MOTOR-DRIVEN MULTI-ROTATION SYSTEM FOR ANTENNA BEAM STEERING

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STATEMENT OF CANDIDATE

I, Elton D'Souza, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Mechanical Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment an any academic institution.

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Date: 7/11/16

ABSTRACT

Macquarie University has invented a new class of planar high-gain antennas with steerable beams that are targeted for a variety of telecommunication applications. The antenna design will also need to be considered to facilitate its future specification, especially regarding low energy consumption. The low energy consumption is one of the fundamental pillars of 5G specification as it aims to facilitate machine type communication over its interface. In order to commercially deploy such a framework a unidirectional antenna design is proposed. Unlike an omnidirectional antenna, the unidirectional properties significantly minimize energy loss making it not only more energy efficient but significantly reducing overall energy consumption, so as to fit in to the frame of 5G specifications.This project is to develop methods to rotate two disks in the antenna using stepper motors and build a prototype.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Satellites are used for communication between two points in which data is sent from one antenna to another. Originating in the late 1800s the first antenna was built to transmit and receive a frequency band in which proved the existence of radio waves. It was not until world war 2 that antennas were developed and used to communicate between people and planes over long distances. During the 1960s the era known as the space age, the first satellites were developed were used and put into orbit. These early satellites paved a new way in which data could be transfer over continents in mere seconds. It was realised that key communications such as television and telephone call could heavily benefit through this infrastructure.

The way that this system work is a base station would send data to an antenna on the satellite dish and revert it back to earth to another base station with a satellite dish. This allowed high volumes of data to flow to and from continents easily. In the past 15years the globe has gone through a technological revolution where everyday people have been connected to other people around the world. Mobile phones have allowed people to interconnect to people in another regions and have push the need to be connected to the internet at all times. The unprecedented growth in mobile phones meant that almost every region on earth is connected to a satellite which beams critical data.

However, there are some regions and areas where there is no cellular coverage. Around the world there are still many places where continuous data services are unavailable such as planes, high speed passenger movement or in key remote areas where mobile towers are not feasible. This new system that has been made, is to be able to bring commercially to market a new satellite that can work on systems which would effectively close black holes in the network.

This document is intended to show the development of a new satellite system that would be created to provide the missing links where services cannot reach. This project has to meet key requirements in order to successfully deliver a working prototype model.

Technical requirements

- The satellite must be able to rotate two disks independently
- The two disks rotation movement is critical and the accuracy must be 1/3600 step

- There has to be a housing structure which surrounds the sensors protecting it from elements
- The satellite must have a slim profile with no more than 50mm in height
- No electrical components can pass the shielding barrier that protects the sensors

Manufacturing and cost requirements

- The costs associated with the manufacture and parts cannot exceed 400
- The project must be delivered by October to ensure testing can continue

Chapter 2

Background

2.1 Antennas

An antenna is used in to both send and receive data over a distance between two points. The data that is transmitted is sent via electromagnetic waves which is sent on a particular wave length. Antennas consists of both reflector and arrays which are used to convert the signal from the rf wire to a wave form. Antennas are used in everyday objects that need to send and receive communication such as aerials, radar, mobile phones, gps, radio etc. Antennas form the critical backbone of the communication network which everyday objects need to work. [4]

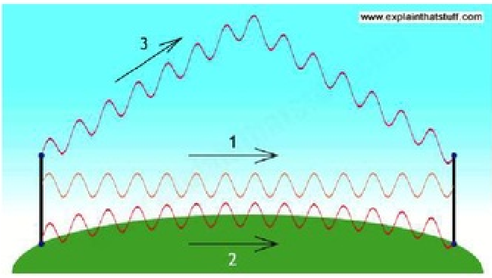


Figure 2.1: Antenna Transmission between two points

There are many different types of antennas which the signal is often sent depending on the application and coverage. The most common types are dipole, monopole, array, loop, aperture and travelling wave. [2] [3]

Monopole

There are many types of antenna exists but the most common is monopole antennas that we use in our daily life. It is conductive metallic pole which is mounted on ground plane, it usually have spikes at the top to increase its efficiency. Monopole antennas are commonly used in the transmission or receiving of the radio signals. The signal is received or transmitted from the region between the lower end of the monopole and the ground. It is also known as half dipole antenna as the rod and the ground act as only one radiator. The length of the antenna is times of the wavelength of the radio signal.

Figure 2.2: Monopole Antenna Design

Array

Array antennas are the collection or set of antennas which are also used for transmission or receiving of the radio signals. All the antennas in the array are connected in such a way that their individual current are of specified phase and amplitude that comprises together to form a whole signal. Array antennas are usually used to increase the antenna gain which will be useful for the betterment of quality of the signal. The working of the array antennas are same as monopole antennas but with more efficiency and as well as they maximize the signal to interference noise ratio increasing the performance.

Figure 2.3: Array Antenna Design

Loop

The loop antennas are the closed loop of wires or tubes generally used to receive the signals as it has low radiation resistance which increases its impedance, which makes it difficult to use for transmission. They are better in every aspect as they have a perimeter same as the wavelength of the signal which behaves like a rounded dipole antenna and a way better than half dpole antennas. They are also known as magnetic loop antennas as the magnetic fields near the antenna is comparatively very strong which lowers the radiation resistance and makes it better for receiving. These antennas are commonly used in pagers and act as field strength probes in a wireless measurement.

Aperture

Fixed Antenna

Fixed aperture antennas are parabolic antennas with a curved surface. The main advantage of this type of antenna is high directly towards radio waves. They are to narrow beam widths and its size is much greater than the wavelength of the radio wave. Fixed aperture

Figure 2.4: Loop Antenna Design

antennas has high gain therefore it is used in microwave relays, satellite communication etc. They are also used in radio telescopes. It has a huge parabolic reflector dish which focuses the signal to the feed antenna, feed antenna is similar to half dipole antenna with a better gain which gives us a best possible result of the signal.

Figure 2.5: Fixed Antenna Design

Rotational Antenna Like parabolic antenna only, rotational works on the same principle of aperture antenna that is to concentrate all the signals at some point making it more directive and has high gain to retrieve exact information. Rotational aperture antennas are used at airports, ships, military bases etc. They transmit electromagnetic or microwaves which are reflected back from a surface and feed the receiver with the informations like speed, position, altitude. The best example of Rotational aperture antenna is radar system.

Figure 2.6: Rotational Antenna Design

Travelling wave

Travelling wave antenna is a directional antenna in which a travelling wave of electromagnetic waves oscillations is propagated along its geometric axis. There are many types of travelling antenna but the helical antenna is the most common. The traveling antenna has its maximum radiation or reception in the direction of its axis. The antenna acts similarly to an electrically short pole or monopole, and the radiation pattern is similar to these antennas are omnidirectional, with maximum radiation at right angles to the axis. They are commonly used as the television broadcasting antennas and satellite communication as well.

Figure 2.7: Travelling Wave Antenna Design

2.2 Satellites

Satellite can be anything, it is defined as an object that moves or rotate around a larger object. Earth is also a satellite as it rotates around the sun and the moon is also the satellite of earth. But in-common when we say satellite we are always talking about the man-made satellites. They are the complicated machines which rotates around the earth in free space. There are many useful functions of these satellites like taking pictures of planet sun stars and other things, pertaining the national security of the country, communications, internet etc. With the help of these satellites, TV signals and phone calls range wider and we can communicate with anyone we prefer.

Satellites come in many shapes and sizes, the most common parts they have are an antenna and a power source. The antenna is used to receive or send information from or to the earth. The power source can be solar panel or battery. Some satellites may have cameras, scientific sensors, and many other things depending on their functions.

The first satellite which was successfully sent into the space was launched by the Soviet Union in 1957 called Sputnik 1 and then afterwards many countries launch their own satellites into the space. One of the main uses of satellite is weather forecasting. Satellites also tell us a lot about the space. There are many types of satellites like communications satellites, navigation satellites, geostationary satellites, weather satellites etc. Satellites have a quite but a profound effect on our daily life, they link remote areas of the earth through telephones and television, they guide us to find our way to destination etc.

