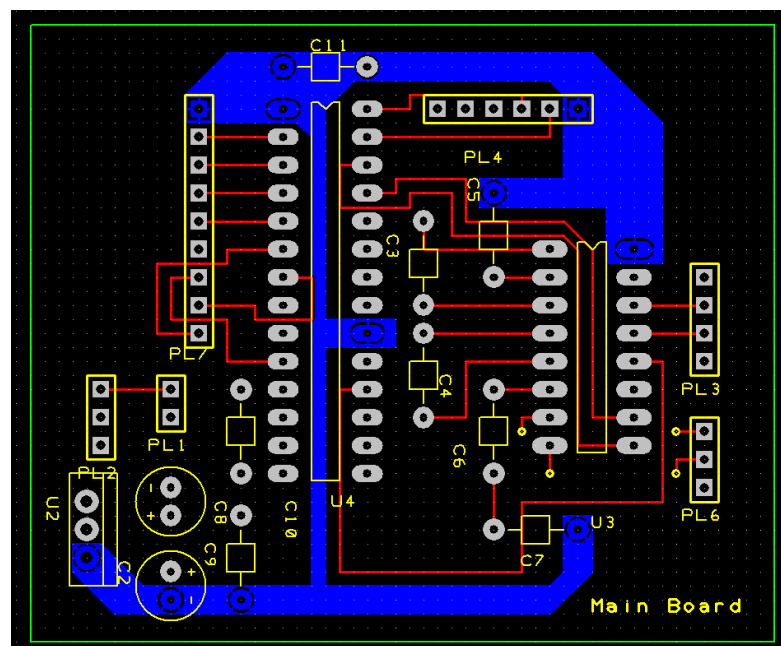


Figure 81 – PCB Top Silk & Copper

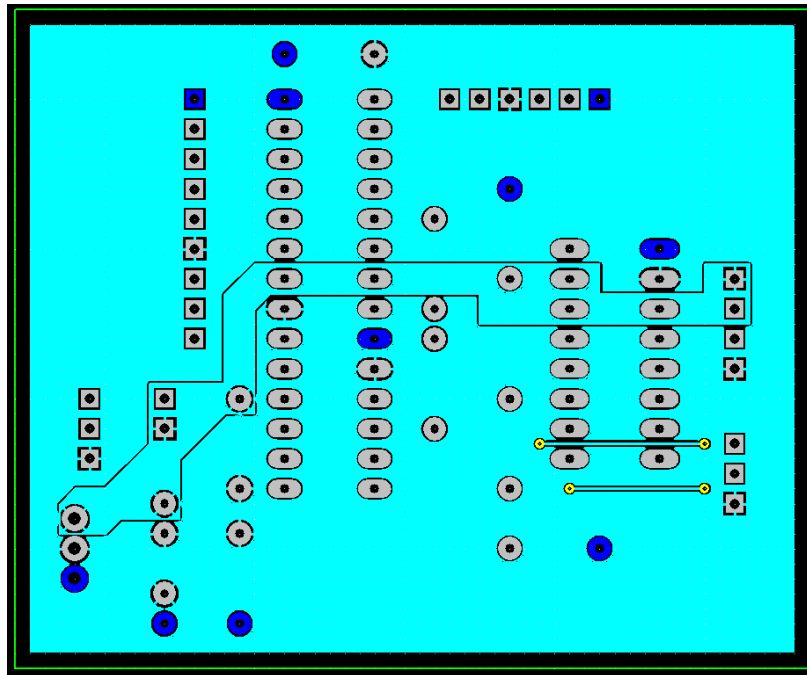


Figure 82 – PCB Bottom Silk & Copper

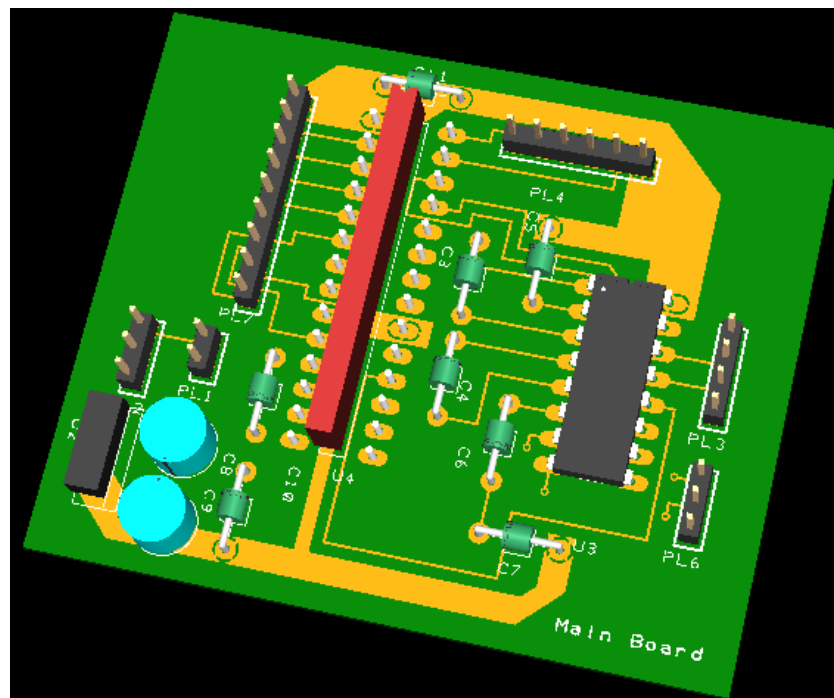


Figure 83 – PCB 3D View Top

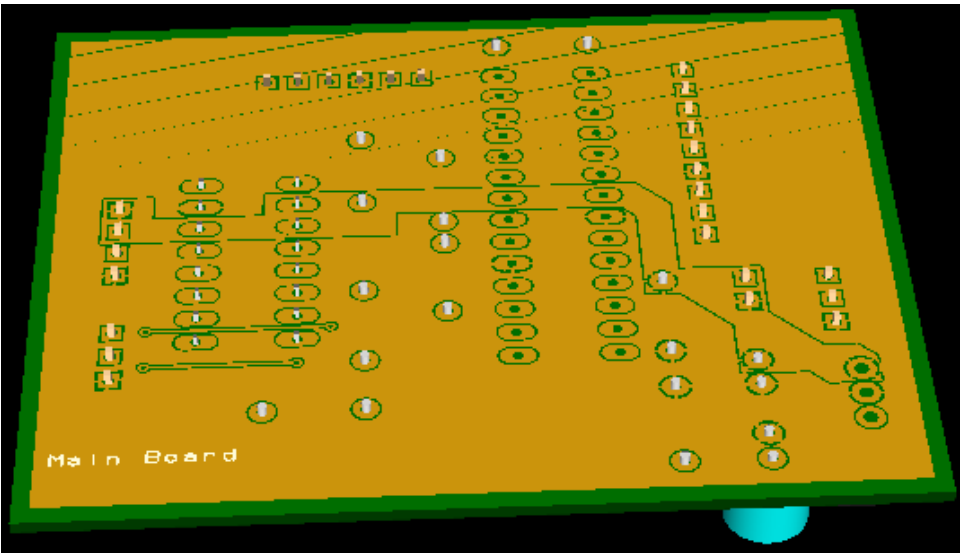


Figure 84 – PCB 3D View Underside

6.8.2. Remote Unit

The schematic was modified slightly in Easy PC prior to making the PCB, as some components wouldn’t actually be on the board, so connectors were used in their place. This is shown in Figure 85 and a larger version in Figure 86.