There many types of orbit round the earth but the most common one are geostationary which is directly above the equator and other is polar orbit which passes through the poles of the earth.

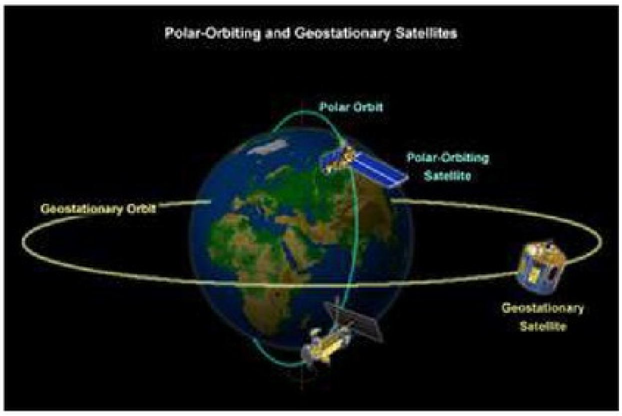


Figure 2.8: Satellite Orbits around the Earth

Geostationary satellites rotate around the earth in a special type of orbit known as geosynchronous earth orbit or Clarke orbit. It is at the approximate distance of 22000 miles that can rotate in the orbit around the earth in every 24 hours. Since the satellite revolves at the same speed of the earth so it appears to be at rest with respect to the earth surface ; thats why most antennas does not need to move once they get installed properly aiming at a target satellite in the sky.

Polar orbit satellites rotate around the earth in the orbit, inclined at 90 degree with equator. It is used to keep an eye on the natural phenomenons taking place on the poles and maintain a record of the weather too.

Chapter 3

Related Work

Currently there are many designs on market that target the specific way of sending and receiving data. Mostly used on aeroplanes and vehicles in remote areas, companies have been trying to seek out the best design for the purpose.

3.1 Gimbal systems

The gimbal system is a very early system developed in the 1990s. This system uses a series of stepper motors which precisely line up the direction of communication to its source. Stepper motors are used in 3 axis, x, y and z planes to send information in all directions. This particular system can maintain a strong communication point in quick moment between two points. The stepper motor in the z direction allows to be able to turn the antenna 360 degrees to maintain contact regardless on the motion of the antenna. [7] The y and x axis is critical in keeping the antenna in the correct elevation which helps maintain communication contact. Both the x and y axis pivots on two points allowing it to move easily. Having all 3 stepper motors work in unison allows the gimbal system to be able to move the full hemispherical coverage. This unique design allows the design to be highly versatile in varying terrain. The gimbal is primarily used in military systems where terrains can vastly change. [14] [13]

One of the down sides with this particular design is since the gimbal design is a quite a bulk and large structure it is difficult to implement into the design criteria in size. However the use of stepper motors to correctly send data in pin point accuracy will be adopted in the design we currently have. Figure 3.1 shows a illustration of the gimbal system developed by NASA.

3.2 2ku Flat Antenna

The VICTS -2ku is a mechanically controlled antenna primarily used in military planes. The array which sits on top of the plane provides a continuous data link between the plane and the satellite. The 2ku is a unique design allowing the plates to rotate within

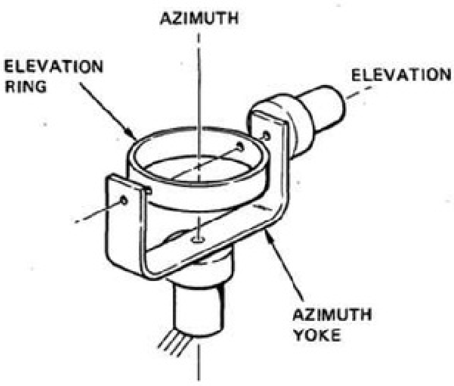


Figure 3.1: Nasa design a gimbal system [14]

each other 360 degrees. This entire design is mechanically controlled with an accuracy of 0.2 degrees. Due to its flat design it has an elevation range to 10-15degree. [12] An example of the 2ku flat antenna is in figure 3.2.

Figure 3.2: 2ku Flat Antenna

3.3 AMCAS antenna system

The AMCAs is used usually for military purposes but has moved into the commercial airlines sectors. This low profile antenna design can transfer data at 1.5Mbps. The AMCAS system is entirely mechanical using a direct system of gears and stepper motors which rotate the antenna arrays. The unique low profile design allows it to be placed on top of planes and in strong hostile environments where temperatures can be as low as -40 degrees. The system also is unique as to increase the elevation the array plats are sitting on two angel cases which when rotated change the elevation of the signal. Another thing to note if a system has to be designed, correct operating temperatures have to be looked into. [1]

Figure 3.3: AMCAS antenna fitted on a plane

3.4 KU Band Antenna

The Ku application illustrated the difficulties in providing a commercial design in data services. It was noted that current designs are usually large and bulky since they are all mechanically operated and a new methodical approach should be seen. One of the main challenges is selling to a market where data services are needed such as the automotive and airline industry. But both these industries rely heavily on aerodynamics and design. It was noted that incorporating a design that could be a hybrid of current designs could solve the problem. Having a mechanical/electronic phased array could be a possible solution. A diameter of 25cm with a maximum thickness of 6cm could allow the design to come to the market. [11]

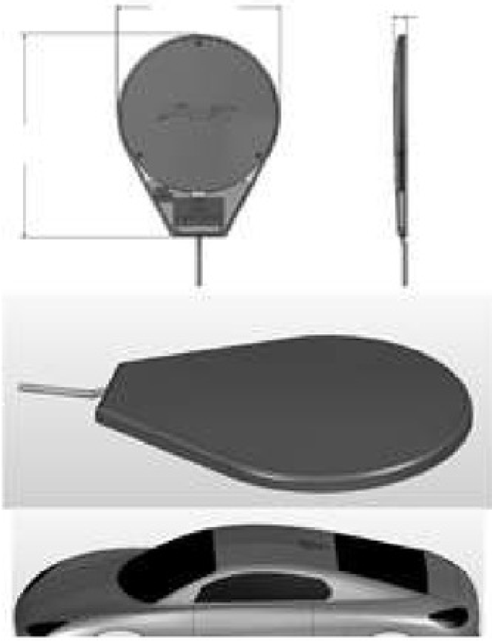


Figure 3.4: Ku Band prototype application

3.5 Patent

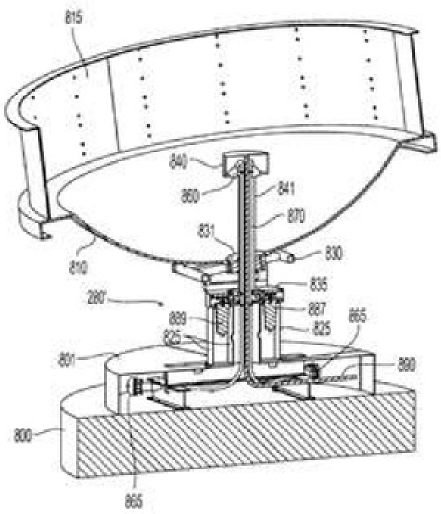


Figure 3.5: Current Patented design

This gimbal design is the most common design. Developed by NASA in the early 70's to send signals to satellites it is now the most common form of data communication in remote areas. The gimbal pivots on 3 axis in which stepper motors are used to precisely line up the data transmission. This large design can stand over 500mm tall and is not suited for general commercial use.

3.6 ThinKom

Figure 3.6: Thinkom Military Design

Thinkom is a new commercial grade design for military use. The design is small and thin measuring at thickness of 15cm. Each design is made using a system of belts and pulleys which turn the antenna disks around. One of the main disadvantageous of this particular design is the intricate parts needed to ensure the system works. There are many parts within this system which would have a high failure rate. More parts would also mean a longer assembly time and greater cost in mass manufacturing.

Chapter 4

Components

4.1 Gears

4.1.1 What are gears

Gears are a toothed machine part, such as a wheel or cylinder that meshes with another toothed part to transmit motion or to change speed or direction.

Gears are one of the most common mechanical systems used to drive mechanism components. A gear is a wheel that has accurately-cut teeth around its edges with a shaft which passes through its center. A group of gears is called a gear train. Thus, the gears in a gear train are arranged so that the teeth interlock with each other and relieves on this contact between the larger gear also known as a wheel and a smaller gear (pinion) to drive the mechanism using the rotational exchange between the output and the input forces. The input forces and motion is applied by the driver gear, while the output motion and force is transmitted by the driven gear. [10]

4.1.2 How they work

Because of the alignment and interlocking of teeths in a gear train, when one gear turns, the other will also turn. For example, when u connected a small gear with a bigger gear as shown in figure 4.1, the work done would result in the bigger gear turning slowly and thus making the little gear turn quickly. This all works on a simple principle, the gear on the bigger sized gear on the right had more teeth than the one on the left, this means that the smaller gear would have to turn twice as fast to keep up with the bigger gear. So this means, with the gear alignment the smaller gear with less teeth would turn faster than the bigger gear but with less force, thus the reason it is energy efficient, the output is greater than the input. For gears to properly mesh, the tangential or linear speed of the teeth must be the same on both gears.

Therefore, to calculate the tangential or linear speed for a gear with radius r and rotational speed , the formula v=rw can be used.

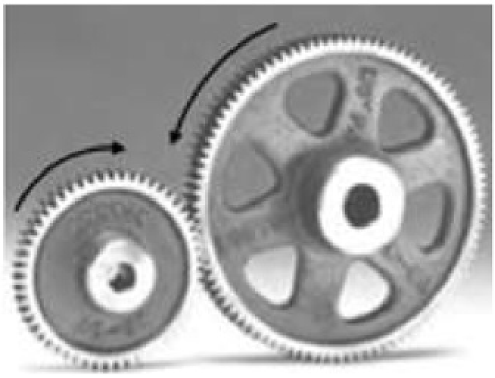


Figure 4.1: Movement of a simple gear system

Helical

The helical gears are different from spur gear as the teeth are aligned at an angle with respect to the parallel shaft axis. Figure shows the alignment of the teeth of the helical gears require good precision that is when the two gears engage, the contact starts at one end of the tooth and gradually spreads as the gears rotate, until the two teeth are in fell engagement. Since meshing teeth do not make full-face contact all at once, these gears are smoother, less noisy and can run faster, and are able to create a thrust load on the gear when they mesh due to the angled alignment of the teeth

Spur gears

Spur gears have straight teeth that are mounted on parallel shaft which make it the simplest tooth alignment offering maximum precision. The advantage of spur gears is that they can be used to create very large gear reductions, and thus are highly efficient. However, when operating the spur gears can be really loud, this is due to the collision that occurs when the teeth of the two gears engage with each other, which also can in create the stress on the gear teeth. [10]

Worm Gears gears

A worm gear also known as a worm drive is a specific gear composition in which the worm or the driving element (screw) meshes with a gear/wheel. They are used for used to transmit power between two non-parallel and non-intersecting shafts. This set-up helps in the determination of rotational speed and also allows for the transmission of higher torque. Worm gears are used in large gear reductions ranging from 5:1 to 300:1. The reduction ratio is determined by the number of starts of the worm and number of teeth on the worm gear. Worm gears also possess an interesting property of self-locking which distinguishes them from the other gears and makes it highly useful in many applications that the gear can be easily turned by the worm or the screw, but the worm cannot be turned by the gear. This can be attributed to the shallow angle on the worm which on being spun by the gear results in friction between the gear and the worm which holds the worm in place.

Types of Worm Gears

Worm gears are classified into the following types based on their handedness (left or right) and the concavity available to worm drives and worm gears along gear widths:

1. Non-throated worm gears lack concave features and are assembled in a manner that places the highest level of stress on the gear teeth due to the straight plane of contact between gears.

2. Single-throated worm gear sets contain concave helical teeth wrapped around the worm for line contact, allowing the worm drive to nestle into the gear and increasing efficiency.

3. Double-throated worm gear sets contain concave teeth on both the worm screw and the gear itself increasing the contact area and allowing for increased unit loads with lower wear and tear.

Applications Worm gears are mostly applied in:

- Gate control mechanisms
- Tuning instruments like guitars, banjos and basses
- Hoisting machines
- Automobile steering mechanisms
- Elevators/Lifts
- Gates and Conveyor belts
- Presses

Bevel gears

Bevel gears are gears having intersecting axes of the two shafts and conically shaped tooth bearing faces of the gears. It can be said to be a cone-shaped gear which helps in transmitting power between 2 intersecting axels. Although, bevel gears are designed to work at various angles, they are usually mounted on shafts that are 90 degrees apart. They are mostly applied when a change in the direction of a shaft's rotation is required.

Types of Bevel Gears Bevel gears are classified into the following types based on their geometry:

1. Straight Bevel Gears are the most commonly used bevel gears, which have straight teeth which will be tapered from larger diameter of tooth to the smaller diameter of tooth.

2. Spiral Bevel Gears are the gears of choice in case of applications associated with high rpm and high torque and have teeth which are curved at an angle to allow gradual and smooth tooth contact.

3. Zero Bevel Gears are also a type of spiral bevel gear but in their case the spiral angle of teeth will be zero.

4. Hypoid Bevel Gears are also similar to spiral bevel gears but the center lines of both shaft will not intersect to each other.

Applications of Bevel Gears Bevel gears have many applications in different fields like:

- Bevel gears are used in differential drives which allow the wheels of an automobile to rotate at different speeds.

- Hand drills are the most common application of bevel gears as they allow the change in the direction of rotation and also increase the rotation speed allowing the possibility of drilling a wide range of materials.

- The use of bevel gears which allow minor adjustments during assembly and also permit displacement due to deflection under operation loads.

4.5

4.2 Motors

4.2.1 Servo Motors

It is a simple electrical motor that allows precise control of linear and angular position, velocity and acceleration. Servo motors works on pulse width modulation principle. It is controlled with the help of servo mechanism. Servo motor consist of important components a controlled system, output sensor and feedback system. Servomechanism is a closed loo control system. Servomechanism states that instead of controlling the device by varying input system, we can control it by a feedback signal produced by combined result of the output signal and the reference input signal. Reference input signal is the signal generated by the feedback system and sent as the input to the input of the motor and the loop keep going like this only. It can be moved in any direction, either clockwise or anticlockwise. It can sustain a holding torque at zero speed. Servo motors are used in many fields like in robotics, conveyor belt.

4.2.2 Stepper Motors

Stepper motor is a dc motor without any motors and divided into equal phases or steps. The stepper motors work on the principle of open loop controller and has no feedback sensors. They are more precise in positioning over servo motors under the computer control. It is used in many equipments like 3D printer, CNC, camera platforms and plotters. One of the most significant advantages of a stepper motor is its ability to be controlled accurately in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Your position is known simply by keeping track of the input step pulses. [8]

4.2.3 DC Motors

Dc motor is an electric machine which converts electrical energy to mechanical energy. The main principle which works behind the working of the dc motor is an electromagnetic induction, when a current carrying conductor is placed in a magnetic field, it experiences torque and tends to move. Dc motors are classified on the basis of their excitation procedure which are separately excited and self-excited. In separately excited the field windings are fed by some external force and in self excited the field windings are connected directly with its own armature. And when the current is reversed the direction of rotation is reversed. The speed of the dc motors can be controlled by varying the strength of voltage applied to it. Dc motor contains three main components which are armatures, brushes and shaft. When an armature windings are connected to the dc supply, current sets up in the windings. Magnetic fields are provided by the permanent magnets. In this case, current carrying armature conductors experience force due to the magnetic field. We use dc motors in our day to day life like in toys, electronic equipments etc. [9]

4.2.4 AC Motors

Ac motor is an electrical motor which works same as the dc motor but it is driven by the alternating current. The ac motor contains 2 main parts- the outside part is known as the stator and the inner part is known as the rotor. The stator is a stationary part having coils supplied with ac current to produce rotating field which rotates the inner rotor part. The working principle behind the ac motor is the magnetic induction. There are two types of ac motor- induction motor and synchronous motor. When Synchronous speed is equal to the speed of the motor, then there is a relative motion between the stator field and the rotor conductors, hence a current is induced and there will be no torque but induction motor can never run at the synchronous speed. One of the major advantages of the induction motor is that it does not need a commutator. Induction motors are therefore simple, robust, reliable, maintenance free and relatively at low cost. There are many applications of the ac motor but most common is in the generation of the electrical power through ac generators. [6]