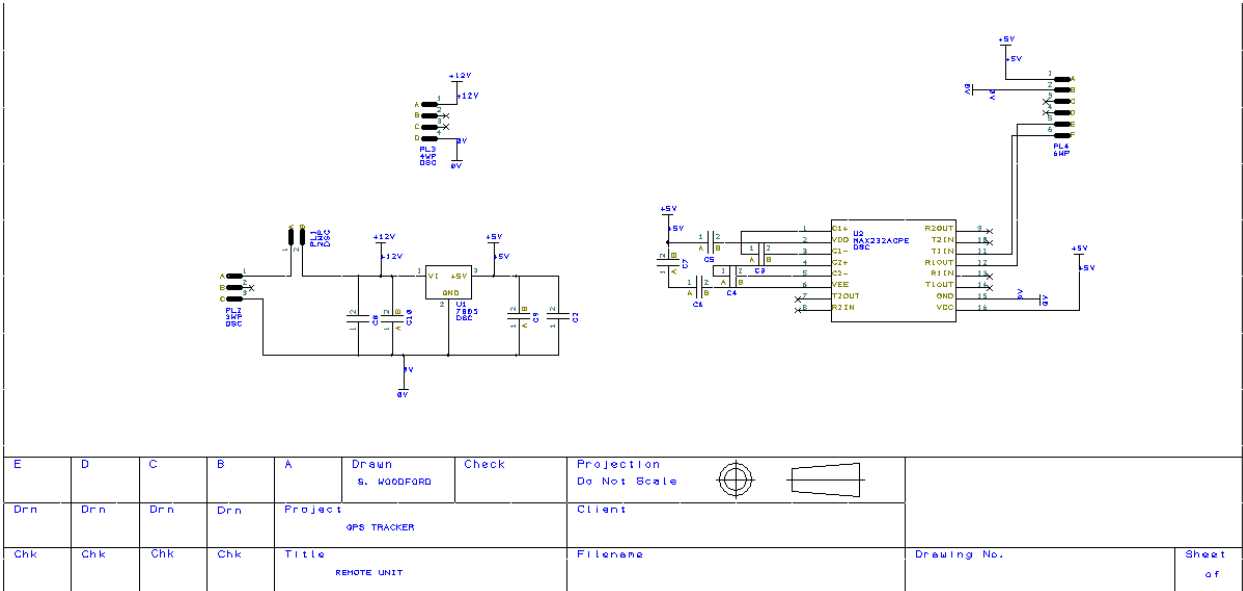


Figure 85 - Easy PC Remote Schematic

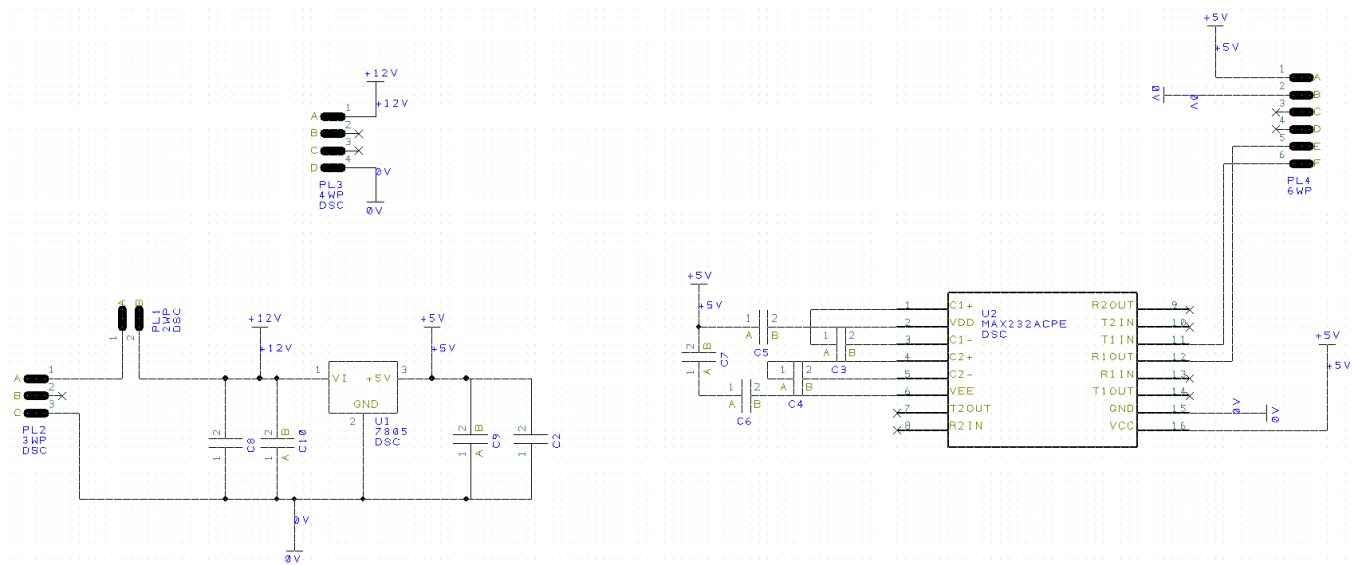


Figure 86 -Magnified Easy PC Schematic

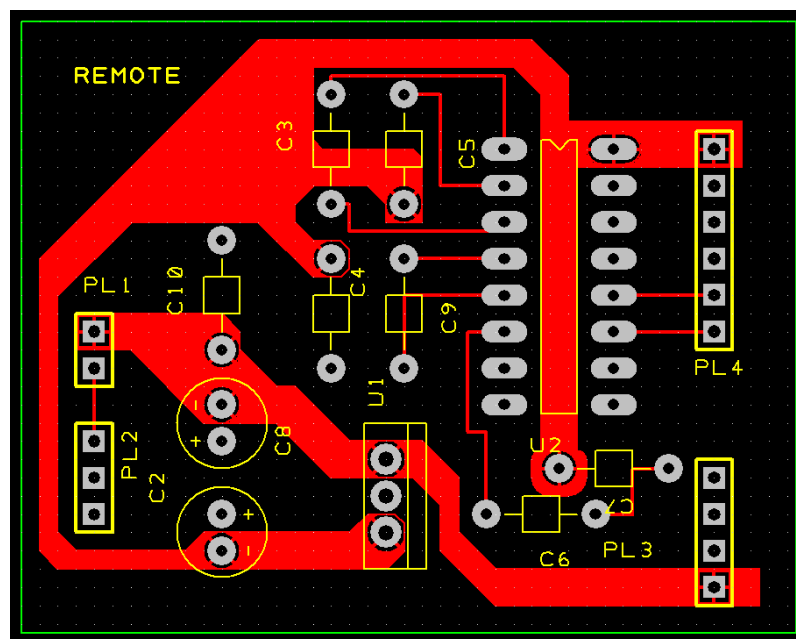


Figure 87 Remote Top Silk

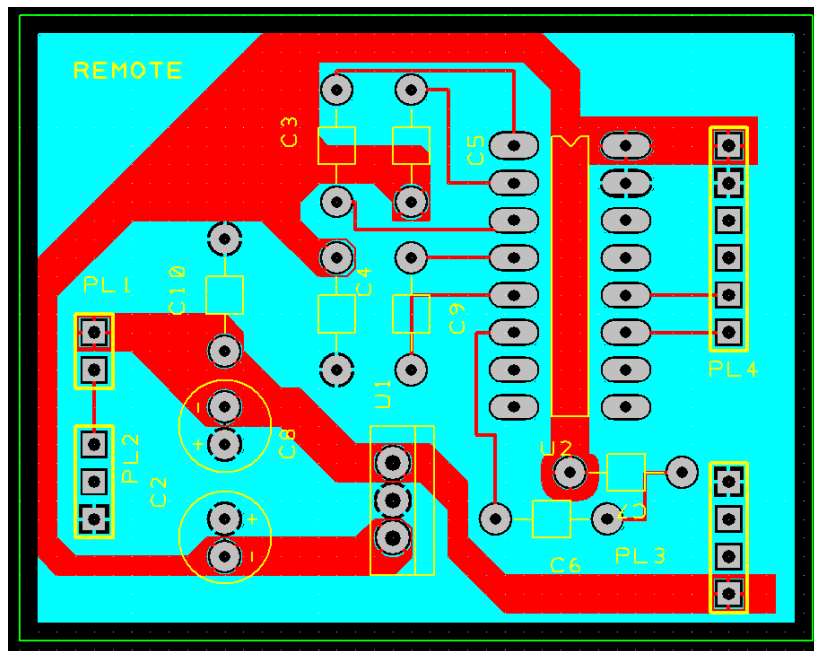


Figure 88 - Remote Top & Bottom Silk

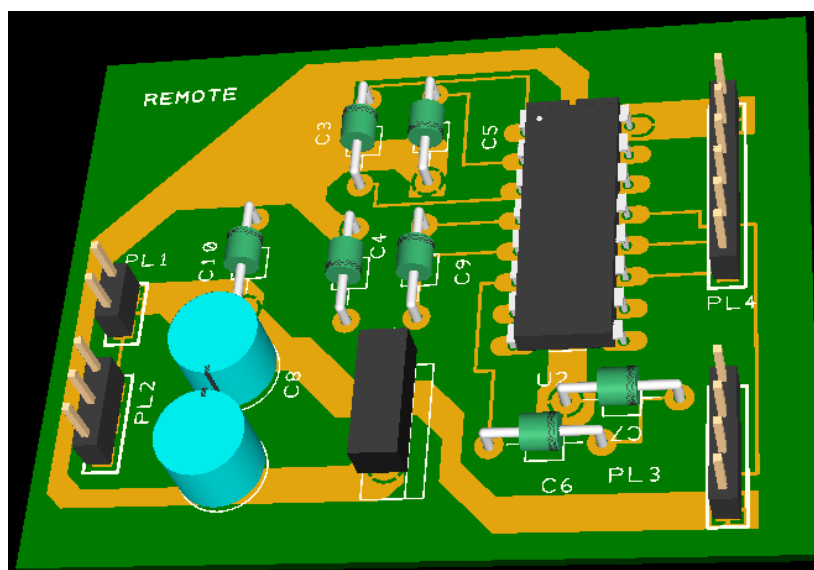


Figure 89 - Remote 3D View

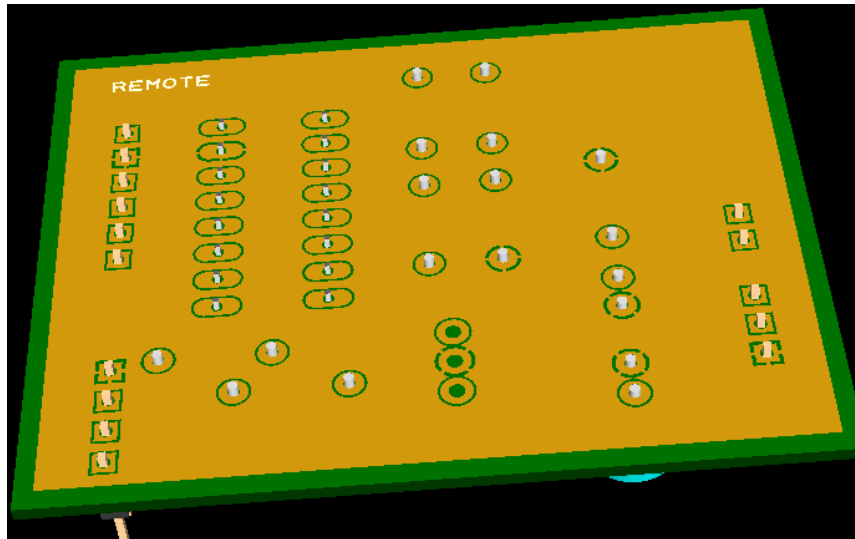


Figure 90 - Remote Underside 3D View

6.8.3. PCB Design Conclusion

Although a PCB wasn't actually created for this project, it is generally cost effective to go down this route when multiples of the same board are required. Easy PC proved to be a good and user friendly software package, once the basics were mastered. It allows for components to be positioned logically in terms of the different Nets and voltages, along with the aesthetics of the board, which can be viewed in 3D.

6.9. Mechanical Elements

6.9.1. Main Enclosure

A fairly large Aluminium housing was found in the stores at work that looked suitable to fit the main circuit in, along with allowing for an internal battery, keeping it self-contained. This was primarily for ease of display as part of the major project; a different solution would probably be used for a final design. Due to the enclosure being metal, a hole was cut along with a nylon cover turned on a lathe by a colleague, to allow the modem aerial to protrude.

Length	Width	Height	IP Rating	Material	Temperature
230	200	110	66	Aluminum	-40 + 100°C



Figure 91 - Main Enclosure

6.9.2. Remote Enclosure

After extensive searches online for a suitable enclosure that could house the GPS receiver, transceiver and a small 5V Power bank for the purposes of demonstration, and to keep the unit self-contained. In order to fit these components the enclosure was going to have to be fairly large, with a lot of space wasted. The requirement was reevaluated and the battery left as an external component, as it would be in the final application.

The enclosure selected was the PC F 65 G from piccolo, as it allowed the data modem and antenna to be housed inside, which would prevent any water ingress. The GPS was then fixed on top of the housing, with a hole to allow mounting and cable entry, flowable silicon was used to maintain the seal.

Length	Width	Height	IP Rating	Material	Temperature
230	80	65	66/67	Polycarbonate	-40 + 80°C



[55]

Figure 92 - Piccolo Enclosure

6.10. Power

Requirements of the different components in both units have been ascertained from the datasheets.

Remote Unit:

MR-350- 80mA

Gamma Lora – 150mA when transmitting

- 20mA when receiving/ standby

Based on the modem transmitting 50% of the time, an average value of 85mA was used, along with 80mA for the GPS gives 165mA. Using a 10,400mAh Li-ion Power bank this would give approximately 63 Hours runtime.

Main Unit:

Compass – 0.36A

Main Circuit including receiving modem – 50mA

0.41A total

Using a 7.5Ah lead acid battery not running it below 50% to preserve the battery, would give an approximate runtime of 9 hours.

6.11. Software

The CCS C compiler from microchip was used for the software development of this project, as it linked in with the Proteus software easily, allowing the design to be simulated after any software changes. This was a tremendous help during the development. It also allowed lots of parameters to be configured initially, which created a .hex file for the program, reducing the amount that had to be included in the .c file.

The flow diagram Figure 93 was created for the main loop of the program, to help the reader visualise the operation of the program. The actual code will be shown and discussed further in Figure 94.

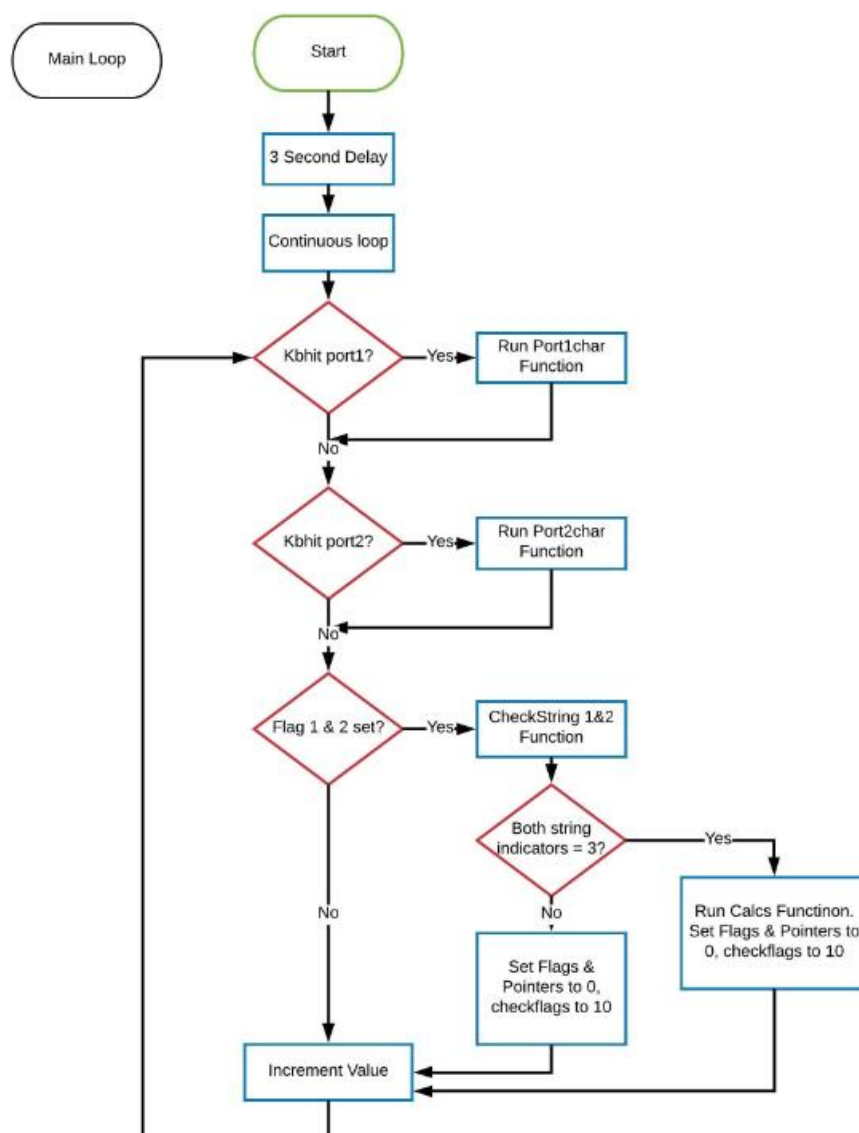


Figure 93 - Main loop Operation

In order to be able to handle the incoming GPS data on both serial ports, the main loop has been kept fairly basic, but calls on several interrupt routines. The Program begins by printing a message to the serial port, followed by a 3 second delay to allow the receivers to settle after switch on. The KBHIT C function is used to catch the incoming data on both ports, it then drops into separate functions to store the data in the corresponding string. Once both strings are complete, they'll flag up, allowing the next section to run. This involves checking the received data to ensure they're both GPRMC sentences and parsing to get the Latitude and Longitude, from both strings. If everything functions correctly and the required data is available, the CALCS function is called which performs the data conversions and mathematics, in order to give the range and bearing between the two points as the output. This can be seen in Figure 94.

```

44 void main(int argc, char* argv[])
45 {
46
47     fprintf(PORT3, "Waiting for Satellite lock \n\r");
48     fprintf(PORT3, "\n\r");
49     delay_ms(3000);
50
51     while(true)
52     {
53
54         if (kbhit(PORT1))
55             {port1char();}
56         if (kbhit(PORT2))
57             {port2char();}
58
59
60
61
62         if( p1flag && p2flag )
63             {
64                 checkflagp1=check_string(1);
65                 checkflagp2=check_string(2);
66                 if((checkflagp1 ==3) && (checkflagp2==3))
67                 {
68                     run_calcs();
69                     checkflagp1=10; checkflagp2=10;
70                     p1flag=0; p2flag=0;
71                     p1point=0; p2point=0;
72                 }
73             }
74         else
75         {
76             p1flag=0; p2flag=0;
77             p1point=0; p2point=0;
78             checkflagp1=10; checkflagp2=10;
79         }
80
81
82         value++;
83
84
85     }

```

Figure 94 - Main Loop

A flow diagram has also been created for the Port 1 Char function; this can be seen in Figure 95 and is identical to the Port 2 Char function.