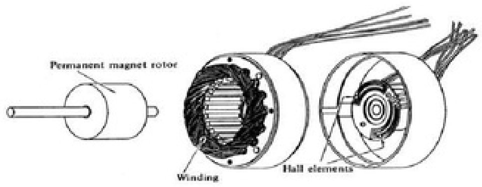


Figure 4.2: Common stepper motor design

4.3 Belts

4.3.1 Timing belts

Timing belt is a non-slipping mechanical drive belt and is used in the internal combustion engine that synchronizes the rotation of the crankshaft and the camshaft so that the fuel valves in the engine opens and closes at exact same time during the each cylinders intake and exhaust to get more efficiency and better performance. There are many types are available like toothed belt, friction drive belt etc. It allows much more flexibility in the relative motion and location of the crankshaft and camshaft. A timing belt is typically made up of rubber with high tensile fibers. Timing belts are typically covered by metal or polymer timing belt covers which require removal for inspection or replacement. The major advantages of the timing belts are- efficient to use, cost effective and works more quietly. There is no slippage when using the timing belt due to the teeth markings that have been designed in the belt.

4.3.2 V-belts and multi V-belts

V-belts and multi V-belts function as grating fit drive components, utilizing the static rubbing between the belt and the belt pulley to transmit control. V-belts have a trapezoidal cross-segment what's more, keep running in a wedge-formed furrow in the belt pulley. They empower maybe a couple segments to be driven. They can transmit considerably higher torques than level belts for a similar space prerequisite. In light of the rubbing on the belt flanks (grinding fit) the heaps following up on the course are lower. On the off chance that numerous segments must be driven in the meantime, a belt drive with various V-belts is required.

Multi V-belts are a further improvement of the V-belt with numerous longitudinal ribs. Power is transmitted by means of the static grinding between the flanks of the individual ribs and the scored belt pulley. Multi V-belts hence have a more noteworthy grating surface region than V-belts and permit higher torques to be transmitted. Drives with turn around flexing and little redirection distances across are conceivable in light of the more adaptable structure. One belt can drive various parts in the meantime and is along these lines perfect for the necessities of a reduced motor design. Elastic multi V-belts are mounted with demand and don't require a tensioner.

4.4 Magnets

Magnets are materials or substances that produce a magnetic field which is a force field capable of attracting or repelling metals like iron, nickel and cobalt. The journey for the discovery of magnets began with the early Greeks who observed that the iron pieces were attracted by the naturally occurring 'lodestone'. A remarkable property of the magnets is that the end of a freely pivoted magnet always points in the North-South direction. And so the end pointing towards the north is referred to as the North Pole of the magnet while the end pointing towards the South is called the South Pole of the magnet. Many experiments have demonstrated that like magnetic poles repel each other whereas unlike poles attract each other.

Types of Magnets Magnets have been classified into the following types based on their composition and source of magnetism: Permanent Magnets These are magnets that retain their magnetism after being magnetized once. They are generally made of Ferro magnetic materials in which the positioning of the atoms and molecules is done in a manner to reinforce each other. They are further subdivided into four categories:

1. Neodymium iron boron (NdFeB)
2. Samarium cobalt (SmCo)
3. Alnico
4. Ceramic or ferrite magnets.

Temporary Magnets These magnets vary with respect to their composition and lose their magnetism when taken out from the magnetic field. Electromagnets Electromagnets are generated using a solenoid which is a wire wound into multiple loops around a core material. Passing of an electrical current through the solenoid to creates a magnetic field and magnetizes the electromagnets.

Magnetic field is the space surrounding a magnet, in which magnetic force is exerted. Magnet forces are experienced by magnets when placed in such a field. However, the field will continue to exist even if the magnet is removed. It has been inferred that the motion of electrical charges produces a magnetic field as it was seen that the flow of current in a wire created a magnetic field around the wire. Thus it can be ascertained that the motion of negatively charged electrons in the magnet is responsible for generating the magnetic field of a bar magnet.

4.4.1 Magnetic lines of force

Magnetic lines of force are the lines which describe a magnetic field. A magnetic line of force is the path traced by a North magnetic pole free to move under the influence of a magnetic field. They can also be said as lines drawn in a magnetic field along which a north magnetic pole would move.

4.4.2 Working of a magnet

Currently, there are explanations widely used for ascertaining the working of magnets and the alignment of magnetic fields in the same direction: a large-scale theory from classical physics, and a small-scale theory called quantum mechanics. The classical theory shows magnetic fields as clouds of energy around magnetic particles that attract or repel other magnetic objects. But according to the quantum mechanics theory, electrons emit undetectable, virtual particles that tell other objects to move away or come closer.

The basic working of a magnet can be understood by the following explanation. The orbiting of electron in the atoms of ferromagnetic materials results in generation of their own magnetic field. A magnetic domain with its own North and South Pole is then formed by small groups of atoms which tend to orient themselves in the same direction. In the absence of magnetism, when the iron piece is not magnetized, the domains will point in random directions rather than the same direction and thus their effect would be canceled resulting in the absence of generation of a magnet with north or south poles. However, upon introduction of current, a magnetic field will be generated and the domains will begin to line up with the external magnetic field. With an increase in the applied current, the number of aligned domains also increases. With an increase in the strength of the external magnetic field, the number of aligned domains increases further until all of the domains within the iron are aligned with the external magnetic field (saturation). On removal of the external magnetic field, soft magnetic materials will revert to randomly oriented domains while hard magnetic materials create a strong permanent magnet by keeping most of their domains aligned.

4.4.3 Magnetic gears

Gears have been widely applied in industrial settings for speed change and torque transmission, mechanical gears had some disadvantages like contact friction, noise, and heat production which led to the need for development of magnetic gears. The magnetic gears have partial resemblance with the traditional mechanical gear but they varying certain features like, in magnetic gears, the cogs of each gear component act as magnets with periodic alternation of opposite magnetic poles on mating surfaces. However they are similar to the mechanical gearing's in a "cushioned" backlash capability which is mounted on the gear components but without the cushioning effect. They are the most suitable choice for configurations that are not possible for gears that must be physically touching and can operate with a barrier completely separating the driving force from the load. Permanent magnets are used in magnetic gears to transmit torque between an input and output shaft without mechanical contact. Magnetic gears can achieve torque densities comparable with mechanical gears with an efficiency ¿99 at full load and with much higher part load efficiencies than a mechanical gear. Magnetic gears are smaller, lighter and lower cost than a mechanical gear for higher power ratings. They do not require lubrication as there is no mechanical contact between the moving parts and hence there is no wear. Magnetic gears also provide inherent protection against overloads by harmlessly slipping if an overload torque is applied, and automatically and safely reengaging when the fault torque is removed. Advantages of Magnetic gears over mechanical gears:The magnetic gear offers the following significant advantages over mechanical gears:

- Reduced acoustic noise
- Improved reliability and reduced maintenance
- No requirement of lubrication
- Higher efficiency in comparison to conventional gears
- Minimum vibration
- Precise peak torque transmission and inherent overload protection
- Physical isolation between input and output shafts
- Inherent anti-jamming transmission

4.5 Ball bearings

Ball bearing, that is shown in figure 4.2 is the most common type of bearing used to reduce friction. Ball bearing is found in everything from incline skates to hard drives. This type of bearing can handle both radial and thrusts loads, there are usually are found in application where it is required to have reasonably small load. In a ball bearing, the load is diffused form the outer race to the ball and from the ball to the inner race. Since the ball in the ball bearing is a sphere, it only contacts the inner and outer race at a very small point this helps the balls to spin very smoothly. However, this also means there is not very much contact area holding the load, if the ball bearing is overload it can squish or deform which will ruin the bearing. Hence, a small contact area between ball raceway lets ball bearing to run faster, for longer period of time and generate less heat the roller types.