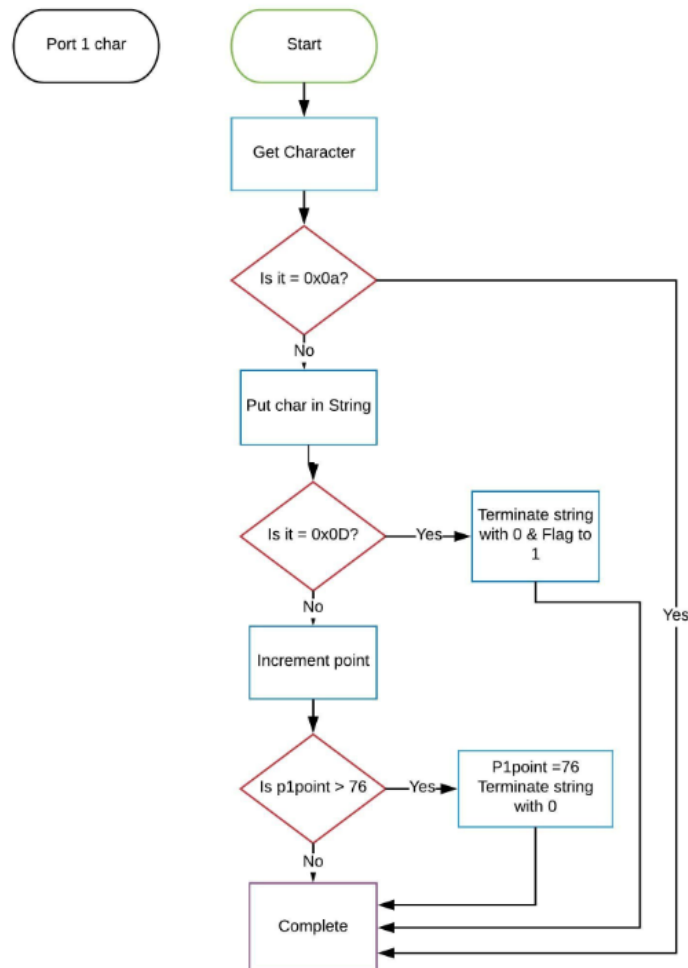


Figure 95 - Port 1 Char Operation

The port1char function was built to catch each character as it came through the serial port, and place them in a new string called port1mes. It does this until either a carriage return or line feed is encountered, which would indicate the end of the NMEA string. Once the string is complete it's terminated with a zero, and a flag is raised to highlight this.

```

121 void port1char(void)
122 {
123     port1in=getch(PORT1);           //get character
124     if(port1in!=0x0a)                // if character is not 0x0a
125     {
126
127         port1mes[p1point]=port1in;   // put character in string
128         if(port1in==0x0D)
129         {
130             port1mes[p1point]=0;     // if character == end of line then terminate string with zero
131             p1flag=1;                 // set flag to say message complete
132         }
133     else
134     {
135
136         p1point++;                   // else increment string pointer
137         if(p1point>76) p1point=76;
138         port1mes[p1point]=0;         // set the next character to zero
139     }
140 }
141
142 }

```

Figure 96 – Port1char Function

With a flag raised for both strings the check string function is used to make sure the data is of the correct format, a GPRMC sentence. This returns answer = 1 if they're both correct.

```

170 char check_string(int port)         // Returns ans as 1 if either of the GPS strings is a $GPRMC sentence
171 {
172     char ans=0;
173     if(port==1)
174     {
175         if ((port1mes[0]=='$')&&(port1mes[1]=='G') && (port1mes[2]=='P') && (port1mes[3]=='R') && (port1mes[4]=='M') && (port1mes[5]=='C') )
176         {
177             ans=1;
178         }
179     }
180     else
181     {
182         if ((port2mes[0]=='$')&&(port2mes[1]=='G') && (port2mes[2]=='P') && (port2mes[3]=='R') && (port2mes[4]=='M') && (port2mes[5]=='C') )
183         {
184             ans=1;
185         }
186     }
187
188     return(ans);
189 }
190

```

Figure 97 – check_string Function

A flow diagram for the remainder of the program can be seen in Figure 98, this concerns the parsing of the NMEA data, followed by the calculations.

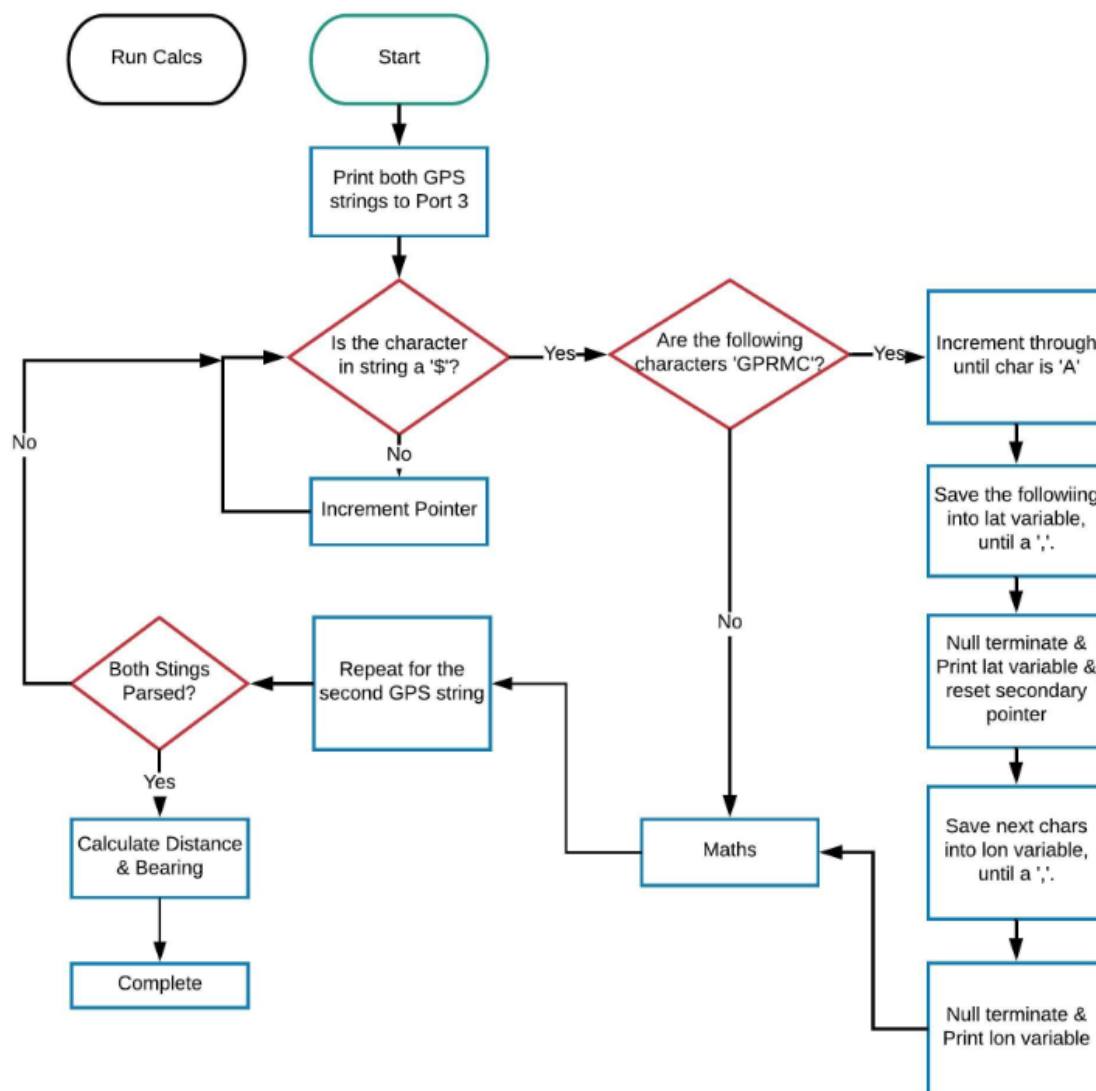


Figure 98 - Calculations Operation

With a basic overview from the flow diagram, the actual code can be seen in Figure 99 and Figure 101. It starts by extracting the Latitude and Longitude values for both strings, this section for parsing the data was modified from code available on edaboard.com, posted by J.Devarayanadurga [56]. The variables were then changed to fit with the program. Once the required data has been extracted, the CHARConv function is run prior to the calculations.

```

253 while (port1mes[i] != '$') // Look for the $ symbol in the string port2mes, keep incrementing i until it's found
254 {
255     i++;
256 }
257 // If the characters after the $ are GPRMC
258 if ((port1mes[i+1]=='G') && (port1mes[i+2]=='P') && (port1mes[i+3]=='R') && (port1mes[i+4]=='M') && (port1mes[i+5]=='C'))
259 {
260     while(port1mes[i++] != 'A'); // Look at the characters after the A
261     i++;
262     while(port1mes[i] != ',') // Increment i until the next comma is found
263         gps1_lat[k++] = port1mes[i++]; // Save the valid characters from port1mes into gps1_lat
264
265     i += 3; // Skip the next 3 characters
266     gps1_lat[k] = '\0'; // Null terminate to finish string
267     fprintf(PORT3, "GPS1 Latitude = %s\r\n", gps1_lat); //
268
269     k = 0; // Set k to zero again
270
271     while(port1mes[i] != ',') // Look at the next characters up to the comma
272         gps1_lon[k++] = port1mes[i++]; // Save the characters from port1mes into gps1_lon
273
274     port1mes[k] = '\0';
275     fprintf(PORT3, "GPS1 Longitude = %s\r\n", gps1_lon);
276
277     GPS1LAT = CHARConv(gps1_lat); // Run the Char Converter function on the gps1_lat string, save the integer to GPS1LAT
278     // fprintf("GPS1 Lat Float = %d \r\n", GPS1LAT); //
279     GPS1LON = CHARConv(gps1_lon); // Run the Char Converter function on the gps1_lon string, save the integer to GPS1LON
280     // fprintf("GPS1 Lon Float = %d \r\n", GPS1LON); //
281     // fprintf(PORT3, "\r\n"); // Leaves a blank line
282

```

Figure 99 - Parsing

The char converter function was added later on, as a method to convert the saved strings from characters into an actual number in order to use in mathematical equations. There is a C function that does this called ATOF, however this was found to introduce rounding errors in the data. In order to minimise this, each character was converted to the corresponding ASCII number, and then multiplied by the position value, e.g. tens, hundreds etc. with this done the number was multiplied by a larger number in order to move the full number into an integer, rather than using floating point maths. There are two separate routines for Lat and Long shown in Figure 100, this was down to the different format the two values take.

```

163 int32 CHARConv(char GPS[]) // Function CHARConv converting the ascii characters into the true integer
164 {
165 int32 res,res2,res3,ctt,ct,ch,ctn,cu,cdt,cdh,cdtn,cdu; // All the variables being used have been defined as int32, as this allows a 9 digit number, max supported by the PIC
166
167 if(GPS[0] == '0') // Handle Longitude as the first character is a zero
168 {
169     ctt = (GPS[0]-48)*10000; // Converting the character in position zero back to ascii number, then multiplying to give true value
170     ct = (GPS[1]-48)*1000; // Character in the thousands position
171     ch = GPS[2]-48; // Character in the hundreds position
172     ch=(ch*100); // Produced errors when multiplying in the same line
173     ctn = (GPS[3]-48)*10; // Character in the tens
174     cu = (GPS[4]-48)*1; // Units
175
176     res = (ctt+ct+ch+ctn+cu)*100000; // Add all the values and multiply to move to a higher range, allowing room for the decimals to be converted to integers
177
178     cdt = (GPS[6]-48)*1000; // Decimal tenths
179     cdh = GPS[7]-48; // Decimal hundredths
180     cdh=(cdh*100); // Multiply by 100
181     cdtn = (GPS[8]-48)*10; // Decimal thousandths
182     cdu = (GPS[9]-48)*1;
183     res2 = (cdt+cdh+cdtn+cdu)*10; // Multiply the decimal number by 10, so it fits with the other
184     res3 = (res+res2); // Add both numbers
185
186 }
187 else // handle Lat
188 {
189     ct = (GPS[0]-48)*1000; // As above
190     ch = (GPS[1]-48)*100;
191     ctn = ((GPS[2] - 48) * 10);
192     cu = (GPS[3]-48)*1;
193
194     res = (ct+ch+ctn+cu)*100000;
195
196     cdt = (GPS[5]-48)*1000;
197     cdh = GPS[6]-48;
198     cdh = (cdh*100);
199     cdtn = (GPS[7]-48)*10;
200     cdu = (GPS[8]-48)*1;
201
202     res2 = (cdt+cdh+cdtn+cdu)*10;
203     res3 = (res+res2);
204 }
205 return(res3); //

```

Figure 100 - Char Conv Function

Another flow diagram was created for the calculations section; this is shown in Figure 98. The actual code can be seen in Figure 101 which shows the process of converting the GPS format from Degrees decimal minutes, into decimal degrees. They were then converted into radians before being used in the Haversine & Bearing equations. These equations came from the movable website, as has been mentioned earlier in the document [49]. With values calculated, these are now converted into km for the distance, and back to degrees for the bearing. The last stage is to modify to the bearing from -180° to 180° , to 0° - 360° to replicate a normal compass bearing. Some duplication in the maths have been omitted, due to them being performed on the data from both GPS strings.

```

GPS1_deg = (GPS1LAT / 10000000); // Divided to leave a 2 digit whole number, for Decimal.Degrees Calculation
// Printing Unsigned Integer, GPS1_deg
GPS1_min = (GPS1LAT-GPS1_deg*10000000); // Subtracting the Degree part from GPS1LAT to leave Decimal Minutes
// Printing Integer, GPS1_min
GPS1_latDdeg = ((GPS1_deg*1000000)+GPS1_min/6); // Divide Decimal Minutes, and add onto the degree value, multiplication required due to whole number
fprintf(PORT3,"GPS1 Lat D.Deg = %8lu\n", GPS1_latDdeg); // prints a GPS1 Latitude value in decimal degrees shifted 6 decimal places to give whole num

GPS1_latRAD = (GPS1_latDdeg*(PI/180)*10) / 10000000; // Converts into Radians, large divisor required to bring the number down to a decimal float
fprintf(PORT3,"GPS1 Lat RAD = %.9f\n", GPS1_latRAD); // prints a GPS1 Latitude value in Radians, shifted to a whole number
fprintf(PORT3,"");
GPS1_londeg = (GPS1LON / 10000000); // Divided to leave a 2 digit whole number, for Decimal.Degrees Calculation

GPS1_lonmin = (GPS1LON-GPS1_londeg*10000000); // Subtracting the Degree part from GPS1LON to leave Decimal Minutes

GPS1_lonDdeg = (GPS1_londeg*1000000)+ (GPS1_lonmin/6); // Divide Decimal Minutes, and add onto the degree value, multiplication required due to whole number
fprintf(PORT3,"GPS1 Lon D.Deg = %8ld\n", GPS1_lonDdeg); // prints a GPS1 Longitude value in decimal degrees
GPS1_lonRAD = -(GPS1_lonDdeg*(PI/180)*10) / 10000000; // Converts into Radians, large divisor required to bring the number down to a decimal float
fprintf(PORT3,"GPS1 Lon RAD = %.9f\n", GPS1_lonRAD); // prints a GPS1 Longitude value in Radians *** rounding errors 19.03

fprintf(PORT3,""); // Leaves a blank line
// Calculation for distance between two GPS points, in Radians
Distance = acos(sin(GPS1_latRAD) * sin(GPS2_latRAD) + cos(GPS1_latRAD) * cos(GPS2_latRAD) * cos(GPS2_lonRAD - GPS1_lonRAD));

fprintf(PORT3,"Distance = %.2fkm\n", Distance*6371); // Prints the Distance in km by multipling the RADS by the Earth's radius
// Calculation for Bearing between two GPS points, in Radians
Bearing = atan2(sin(GPS2_lonRAD - GPS1_lonRAD) * cos(GPS2_latRAD), cos(GPS1_latRAD) *
sin(GPS2_latRAD) - sin(GPS1_latRAD) * cos(GPS2_latRAD) * cos(GPS2_lonRAD - GPS1_lonRAD));
DEG_bearing = (Bearing* (180/ PI)); // Converts the Bearing in Radians back to degrees

if( DEG_bearing <0)
    DEG_bearing = DEG_bearing+360; // If the bearing is negative, convert to a positive value from GPS1 Position

fprintf(PORT3,"Bearing RAD = %011.8f\n", Bearing); // Prints the Bearing in Radians
fprintf(PORT3,"Bearing = %.2f Degrees\n", DEG_bearing); // Prints the Bearing in Degrees

fprintf(PORT3,""); // Leaves a blank line

```

Figure 101 – Software Calculations

6.12. Cost List

A summary of all the components and associated costs has been created, as if this system was going to be manufactured again. In reality not all the components had to be purchased, due to availability in work stores, and borrowing items such as the GPS Compass.

Item	Part No	QTY	Supplier	Min QTY	Cost	Total
Hemisphere Compass	V103	1	Saderet	1	£2,699	£2,699
Lora Transceiver	868	2	RF Solutions	1	£17.54	£35.08
MAX232	195-1195	2	RS	1	£1.07	£2.14
Stripboard	292-6881	1	RS	1	£8.34	£8.34
PIC	715-4429	1	RS	1	£1.77	£1.77
Remote Enclosure	PC F 65 G	1	Time.eu	1	£13.27	£13.27
Main Enclosure	501-856	1	RS	1	£111.36	£111.36
Battery	597-835	1	RS	1	£20.2	£20.2
1uF Capacitor	684-4398	10	RS	5	£1.15	£11.5
NMV1205	544-3294	1	RS	1	£5.72	£5.72
Fuse holder	563-756	2	RS	25	£0.346	£0.70
Cable Gland	389-577	3	RS	10	£1.02	£3.02
HE14 4way Header	531-970	3	RS	10	£0.535	£1.60
HE14 4way Socket	532-349	3	RS	10	£0.305	£0.92
HE14 pins	682-7038	40	RS	100	£0.109	£4.36
Aluminium sheet			M.Pearce	1	£5	£5
4 core cable	660-4046	4	RS	100m	£44.29	£0.5
GlobalSat	MR-350	1	Amazon	1	£40	£40
4 Pin panel mount	395-484	1	RS	1	£6.16	£6.16
4 Pin Cable Mount	540-1896	1	RS	1	£7.45	£7.45
7805 Voltage Reg	843-1566	1	RS	1	£0.54	£0.54
Female db9	544-3749	1	RS	5	£0.55	£0.55
HE14 12way Header	532-030	1	RS	10	£1.147	£1.147
HE14 12way Socket	532-399	1	RS	10	£0.858	£0.858
HE14 3way Header	532-333	1	RS	10	£0.24	£0.24
HE14 3way Socket	531-970	1	RS	10	£0.54	£0.54
20x4 LCD		1	Ebay	1	£6.59	£6.59
Switch	440-6979	2	RS	1	£1.86	£3.72
D-type shell	484-789	1	RS	1	£0.89	£0.89
Single core wire			RS		£0.	
2.2uF Cap	414-9159	2	RS	25	£0.076	£0.16
TOTAL =						£2,993

7. Final Build, Testing & Analysis

7.1. Power supply

The performance of the NMV1205 was compared with that of a 7805 linear regulator, prior to its use in the design. Using a DC/DC rather than a linear regulator does offer some improvements in terms of efficiency, due to the different conversion process, this is quoted as 79% on the NMV1205 datasheet. The results can be seen Figure 102 where an input voltage of 13.5V returns an output of 7.21V, this is considerably higher than the specified 5V, but it is fairly common for DC/DC converters to output a higher voltage offload. From the results and graph it can be seen that the relationship between V_{out} and V_{in} is fairly linear in its decline.

NMV1205SAC off load	
Input Voltage(V)	Output Voltage(V)
13.5	7.21
13	6.88
12.5	6.54
12	6.27
11.5	5.95
11	5.65
10.5	5.34
10	5.06
9.5	4.68
9	4.38
8.5	4.06
8	3.81
7.5	3.56
7	3.28
6.5	3.1
6	2.75
5.5	2.52
5	2.25

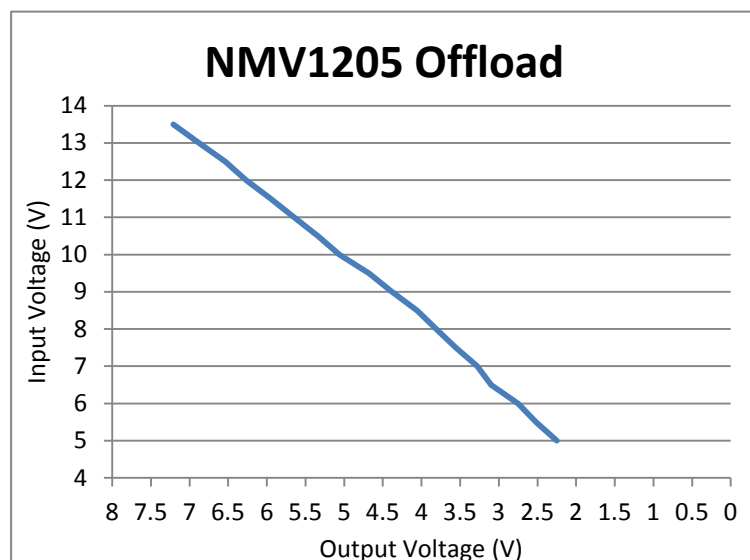


Figure 102 - NMV1205 Offload V_{out}

The test was repeated with a resistive load to ground, to see how the performance changed. This can be seen in Figure 103 where the initial voltage is much closer to the quoted 5V. The relationship between the two is still fairly linear, with slightly smaller drops in the output voltage as the input is reduced. Down to about 11V the output should still suffice to power the components lower than that it may become unusable. There's a slight discrepancy at 10V where the output has increased compared with 10.5V.

NMV1205SAC on load	
Input Voltage (V)	Output Voltage (V)
13.5	5.6
13	5.32
12.5	5.15
12	5.01
11.5	4.73
11	4.56
10.5	4.21
10	4.33
9.5	3.76
9	3.53
8.5	3.22
8	3
7.5	2.8

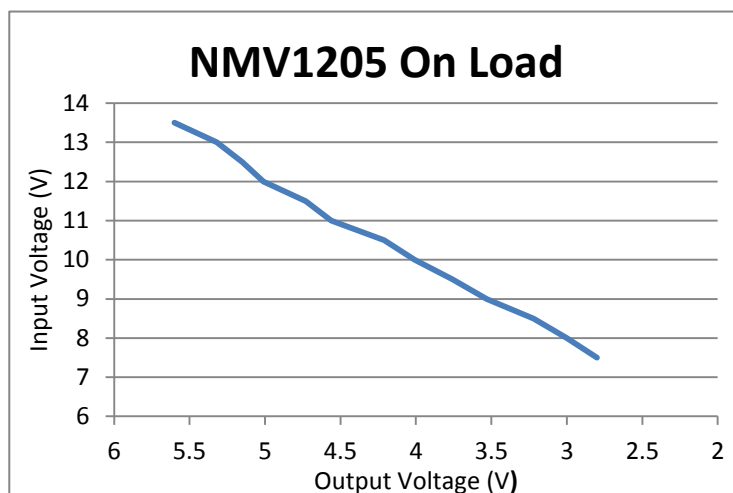


Figure 103 - NMV1205 On load

The same test was repeated with a 7805 on load, it's immediately apparent from the shape of the graph that this works in a different manner. It's able to maintain an output voltage close to 5V for a range of inputs, 13.5 – 6.5 in this test. Below that the output starts to decline, until below 4V where the output drops to zero. This is fairly impressive, although possibly unnecessary for this application. If the lead acid battery has dropped this low, it may not recover with charging. Another drawback of a linear regulator is the heat they produce; this is down to the inefficiency in the conversion process, which wastes the excess energy as heat. For this reason it's common to use a heat sink with these components.

7805 on load	
Input Voltage(V)	Output Voltage(V)
13.5	4.95
13	4.94
12.5	4.94
12	4.95
11.5	4.94
11	4.94
10.5	4.94
10	4.95
9.5	4.94
9	4.94
8.5	4.95
8	4.95
7.5	4.95
7	4.98
6.5	5.01
6	4.6
5.5	4.1
5	3.65
4.5	3.16
4	2.72
3.5	0.06

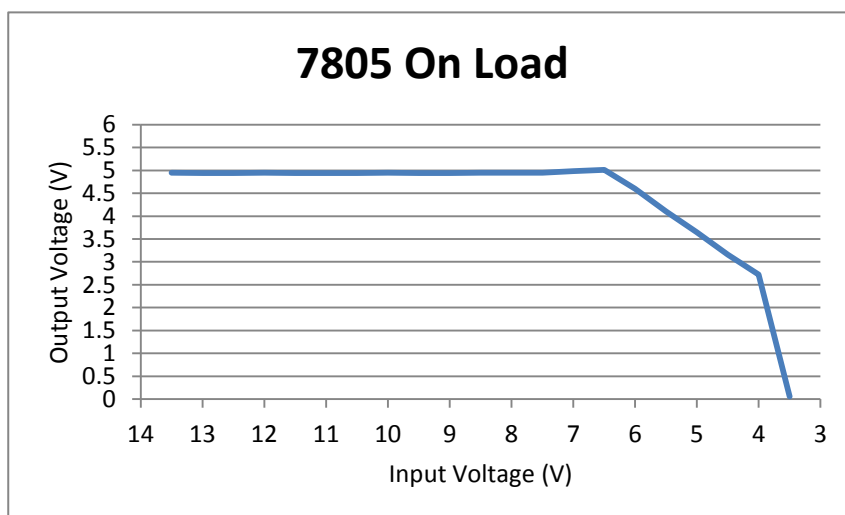


Figure 104 - 7805 on Load

7.2. Software Calculations

```

Virtual Terminal - PORT3
GPS1 -- $GPRMC,163801.285,A,5209.5938,N,00428.0132,W,000.0,000.0,
GPS2 -- $GPRMC,163801.285,A,5202.6415,N,00441.5615,W,000.0,000.0,

GPS1 Latitude = 5209.5938
GPS1 Longitude = 00428.0132
GPS1 Lat Float = 5209.59392
GPS1 Lon Float = 00428.01320

52
9.59375
GPS1 Lat D.Deg = 52.1599040
GPS1 Lat RAD = 0.910361920
4
28.01321
GPS1 Lon D.Deg = -4.4668872
GPS1 LonRAD = -0.077961896

GPS2 Latitude = 5202.6415
GPS2 Longitude = 00441.5615
GPS2 Lat Float = 5202.64192
GPS2 Lon Float = 00441.56148

52
2.64160
GPS2 Lat D.deg = 52.0440256
GPS2 Lat RAD = 0.908339712
4
41.56149
GPS2 Lon D.deg = -4.6926920
GPS2 Lon RAD = -0.081902928

Distance RAD = 0.003088117
Distance = 19.67km
Bearing RAD = -2.26519298
Bearing = 230.214 Degrees
  