Thrust bearing are designed to carry high axial loading. A thrust bearing has two rings a low and an upper ring. The lower ring is in contact with the structure and does not rotate with respect to it. The upper ring rotates the object with a force acting in a vertical position. The segments between the upper and lower plates are free to rotate, thereby creating a wedge of holds the moving surfaces apart and prevents wear. [5]Due to the design this orientation is not appropriate for spiral loads. Typical applications incorporate vertical shaft direction, guiding sections and so forth.

4.5.1 Lubrication types and methods

Bearing Lubrication assumes a key part in the execution and life of moving component course. The main purpose of grease is to separate moving parts with respect to each other

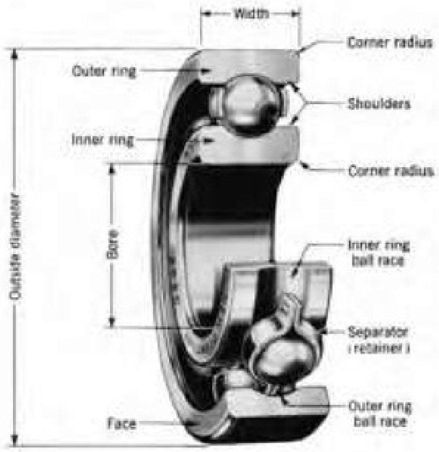


Figure 4.3: Cross section of a Ball Bearing

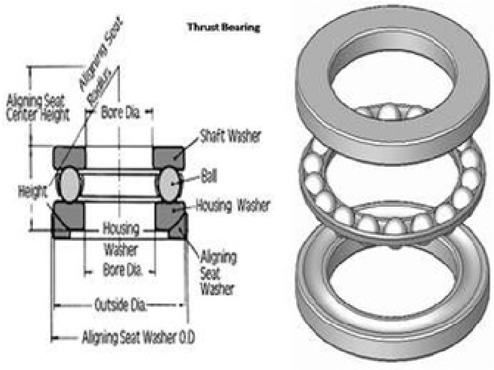


Figure 4.4: Exploded view of a Thrust Bearing and it's inner workings

(balls or rollers and raceways) this is to ensure to minimize rubbing and avoid excessive wear.

Lubricants utilized as a part of moving component heading ought to have the accompanying attributes:

- Mineral or manufactured based lubricants are the most ordinarily utilized and are intended for general and rapid utilize. Finely separated adaptations are utilized for low commotion applications. There are renditions that are water safe, offer low or high temperature abilities.

- Silicon ointments have wide temperature ranges and change thickness less with temperature. They additionally have great water-resistance and are protected to use with generally plastics. They are not reasonable for high loads and speeds.

- Perfluorinated oils or PFPE oils are non-combustible, oxygen perfect and exceptionally impervious to numerous chemicals. They don't respond with plastics or elastomers. Numerous have low vapor weight and are reasonable for vacuum or clean-room applications. Some can likewise withstand temperatures of up to 300C.

- Dry lubricants are regularly indicated where standard oils may bring about tainting, for example, vacuum situations. Dry coatings, for example, molybdenum disulphide or tungsten disulphide are frequently shined on to the balls and raceways of heading to give smooth operation and higher running rates than unlubricated. These coatings are additionally impervious to water and weaken acids.

- Dampening grease are broadly utilized as a part of car parts to counteracts rattles and squeaks. They are additionally used to give a "quality" vibe to switches, slides, strings and riggings. They can be utilized as a part of moderate pivoting heading in, for instance, potentiometers for a similar reason. Food grade based oils are required for the nourishment and refreshment enterprises to accommodate with strict cleanliness controls. Hello endorsed ointments are required for orientation were there might be coincidental contact with sustenance and H2 affirmed oils are utilized where there is no contact. These oils are likewise intended to be exceptionally impervious to being washed out by cleaning forms.

- Oil: Both petroleum based and engineered oils are accessible. Cases of engineered oils are silicone, diesters, PAO's, and fluorinated mixes. Heading greased up with oil will show less start up and running torque and have higher speed ability. Oils are liable to evaporative misfortunes so their administration life in an orientation is not as much as oil. Smaller than expected and instrument heading are regularly just greased up once for the life of the bearing, settling on the decision of oil basic. Bigger course is liable to re-oil as a major aspect of the apparatus support cycle. These directions are regularly greased up by means of oil distribution frameworks that are composed into the apparatus or gear. Temperature extend, consistency, evaporative rate are key attributes to consider while selecting an oil.

- Grease: Grease comprises of a base oil with a thickener included. These thickeners comprise fundamentally of metal cleansers (lithium, sodium, aluminum, and calcium) or inorganic mixes. While these thickeners significantly impact the qualities of the oil, the greasing up properties of the oil are inferable from its base oil. What's more, oil can contain added substances that enhance its execution. Added substance sorts incorporate cell reinforcement, anti-corrosion, against wear, fillers, fortifiers, and outrageous weight fortifiers. Temperature extend, base oil consistency, and firmness or infiltration level are key attributes to consider while selecting an oil. Most oils utilized as a part of moving component orientation.

- Strong Films: These are non-liquid coatings connected to the erosion's surfaces to counteract wear. They are utilized as a part of outrageous circumstances where an oil or oil can't survive and are regularly chosen if all else fails or choice. These incorporate brutal situations, for example, outrageous temperatures, vacuum, or radiation. These coatings incorporate graphite, MoS2, silver, gold, or PTFE. Hard coatings incorporate TiC or chrome. Strong movies are built on a particular application by application premise. The grease (and sum) chose additionally impacts the most extreme working velocity and torque (both beginning and running). In smaller than expected heading the oil can affect the clamor level. Separated oils and oils are suggested for use with little or instrument direction.

Chapter 5

System operational requirements

5.1 Overview

The design of a dual rotational antenna is to be able to establish a constant connection between the user and a base station and/or satellite. This new concept is to improve battery life and increase the range of a particular antenna signal by concentrating the signal a particular direction. The method of movement to rotate the two antenna plates is by using stepper motors which would provide precision rotation of the antenna plates.

5.1.1 Temperature range

There are currently multiple uses which the dual band antenna will have to work with. Given that there are quite broad ranges in each application it is expected that the current system would have to be modified to ensure reliability in the equipment

- Plane operating range 40- -60 degreess
- Train 70- -30 degrees
- Car 60- -15 degrees
- Bus 60- -15 degrees

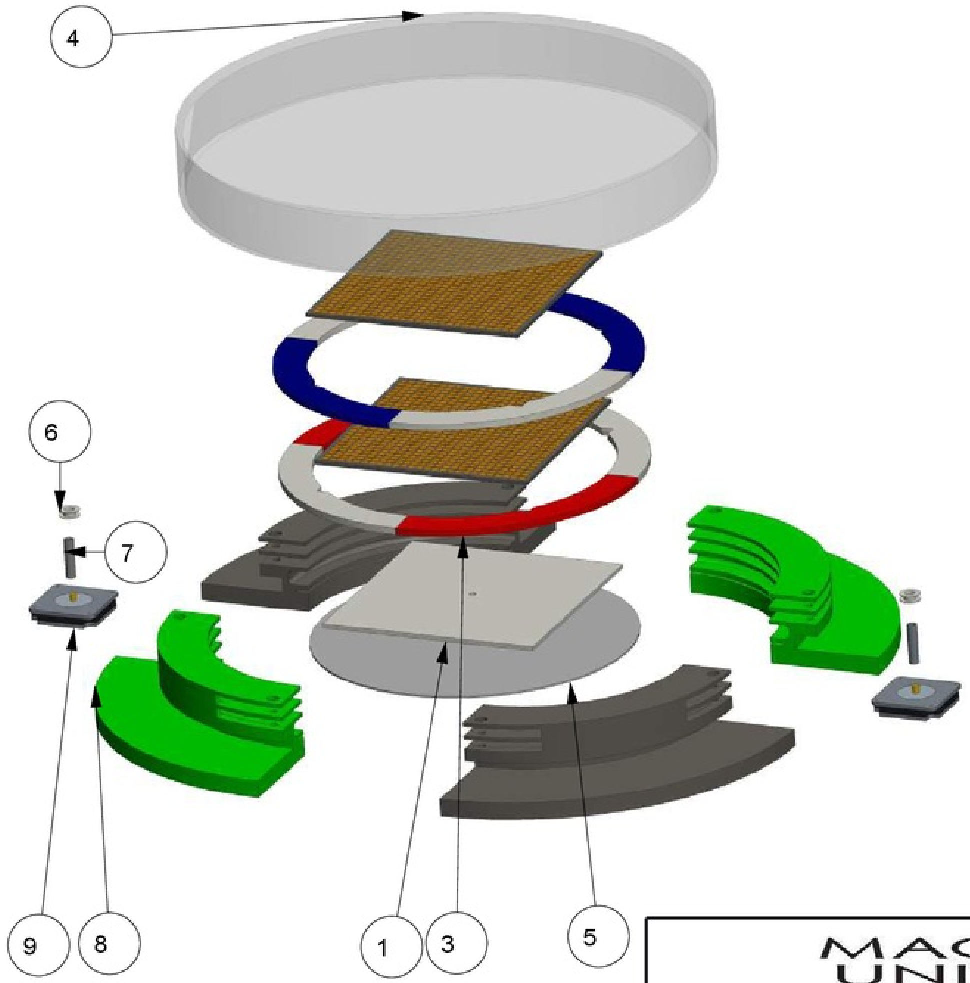
The current operating ranges stated above show the possible maximum outside temperatures. Insulation to wires and motors to ensure that they are working within their operation temperature ratings. Oil lubrication is important when working within these temperature rating zones. The lubrication must not be able to freeze which would stop the rotation of the antenna. Freezing would also allow water moisture to build up within the joints which would increase friction and could cause early corrosion of the antenna. Correct material selection during large temperature ranges. This is due to expansion and contraction of the material which can cause irreparable damage to the overall structure of the part.