```

Figure 105 - ATOF Errors

Whilst writing the code to perform the mathematical calculations using the two GPS positions it was noticed that there were some errors when converting between data types, and additional rounding errors. As an example in Figure 105 GPS1 latitude = 5209.5938 is the original NMEA data saved as a character string, it's then converted to a floating point variable which shows 5209.59392, this works out as 0.73Ft in distance. In order to use the Haversine formula and the bearing formula, the data was converted into degrees decimal, and then into radians as trigonometric functions were required. For the first conversion the degree value is extracted, leaving the decimal minutes. With these two separated, the degrees decimal can be calculated by dividing the minutes by 60. These values are shown under GPS1 Lon Float in Figure 105, it can be seen that the minutes value is also slightly different than the original data, splitting the calculations into a longer sequence still didn't recreate the original value. With slight errors at each calculation they were likely to accumulate by the time the Haversine formula was

actually used, as can be seen from the value in radians, GPS1 Lat RAD in Figure 106. The expected values can be seen in the excel print screen in Figure 107.

```

GPS1 Latitude = 5209.5938
GPS1 Longitude = 00428.0132
GPS1 Lat Float = 5209.59392
GPS1 Lon Float = 00428.01320

52
9.5937
GPS1 Lat D.Deg = 52.1599040
GPS1 Lat RAD = 0.910361920
4
28.01321

```

Figure 106 - Radians Error

5209.5938	52	9.5938	52.15989667	0.9103619343
-----------	----	--------	-------------	--------------

Figure 107 - Radians Calculation

```

if (gps2_lat != '\0')
{
    GPS2LAT = atof(gps2_lat);
    printf("GPS2 Lat Float = %9.5f\r\n", GPS2LAT); // not printing correctly
}

if (gps2_lon != '\0')
{
    GPS2LON = atof(gps2_lon);
    printf("GPS2 Lon Float = %011.5f\r\n", GPS2LON); // its cutting numbers off
    printf("\r\n");
}
}

```

After consulting the CCS help file it was found that CCS didn't support the data type double, which is usually used with the ATOF function, instead it was limited to a float32. To prove this was causing the issues some tests were carried out using a different C development package, and a basic .exe program. This performed the ATOF function correctly as standard, but changing the data type to a float showed similar results to the CCS issue.

In order to overcome this issue a separate function was written to convert the original numbers into whole values, and then perform the initial data conversions and calculations using integer values, and then convert back to a float later on.

Figure 108 shows that sometimes the error varied depending on the input, having either a lesser or greater effect.

5207.9287	52	7.9287	52.1321450		433.9631	4	33.9631	4.566051667
5205.0811	52	5.0811	52.0846850		439.16808	4	39.16808	4.652801333

```

Virtual Terminal - PORT3
GPS1 -- $GPRMC,082558.190,A,5207.9287,N,00433.9631,W,000.0,000.0,300318,,A*72
GPS2 -- $GPRMC,082558.190,A,5205.0811,N,00439.1681,W,000.0,065.3,300318,,A*75

GPS1 Latitude = 5207.9287
GPS1 Longitude = 00433.9631
GPS1 Lat Float = 5207.92800
GPS1 Lon Float = 00433.96306

52
7.92822
GPS1 Lat D.Deg = 52.1321376
GPS1 Lat RAD = 0.909877440
4
33.96307
GPS1 Lon D.Deg = -4.5660520
GPS1 LonRAD = -0.079692632

GPS2 Latitude = 5205.0811
GPS2 Longitude = 00439.1681
GPS2 Lat Float = 5205.08160
GPS2 Lon Float = 00439.16808

52
5.08105
GPS2 Lat D.deg = 52.0846848
GPS2 Lat RAD = 0.909049280
4
39.16809
GPS2 Lon D.deg = -4.6528020
GPS2 Lon RAD = -0.081206704

Distance RAD = 0.001196026
Distance = 7.61km
Bearing RAD = 1.997061888
Bearing = 228.339 Degrees
  
```

Figure 108 - Additional ATOF Errors

```

Virtual Terminal - PORT3
GPS2 -- $GPRMC,181121.498,A,5206.8866,N,00430.8372,W,000.0,133.1,300318,,,A*72
GPS1 Latitude = 5205.0811
GPS1 Longitude = 00439.1681
GPS1 Lat Float = 5205.08160
GPS1 Lon Float = 00439.16808
52
52.0810
GPS1 Lat D.Deg = 52.0846848
GPS1 Lat RAD = 0.909049280
4
39.16809
GPS1 Lon D.Deg = -4.6528020
GPS1 LonRAD = -0.081206704
GPS2 Latitude = 5206.8866
GPS2 Longitude = 00430.8372
GPS2 Lat Float = 5206.88640
GPS2 Lon Float = 00430.83717
52
6.88623
GPS2 Lat D.deg = 52.1147712
GPS2 Lat RAD = 0.909574336
4
30.83719
GPS2 Lon D.deg = -4.5139536
GPS2 Lon RAD = -0.078783352
Distance RAD = 0.001464843
Distance = 9.33km
Bearing RAD = 01.23071968
Bearing = 70.515 Degrees

```

Lat/long distance & bearing between two points												
see:	http://www.movable-type.co.uk/scripts/latlong.html											
Earth's rad:	6371	Names used: lat1=\$Fn, lon1=\$Gn, lat2=\$Hn, lon2=\$In, ER=\$B\$5, where 'n'=row number										
Lat 1 (deg)	Lon 1 (deg)	Lat 2 (deg)	Lon 2 (deg)	Lat 1 (rad)	Lon 1 (rad)	Lat 2 (rad)	Lon 2 (rad)	Dist (rad)	Dist (km)	Bmg (rad)	Bmg (deg)	Bmg (norm'd)
52.084685	-4.652801	52.114777	-4.513954	0.90904924311	-0.081206697	0.909574448	-0.078783360	0.00158	10.1	1.2307	70.51	70.51

Figure 109 - Distance Error

Following the changes to the code described earlier, the new output can be seen in Figure 110. From looking at Figure 111 it shows this has reduced the range error down to 120m for this example; this is down from almost 1km in earlier tests.

Even with the earlier range errors the bearing was always pretty accurate, which was the main requirement. However if the product was going to be continued on to the final specification, accurate distances would be helpful.

```

Virtual Terminal - PORT3
GPS2-- $GPRMC,145937.849,A,5113.4653,N,00458.5593,E,000.0,000.0,300318,,A*6E
GPS1 Latitude  = 5233.3330
GPS1 Longitude = 00433.9631
GPS1 Lat D.Deg = 52555550
GPS1 Lat RAD   = 0.917267520
GPS1 Lon D.Deg = 4566051
GPS1 Lon RAD   = -0.079692624
GPS2 Latitude  = 5113.4653
GPS2 Longitude = 00458.5593
GPS2 Lat D.Deg = 51224421
GPS2 Lon RAD   = -0.086847384
Distance       = 150.58km
Bearing RAD    = -2.95094776
Bearing        = 190.92 Degrees

```

Figure 110 - Modified ATOF

Lat/long distance & bearing between two points												
see:		http://www.movable-type.co.uk/scripts/latlong.html										
Earth's rad:		6371	Names used: lat1=\$Fn, lon1=\$Gn, lat2=\$Hn, lon2=\$In, ER=\$B\$5, where 'n'=row number									
Lat 1 (deg)	Lon 1 (deg)	Lat 2 (deg)	Lon 2 (deg)	Lat 1 (rad)	Lon 1 (rad)	Lat 2 (rad)	Lon 2 (rad)	Dist (rad)	Dist (km)	Bmg (rad)	Bmg (deg)	Bmg (norm'd)
52.555555	-4.566051667	51.224422	-4.975988	0.9172675	-0.0796926	0.8940348	-0.0868474	0.02365	150.7	-2.9509	-169.08	190.92

Figure 111 - Correct Range

7.3.Remote unit

The circuit for the remote unit was built tidily on Strip board, with a few changes from the prototype. The circuit was tested at a couple of stages prior to connecting the GPS receiver and modem, so as not to damage them. Figure 112 shows the 5V output from the dc/dc that would power all the components; the scope was set to 1V per division, with 1ms time base it can be seen the voltage is steady, with a tiny amount of ripple.

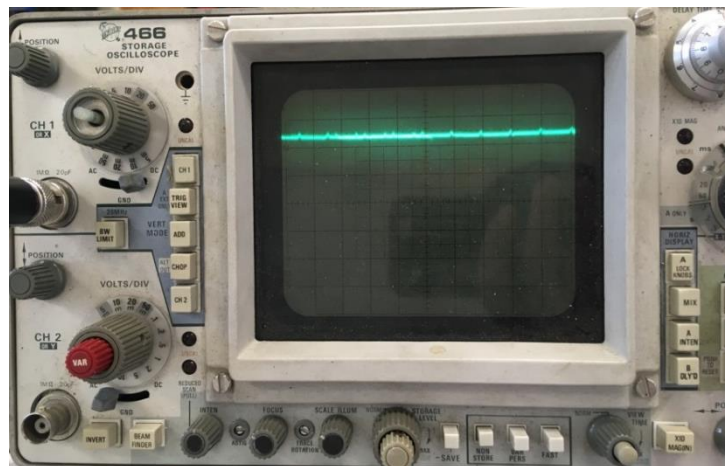


Figure 112 - NMV1205 Output

Figure 113 and Figure 114 show some initial testing of the data coming from the GPS into the MAX232, the Bi-polar data can be seen on the scope prior to being converted.

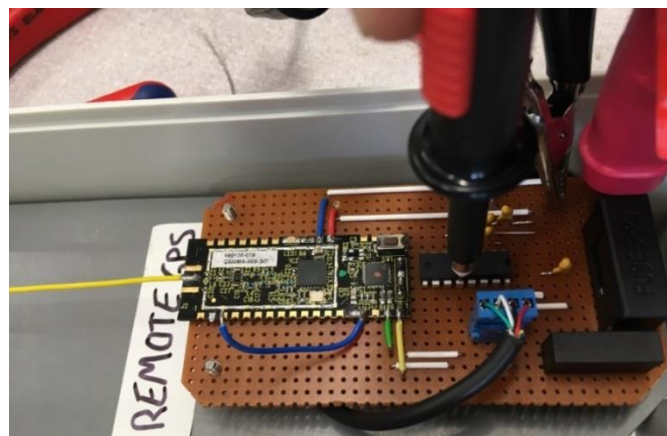


Figure 113 - MAX232 input

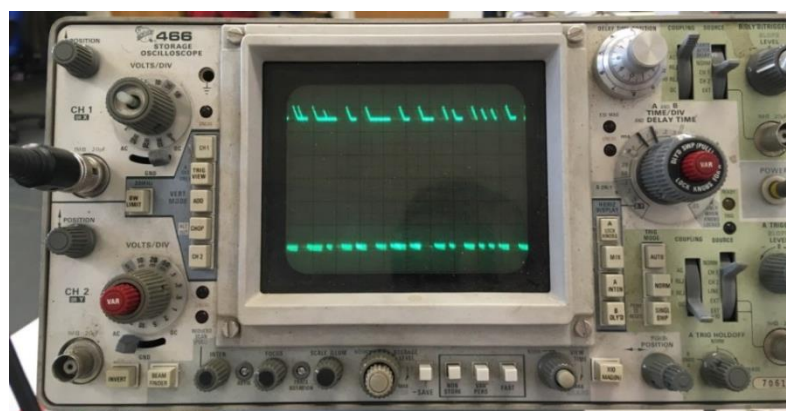


Figure 114 - RS232 GPS data



Figure 115 - TTL Output

7.3.1. Power Consumption

Some additional tests were carried out to see the current draw of the unit, as this fluctuated between standby and transmission an approximate average value was used. A value of 50mA and 90mA can be seen in the two states, Figure 96 and Figure 117. As the data is transmitted regularly at 1Hz, a current draw of 70mA was recorded.