Chapter 6

Preliminary Designs

6.1 Design 1

Design 1 has been created using timing belts and stepper motors. On each side there are two stepper motors that are connected to timing pulleys. These timing pulleys turn the timing belts with are bound round the antenna holders. Timing belts have been used to ensure precise movement of the antenna without slipping. There is 1 shell for this design which are split into 4 sections. These 4 sections are screwed together. The sections have two grooved slots which the antennas rotate within. To reduce friction rollers have been implemented to reduce the wear on the hosing. A cover envelopes the whole structure protecting it from dust and moisture which could penetrate with the structure. An exploded view on pg 32 illustrates how the parts come together.



ITEM NO	PART NUMBER	QTY
1	ANTENNA1	1
2	BELT	2
3	LID2	2
4	LID2	1
5	METALSHEILD	1
6	PULLEY	2
7	SHAFT2	2
8	SHELL	4
9	STEPPER	2

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42501407	Elton D'Souza	Nov-05-16		
Material	Sheet: 1 of 1	Scale: 1:20	Drawing: DESIGN1EXPLODED	Rev: A

NOTES:
DIMENSIONS IN mm
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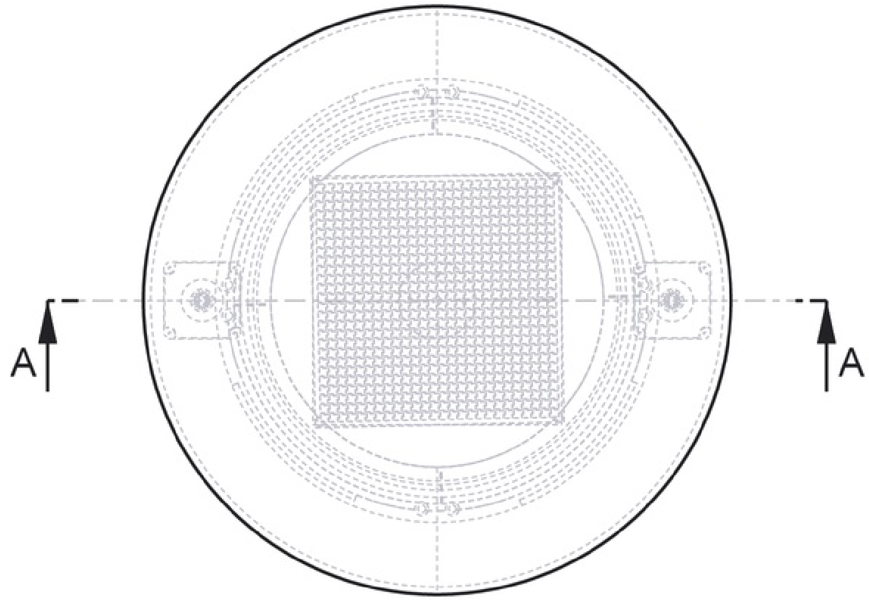

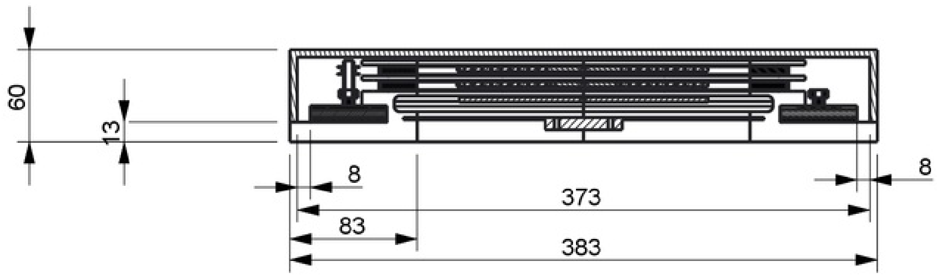

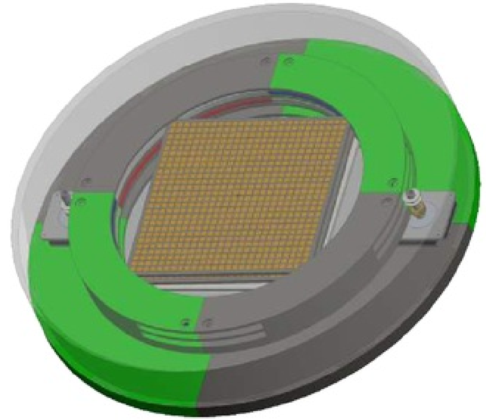

SECTION A-A
SCALE 1:4

NOTES:
DIMENSIONS IN mm
DO NOT SCALE

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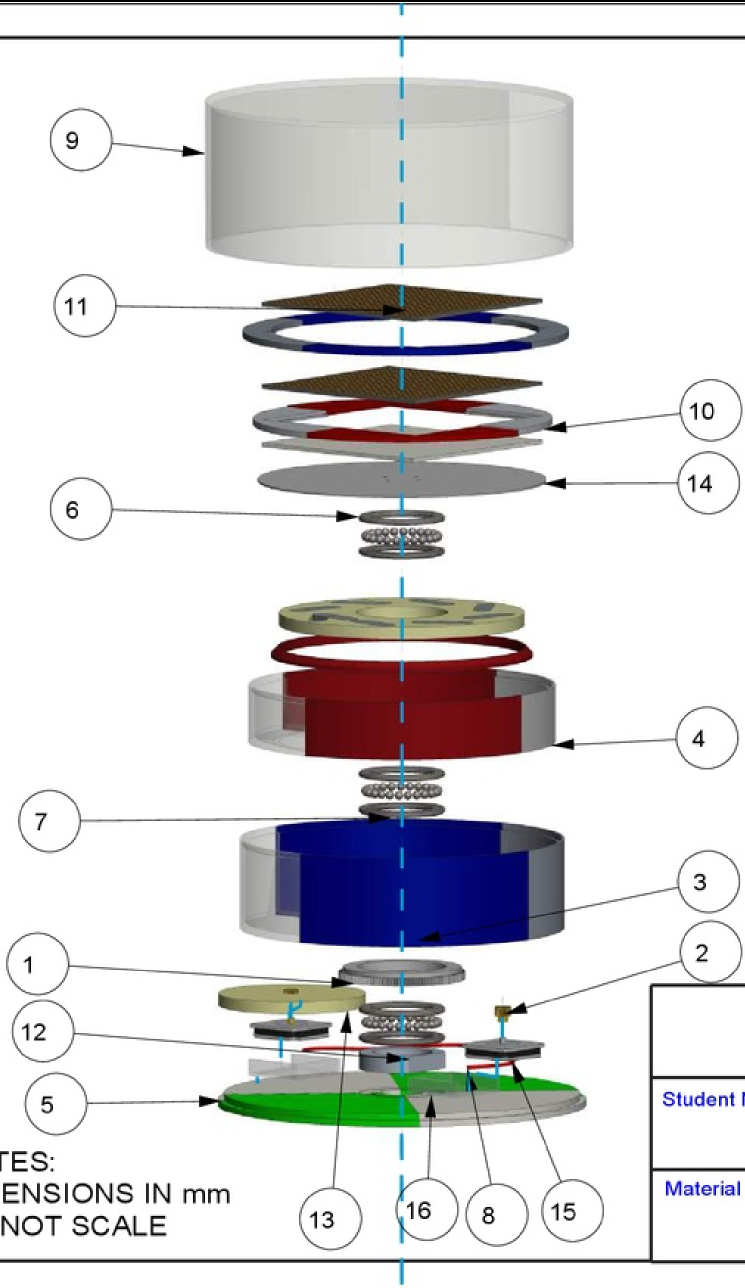
Student No	Drawn:	Date:	Descr:	
42501407	Elton D'Souza	Nov-07-16	Design 1 Section view	
Material	Sheet:	Scale:	Drawing:	Rev:
	1 of 1	1:4	DRW0001	A