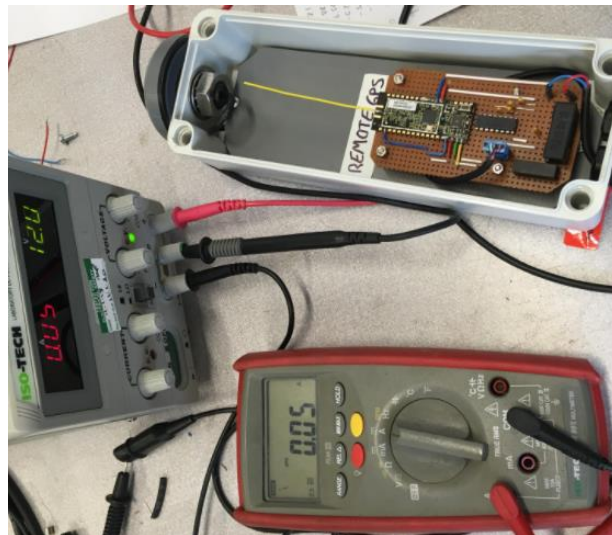


Figure 116 - Current draw standby

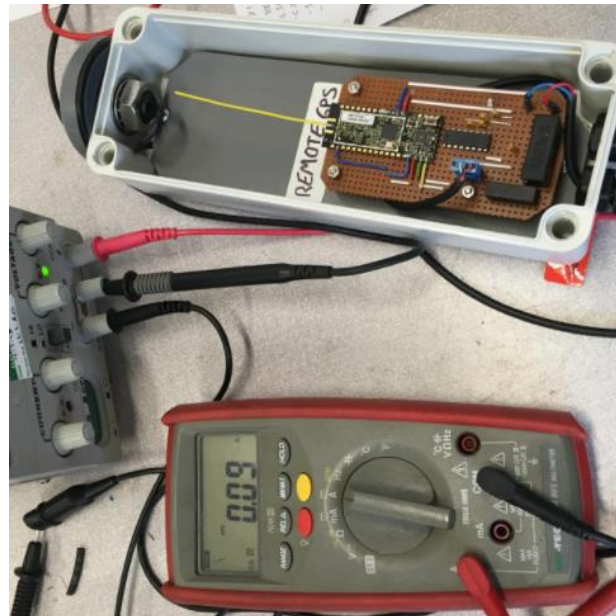


Figure 117 - Current during transmission



Figure 118 - Completed Remote Unit

7.4. Main Unit

Initially the circuit was built on a breadboard for ease of prototyping, prior to the final assembly. The basic circuit can be seen in Figure 119 with the TTL GPS used in earlier tests used. At this stage the main aim was to check the PIC operation with the other components such as the LCD and GPS inputs.

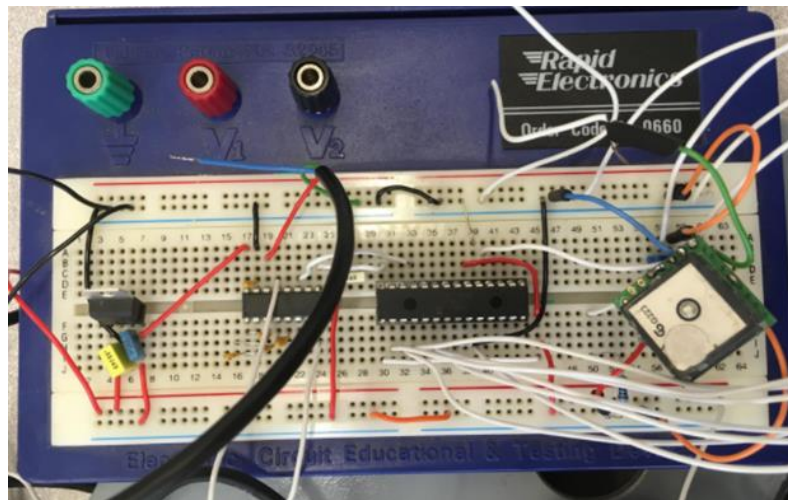


Figure 119 - Breadboard Circuit

Initially there were a few issues, something that took far too long to diagnose was no output on the LCD. Eventually it was noticed that monitoring the R/W pin on the PIC during start up allowed the LCD to initialise correctly, and display some words. Looking at several LCD circuits online it looked like tying the LCD R/W pin to ground should be ok, as data was only being written to the screen; however this proved not to work. Some further attempts using pull up and pull down resistors were tested in the hope that the scope was allowing a better path to ground.

Finally the PIC was moved further down the breadboard; with the connections rechecked this solved the issue. This possible loose connection still doesn't entirely make sense, as the voltage level could be observed changing on the LCD, which suggested a decent contact.

In order to prove correct operation of the PIC it required good GPRMC strings. This involved taking all the equipment outside to get a decent satellite fix, after some tense moments the

LCD began displaying data. As the two GPS receivers were so close this wasn't accurate, but it did prove the operation.



Figure 120 - Prototype Setup

The data being sent from the PIC can be seen in Figure 121, initially there appears to be some corrupt data however this soon stops with good strings being captured in the next instance. Throughout the messages there does appear to be a few rouge characters at the end of the sentences, but they don't appear to be corrupting the actual messages. These rouge characters can also be seen at the end of the messages on the LCD.

Following the succesful prototype testing the circuit was rebuilt on stripbaord, to ensure no connections came loose in transit. It was also fitted in the selected enclosure for display purposes at the final viva, this can be seen in Figure 122 and Figure 123.

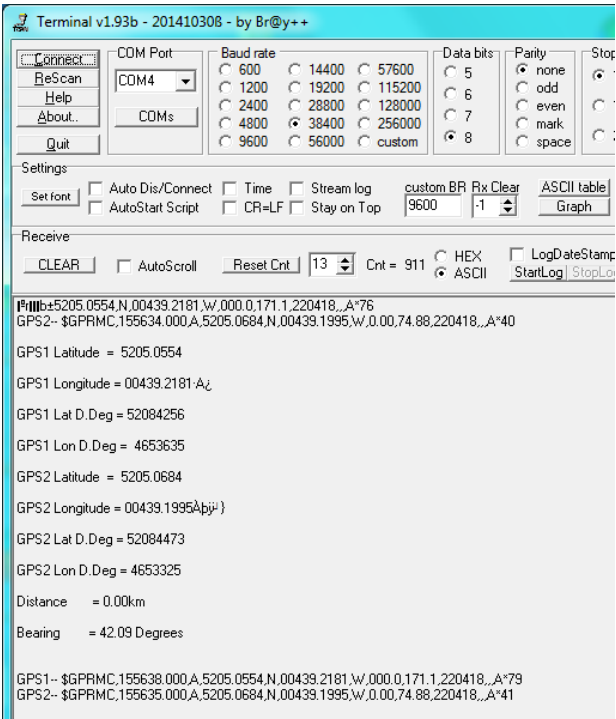


Figure 121 - Serial Output

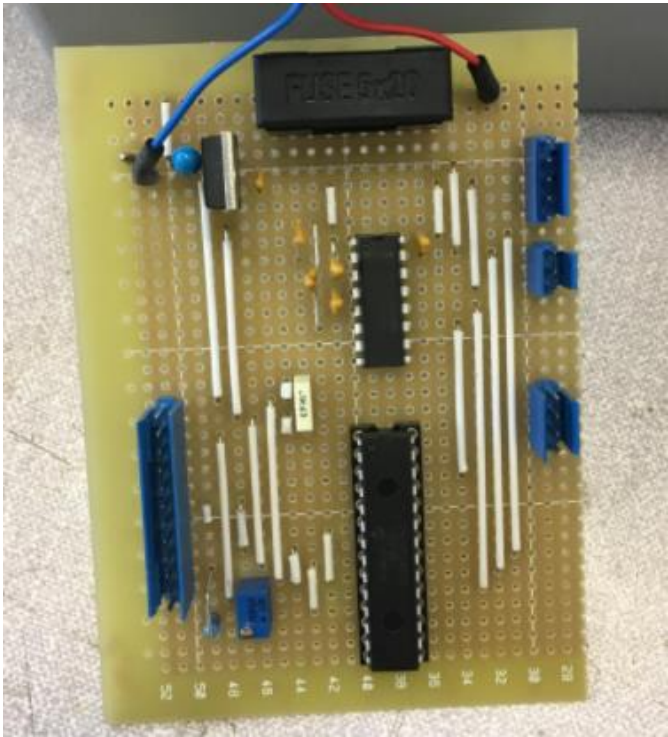


Figure 122 - Completed Circuit



Figure 123 - Completed Unit



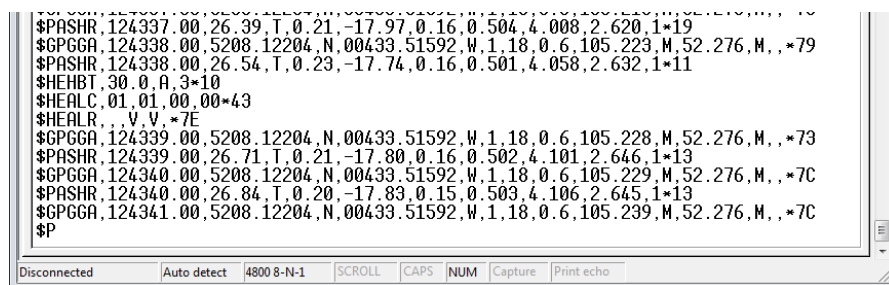
Figure 124 - Completed System

7.5. Real World Testing

The plan for the testing was to print out an A3 image of a compass; this would be aligned with true north using the output from the GPS compass. The main unit would be placed on the compass, whilst the remote unit was taken through 360° around the main unit, at a reasonable distance to avoid any errors. If the system was working correctly the bearing should match up with the printed compass, and travel through 360°.

7.5.1. Test 1

The two units were placed at either end of a yard in work; a second GPS compass was used to point between them as best as possible, the bearing can be seen in Figure 125 the first value after the time in the PASHR sentence, 26.84° true. Figure 126 shows the serial output from the main unit, the bearing at the bottom being 23.84°. The actual setup can be seen in Figure 127 and the two following images; the remote unit is slightly higher than the two tyres, viewed through the stepladder.



```

$PASHR,124337.00,26.39,T,0.21,-17.97,0.16,0.504,4.008,2.620,1*19
$GPGGA,124338.00,5208.12204,N,00433.51592,W,1.18,0.6,105.223,M,52.276,M,,*79
$PASHR,124338.00,26.54,T,0.23,-17.74,0.16,0.501,4.058,2.632,1*11
$HEHBT,30.0,A,3*10
$HEALC,01.01,00.00*43
$HEALR,,V,V,*7E
$GPGGA,124339.00,5208.12204,N,00433.51592,W,1.18,0.6,105.228,M,52.276,M,,*73
$PASHR,124339.00,26.71,T,0.21,-17.80,0.16,0.502,4.101,2.646,1*13
$GPGGA,124340.00,5208.12204,N,00433.51592,W,1.18,0.6,105.229,M,52.276,M,,*7C
$PASHR,124340.00,26.84,T,0.20,-17.83,0.15,0.503,4.106,2.645,1*13
$GPGGA,124341.00,5208.12204,N,00433.51592,W,1.18,0.6,105.239,M,52.276,M,,*7C
$P

```

Figure 125 – Test 1 Compass bearing

```

Bearing      = 23.84 Degrees

GPS1-- $GPRMC,125357.00,A,5208.12167,N,00433.51703,W,0.05,143.79,250418,2.1,W,A,
C*51

GPS2-- $GPRMC,125356.000,A,5208.1553,N,00433.4926,W,0.00,0.00,250418,,D*75

GPS1 Latitude = 5208.12167
GPS1 Longitude = 00433.517030
GPS1 Lat D.Deg = 52135360
GPS1 Lon D.Deg = 4558616
GPS2 Latitude = 5208.1553
GPS2 Longitude = 00433.4926L ♦♦
GPS2 Lat D.Deg = 52135921
GPS2 Lon D.Deg = 4558210
Distance      = 0.00km
Bearing      = 23.84 Degrees

```

Figure 126 – Test 1 Serial Output

Figure 128 shows an enlarged version of the remote units' position, and Figure 129 the data displayed on the main unit LCD.

A short period of time may have elapsed between the hyper terminal screenshots and the photographs being taken, as the serial output and LCD screen do display the same data. It's possible that as one of the GPS receivers has recalculated its position, it has created a slight change in the bearing.

Even with this slight discrepancy and rudimentary test, it does show that the system is matching up fairly well with the output from the GPS compass.



Figure 127 – Test 1 Setup

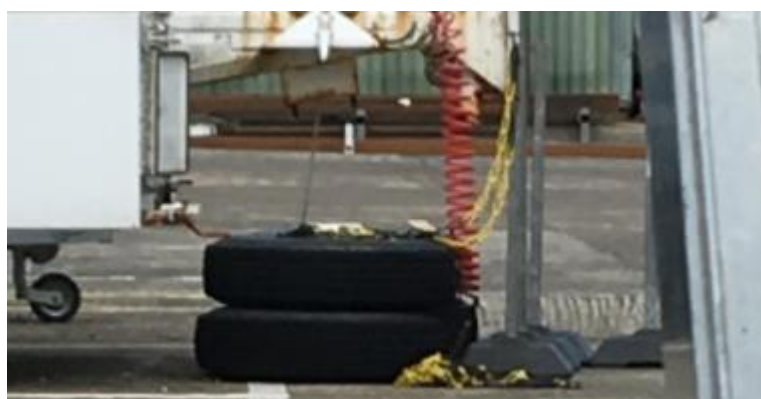


Figure 128 – Enlarged Remote Position



Figure 129 – Test 1 LCD Display

7.5.2. Test 2

The remote unit was re positioned, and the test repeated. Figure 130 shows the compass bearing between them; Figure 131 shows the alignment of the compass, and Figure 132 the output from the LCD screen. Again this test is only done by eye, but the results tie in fairly well.

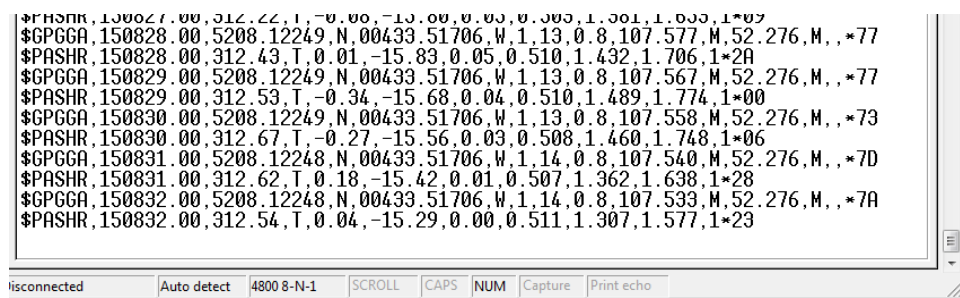


Figure 130 – Test 2 Compass Bearing



Figure 131 – Test 2 remote Position



Figure 132 –Test 2 LCD

7.5.3. Test 3

The third test was a moving test along the lines of the test plan at the start of the section. Conditions were awkward with windy conditions (piece of paper blew away), and time constraints due to the assistant having to leave. Initially the plan was to conduct this in a large open space, however due to the issues the baseline was shrunk quite a lot, the assistant carried the remote unit in a rough circle around the main unit at a radius of 4/5 metres. The data from the main unit was recorded and can be seen in the appendix. As expected it does show the change of bearing throughout, and a video was also made to try and capture the test. Because of the short baseline and the quick walking pace the incremental change in the bearing at each update is fairly large. This is to be expected when using a 1hz update and such a small baseline, a larger area would have been an improvement.

7.5.4. Test 4

Additional stationary test shown in the following three figures.



Figure 133 – Remote Unit behind Trailer

```

GPS1-- $GPRMC,152200.00,A,5208.13876,N,00433.49576,W,0.04,227.47,250418,2.1,W,D,S*4B
GPS2-- $GPRMC,152200.000,A,5208.1378,N,00433.4847,W,3.43,260.97,250418,,,D*70
GPS1 Latitude = 5208.13876
GPS1 Longitude = 00433.49576@y
GPS1 Lat D.Deg = 52135645
GPS1 Lon D.Deg = 4558261
GPS2 Latitude = 5208.1378
GPS2 Longitude = 00433.4847Ayy
GPS2 Lat D.Deg = 52135630
GPS2 Lon D.Deg = 4558078
Distance = 0.00km
Bearing = 95.48 Degrees

```

Figure 134 –Test 4 Output



Figure 135 – Test 4 LCD

7.5.5. Test Analysis

Although the testing wasn't carried out to the standard that had been hoped, it was helpful in showing the system operating as expected. The day before had been torrential rain, so to get any functional tests done was a bonus. From the various test images included it can be seen that the system and GPS compass concur on the bearing within a couple of degrees for the stationary tests. An obvious error from the test perspective is the alignment of the actual compass, as it's done by eye.

With more time the original test plan may be achieved, along with testing how slow the remote unit has to move at varying distances to show the bearing incrementing by one degree, this would be useful in ascertaining whether the system would be suitable to track a moving object in the future, or whether a higher GPS data rate is required, possibly that the system won't be suitable for this.

Another issue that was picked up during the simulation and still remains in the physical build is the distance calculation not showing anything below 1km. it would have been good to separate the two units by more than 1km to prove it was working to some degree, however this

wasn't achievable with resources and the tight timescale. The Haversine formula is definitely something that can be revisited, along with the code.

Something that has shown up in testing is the rouge characters that can be seen both at the end of the LCD screen, and the serial data. These were never seen during the simulation so it doesn't appear to be a coding issue entirely. The fact that they don't appear to be corrupting the actual data makes it slightly less of an issue though.

8. Evaluation

There were several aims and objectives highlighted at the start of this report, whilst a great deal of them have been covered there are a couple of major objectives that weren't met due to the time constraints.

Investigation of GPS technology.

A vast amount of time was spent researching GPS technology, how a position can be calculated, and different components within the system, from the satellite network down to the receiver that picks up these signals. It was also necessary to carry out research into how the positional information is displayed to the user, focusing particularly on the accuracy.

With a reasonable understanding of the surrounding technology, and from carrying out market research into both tracking camera systems and different receivers, the hypothesis was that with sufficiently accurate GPS receivers a tracking camera solution would be possible.

Investigation into wireless data transmission.

A key requirement for this to work was the transmission of the positional data from one object back to the main unit, to maintain practicality wireless transmission was selected for this. After some brief research into the various wireless transmission methods RF was selected as the preferred option. This had several benefits over the alternatives for this application, cost and versatility being two major ones.

Obtaining positional information for the object.

There was lots of testing of the various components prior to the final build, in order to ascertain their performance and suitability early on in the design process. This included a selection of GPS receivers, the data link selected, along with the GPS Compass. Following the results of the tests the best GPS receiver was selected, along with proving the suitability of the other components. The system was simulated throughout, in order to develop the code, and to prove its overall operation prior to building it.

Transmission of the objects positional data back to the base (camera location).

Processing the data and calculating the difference between the two positions.

Build the system.

Highlight areas for future work and development.

The first section of the system was completed satisfactorily, with the system calculating the bearing between the two units. There were some issues with the distance calculation not working below 1km which was a slight issue; however the distance measurement wasn't as crucial as the bearing, which proved to be accurate during the initial tests. Further testing of the system was planned, however time constraints and weather conditions prevented these being completed by the report deadline, however the plan is to complete these prior to the final viva.

Processing the data and enabling the camera to adjust its position, to locate target.

Ascertain if tracking a stationary object is possible with the system.

Investigate whether tracking a slow moving object is possible with the system.

Investigate whether tracking a fast moving object is possible with the system

The final objectives weren't completed due to the lack of a physical output such as a PTZ camera, or servo. So the system couldn't be analysed in terms of tracking an object. This is a big drawback to the project outcome; however it does leave the opportunity for additional development in the future.

If this project were to be completed again it's difficult to say whether a different approach should have been taken. The system so far is on the right track to meeting the original requirements, but without the last crucial elements it's hard to evaluate its effectiveness. Some changes that could have improved the process would be to select a method that didn't rely so heavily on software, when this was a particular weakness.

9. Conclusion

This project has a fair selection of both successes and failures, on a positive note a working system has been designed and built following extensive research into the pertinent areas. The drawback of the finished product being that it wasn't possible to fully meet the original specification, and include a servo/ PTZ camera output.

The research stage allowed a vast improvement in the authors understanding of GPS technology, which proved enlightening at the expense of some of the other research areas. That being said the research was sufficient in giving enough information to design a system that utilises several different technologies, from GPS, wireless transmission, serial data transfer, a microcontroller element, along with some maths.

There was a reasonable amount of electronic design for the system, both during the initial component tests, and going towards the final system. The section on testing the GPS receivers was particularly informative, in comparing figures for accuracy that get quoted on receiver datasheets, to actual logged data. This was a time consuming process however, and to analyse the performance to a greater degree would have taken a great deal more time.

The biggest learning curve within this project has been the software development, which took an inordinate amount of time to get to a working solution. There's plenty of room for improvement within the software, and additional features that would have been good, however weren't achievable due to the delays in the development.

Some improvements for the project are listed below.

9.1. Future improvements

9.1.1. Software

There were several improvements that could be made to this design, the software functions but not optimally. If the project was progressed to meet the original specification, a redesign may be necessary. This became apparent when the PASHR data was extracted along with the GPRMC. This would have been required as part of the output, giving the camera system / servo a reference point. Having to deal with the additional string from the compass caused

problems with the code, due to the extra requirements. These problems were only picked up on late in the project, when physical GPS devices were used with the Proteus simulation, rather than relying on the virtual models offered in Proteus. In hindsight earlier testing of the code with real world components would have been a better plan.

A greater knowledge and understanding of C programming from the outset could have sped up the software development greatly, allowing some of the additional features to be developed at the same time.

9.1.2. Camera Position Output

At present the system doesn't have the final stage, which was driving a servo / Pan tilt unit to look at the target, based on the calculated bearing. This is quite a pitfall, as it was a major part of the design. The plan is to further develop this, which would allow more functional testing of the system, with the aim of making it fit for purpose.

With a working camera output, the idea was to use the distance calculated between the two GPS points to adjust some of the camera parameters, e.g. if the distance was less than 0.5km then the zoom setting could have been adjusted slightly, narrowing the FOV. If the distance was between 0.5 – 1km then the FOV could be tightened again etc.

Another improvement would have been to use the rate of change in the bearing to adjust the pan speed of the camera; this would have been developed to work with moving targets of varying speeds.

9.1.3. MCU Upgrade

Perhaps a PIC microcontroller wasn't the best option for this application, this is only mentioned due to the issues when converting between data types, e.g. characters to floating point numbers, which has been discussed, this introduced errors due to CCS /PIC not supporting the data type double. This poses a problem when the aim was to make the system as accurate as possible, these small errors all add up.

Another issue was the program memory size; this was picked up on too late to swap to another PIC, so some of the print lines had to be removed from the serial output. This doesn't affect the output, however they were a 'nice to have' when viewing the conversion process.

9.1.4. Further Mathematics Work

Using the Haversine formula the smallest distance that could be represented using the excel spreadsheet was 100m, ideally this would have been modified to show smaller distances as well. When this was converted into C code on the PIC, and using physical GPS inputs the smallest distance that would show up was 1km, it wasn't conclusively proved whether this was down to rounding errors, or issues with the maths itself. At greater baselines the distance error reduced.

There was another equation that could have been used for this application, rather than using a great circle distance, the maths could have been based on a flat earth model due to the distances we were interested in being sub 5km. from research this model would have been suitable for distances sub 20km, where the curvature of the earth starts to have an effect.

10. Reflection

The aim of this project was to develop a tracking camera system that could be used as part of a trial deliverable in the workplace; if successful it could have improved the customer offering from the department, along with reducing staff workload. I had a vision of how the final system would operate, and believed if I had the necessary skills it could be a useful piece of equipment, rather than something to merely meet the degree project requirements. I was aware from the outset that this would be a challenging project, and at the core of the system would be the software. I had a very basic knowledge of programming from previous courses, but it was not something I did either in work or as a hobby. When the project was selected I wrongly assumed that we'd be covering C programming in one of the University modules, however a couple of months down the line I found out this was a misunderstanding, which made the programming task even more daunting.

During the research phase I spent a considerable amount of time researching GPS technology, possibly concentrating on it too much. It's such a vast subject and very interesting, once you delve into it, you discover other elements and try and expand on those, 'opening a can of worms' as it were, I think where I may have fallen down slightly is trying to give an overview of the technology as a whole, and become slightly overwhelmed with it. It was only after a discussion with the lecturer that I took a step back and realised that although interesting, a lot of information was superfluous for the function of the project.

The software stage was initially plagued with delays; both in terms of overcoming problems setting up the software design suite, and then once those were overcome the steep learning curve of trying to develop the code.

Overall apart from being overly ambitious on my expectations for the project from the outset, I believe there are positives to take from it. It has involved lots of stress and headaches along the way, but has given me the opportunity to develop both my academic skills, along with practical elements of design, along with vast improvements in my knowledge and understanding of writing software (although still not enough). These challenges have allowed me to develop as a person, in trying to overcome them, along with drawing on my knowledge gained from the course and the workplace. I think I think I'll look back on the experience favourably with time, as it's taught many lessons along the way. Not meeting my initial goal

was regrettable, but the fact that the finished system was built to a decent standard, and the main part works well feels like a good achievement.