6.2 Design 2

Design 2 varies significantly from design 1 as it uses a different form of rotation. This particular design has two shells. An inner shell and an outer shell. The outer shell is connected to the top antenna while the inner shell is connected to the bottom antenna. To rotate the inner shell magnets have been introduced into the design show allow movement though the material. Since magnets work differently to gears, this design relies on the magnetic that both magnets induce. Each magnet is connected to the others opposing pole ensuring a strong magnetic connection. To rotate the two shells whilst keeping the shield stationary, 3 thrust bearings have been implemented. Thrust bearings can take vertical loading. The outer shell is connected to a large gear tooth which is rotated by the stepper motors. The shell covers the whole system ensuring there is no dust or moisture entering the system.



ITEM NO	PART NUMBER	QTY
1	128T_GEAR_	1
2	16T_GEAR	1
3	ANTENNA1	2
4	ANTENNA2HOLDER	1
5	BASE	1
6	BEARING	2
7	BEARINGCOMPLETE	1
8	CABLE	1
9	COVER	1
10	LID1	1
11	LID2	1
12	LIFT	1
13	MAG2	1
14	METALSHEILD	1
15	STEPPER	2
16	STEPPHOLDER	2

NOTES:
DIMENSIONS IN mm
DO NOT SCALE

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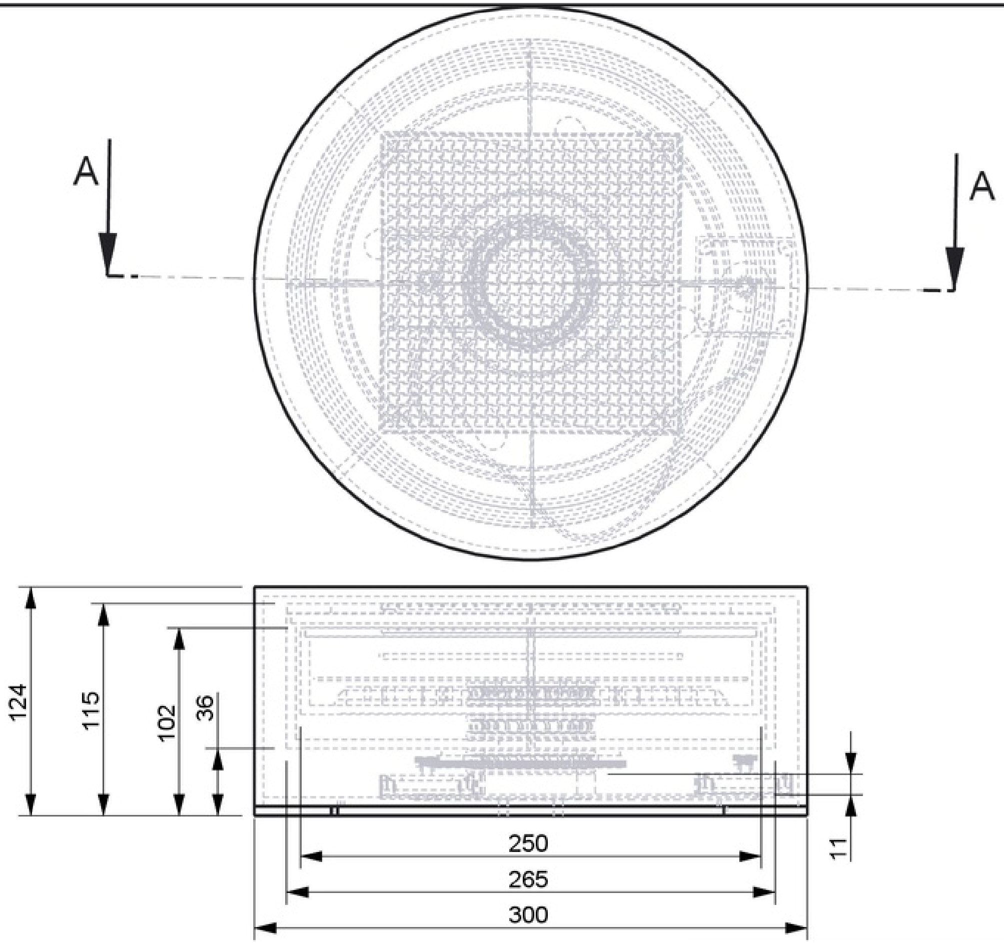
Material	Sheet: 1 of 1	Scale: 1:5	Drawing: DRW0001	Rev: A



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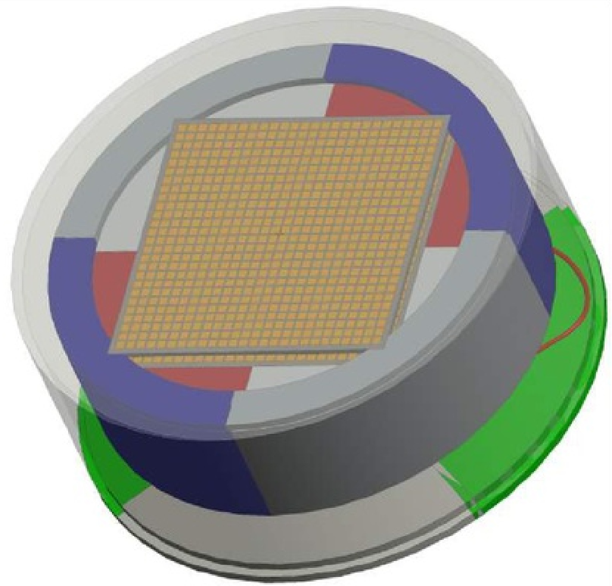