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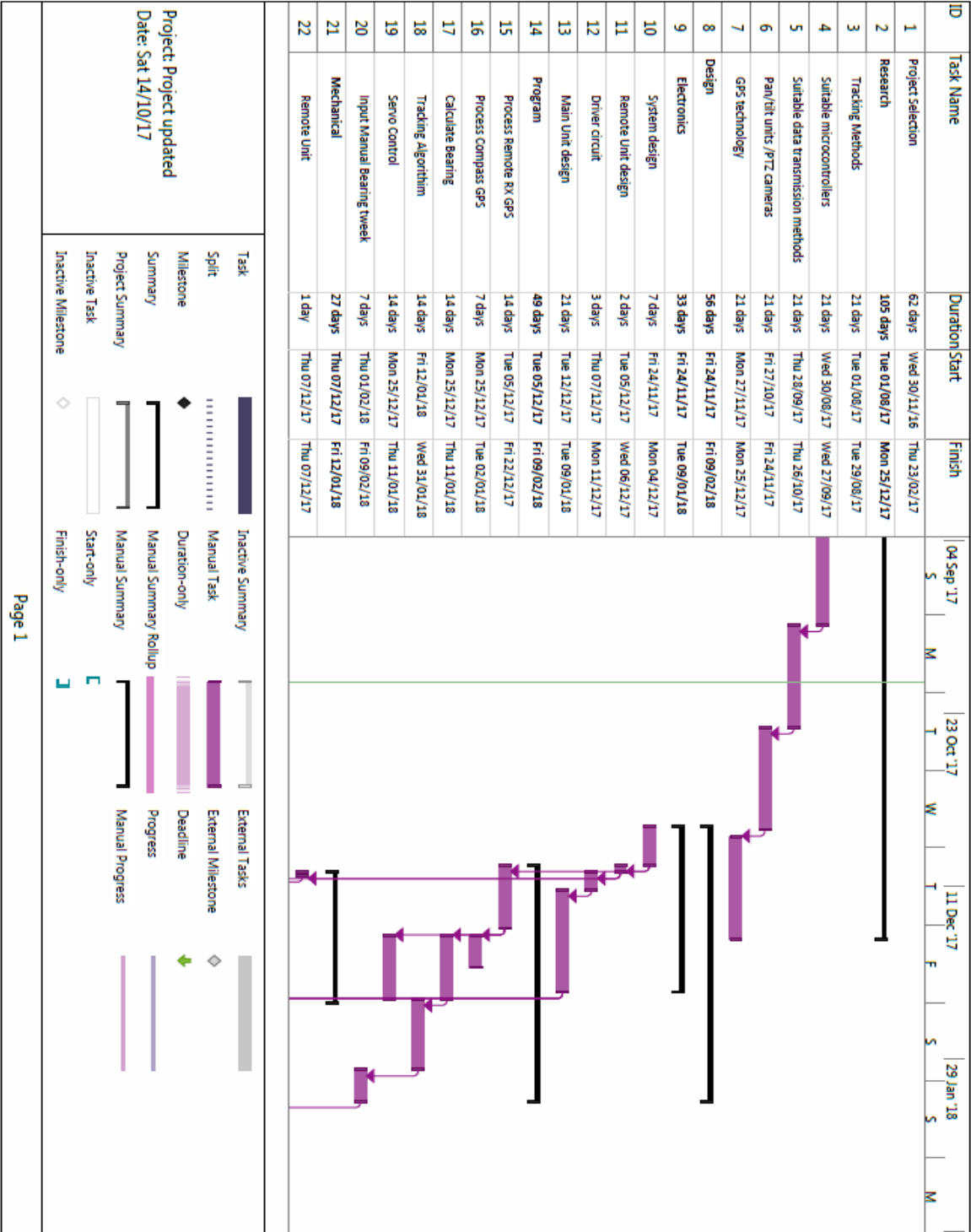
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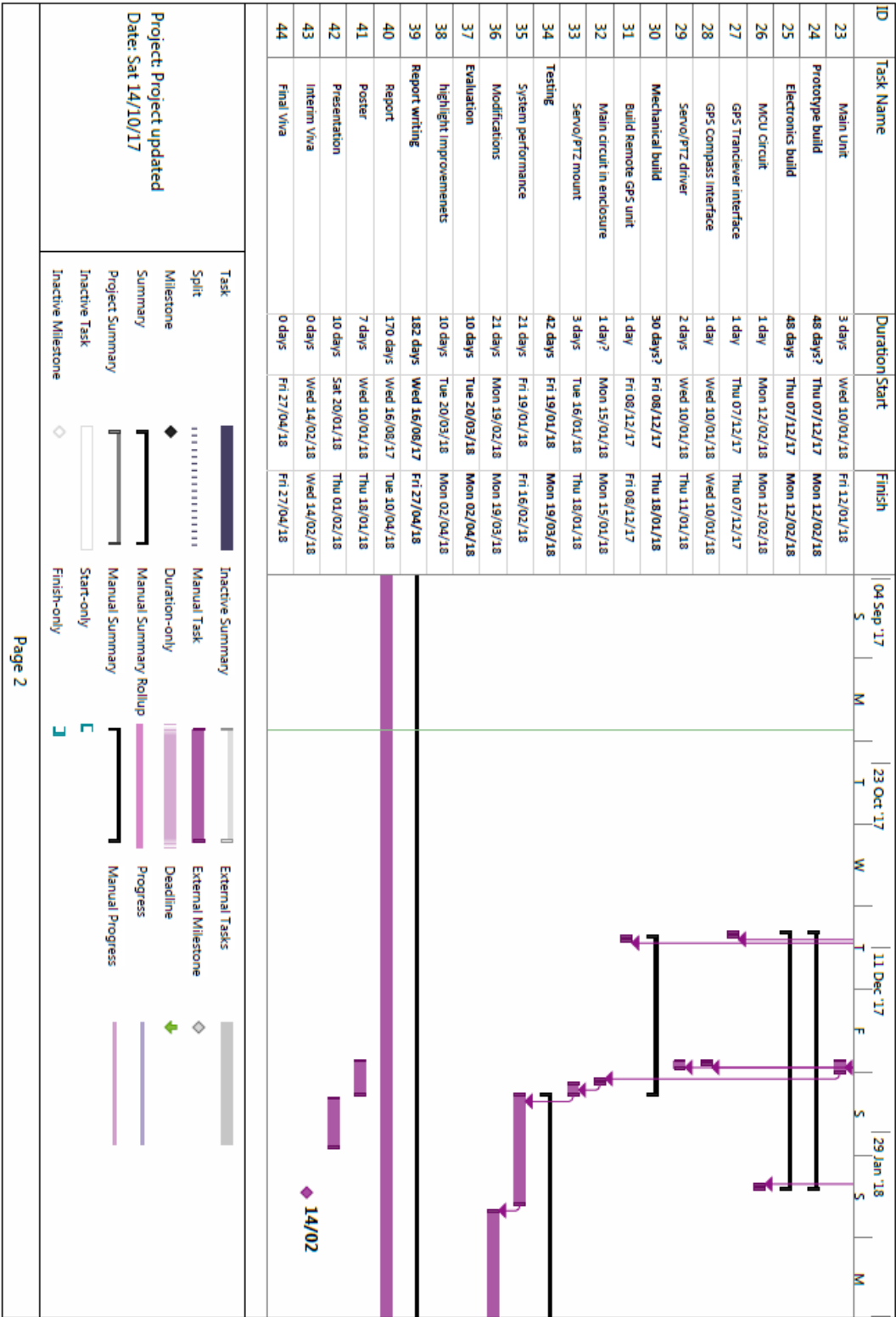
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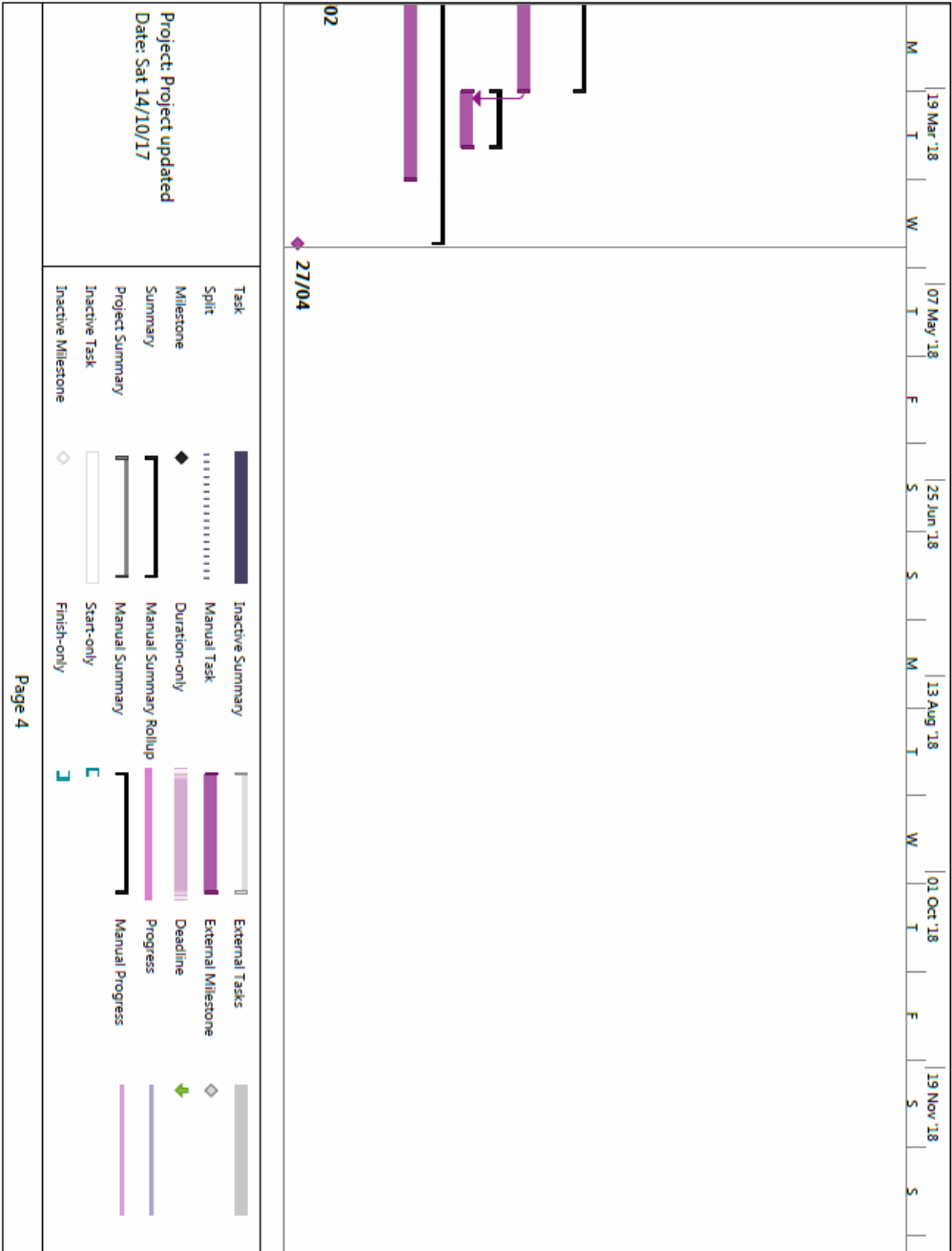
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Appendices

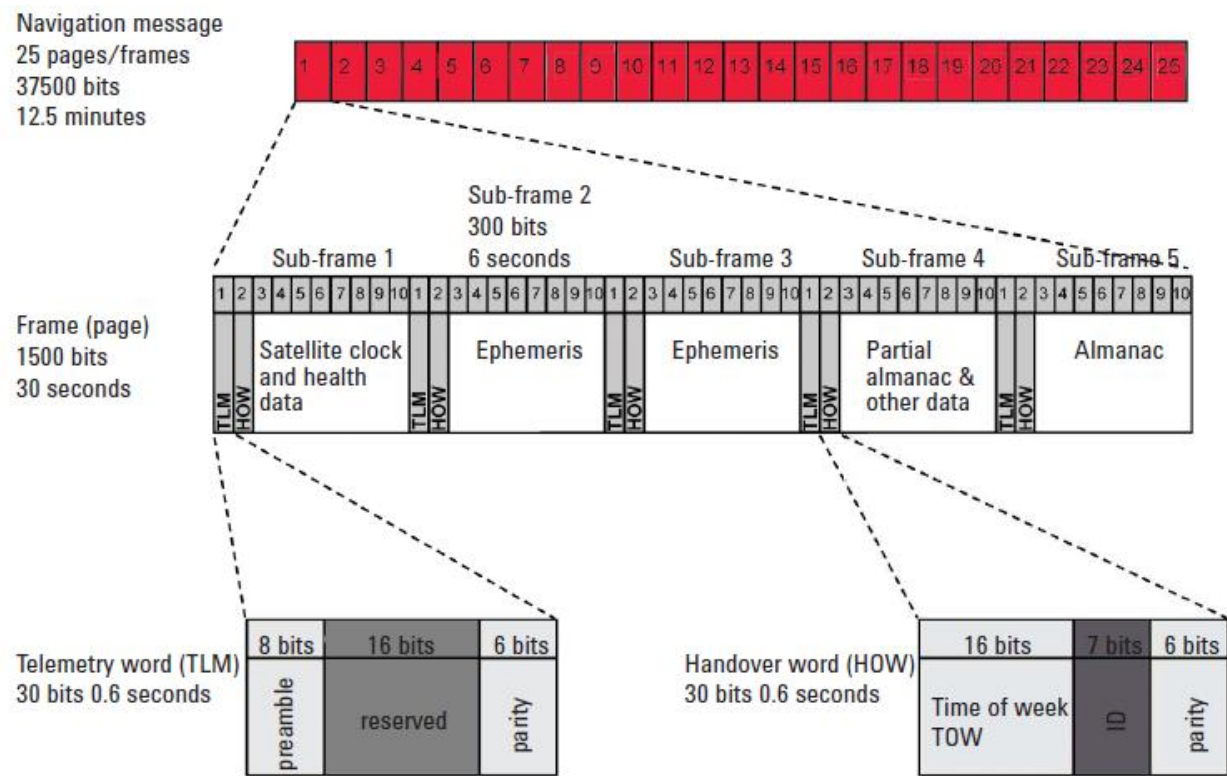
Appendix 1







Appendix 2



<http://literature.cdn.keysight.com/litweb/pdf/5990-4943EN.pdf>

The screenshot displays the CCS C Compiler IDE interface. The main window shows a C program named `main.c` for the PIC18F24K22 target. The code includes standard headers, defines LCD pins, and implements functions for port character handling and string checking. Comments indicate the use of `atan2` and a change to `int32` for a specific function. The bottom status bar shows the project path: `G:\2serial working no lcd latest\PIC18F24K22\main.c`.

The Output window at the bottom left reports a successful build with the following memory usage statistics:

- Memory usage: ROM=94% RAM=32% - 56%
- 0 Errors, 0 Warnings
- Build Successful

The Memory Use section on the right provides a visual representation of these statistics:

- RAM:** 56% (indicated by a green bar)
- ROM:** 94% (indicated by a red bar)