NOTES:
DIMENSIONS IN mm
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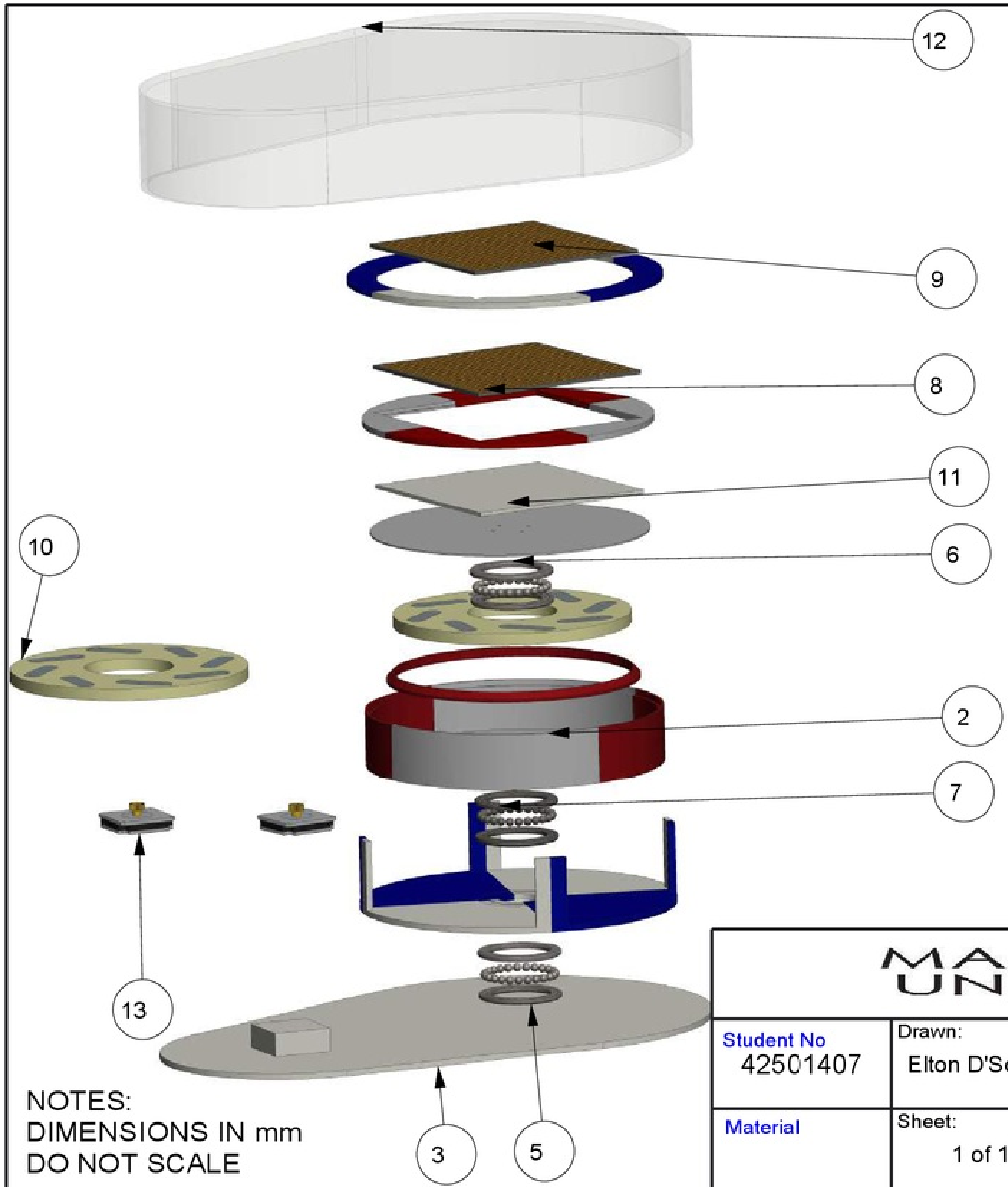
Student No	Drawn:	Date:	Descr:	
42501407	Elton D'Souza	Nov-07-16	Design 2 Section View	
Material	Sheet: 1 of 1	Scale: 3:10	Drawing: DESIGN2	Rev: A

6.3 Design 3

Design 3 is not a redesign but rather an improvement of design 2. Design 2 is utilising magnets in a top down orientation however in design 3 magnets can be realigned into the same plane. As long as the magnetic field lines match together it is still possible for the magnets to rotate one another. The redesign has bought a thinner product it has double the footprint area. This design also has a reduction in plastic used in the shell designs of up to 80%. Stepper motors are still used to drive the two antennas round.



ITEM NO	PART NUMBER	QTY
1	ANTENNA1	2
2	ANTENNA2HOLDER	1
3	B2	1
4	BASE	1
5	BEARING	2
6	BEARINGCOMPLETE	1
7	HOLDER_ANTENNA3	4
8	LID1	1
9	LID2	1
10	MAGNET	1
11	METALSHEILD	1
12	SHEL	1
13	STEPPER	2

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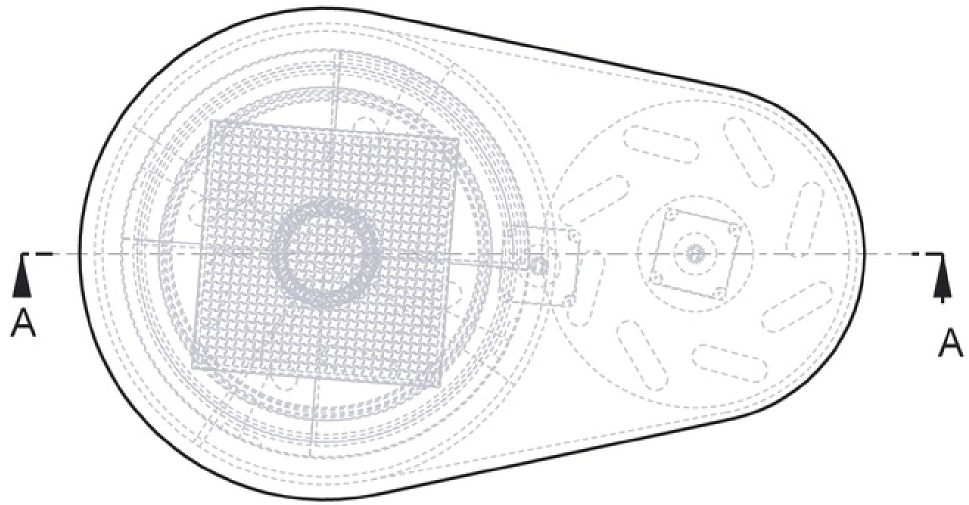
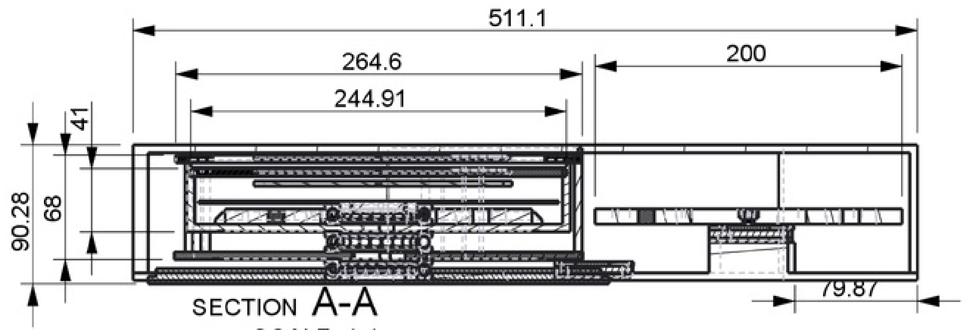
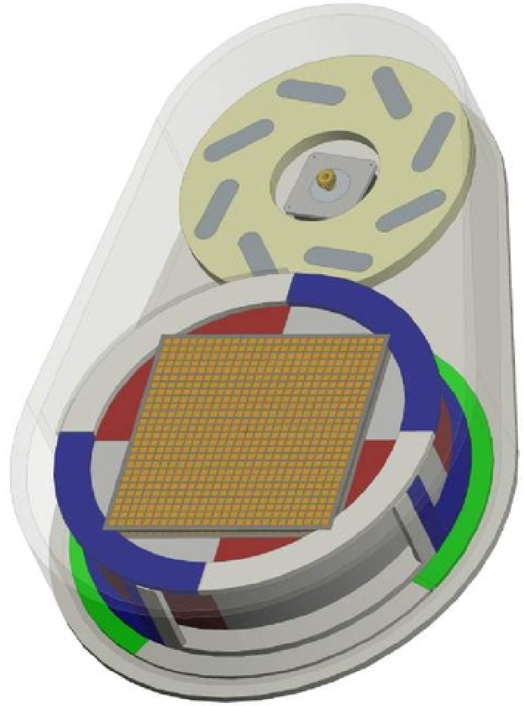
Student No	Drawn:	Date:	Descr:	
42501407	Elton D'Souza	Nov-05-16		
Material	Sheet: 1 of 1	Scale: 1:5	Drawing: DRW0001	Rev: A





SECTION A-A
SCALE 1:4



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DIMENSIONS IN mm
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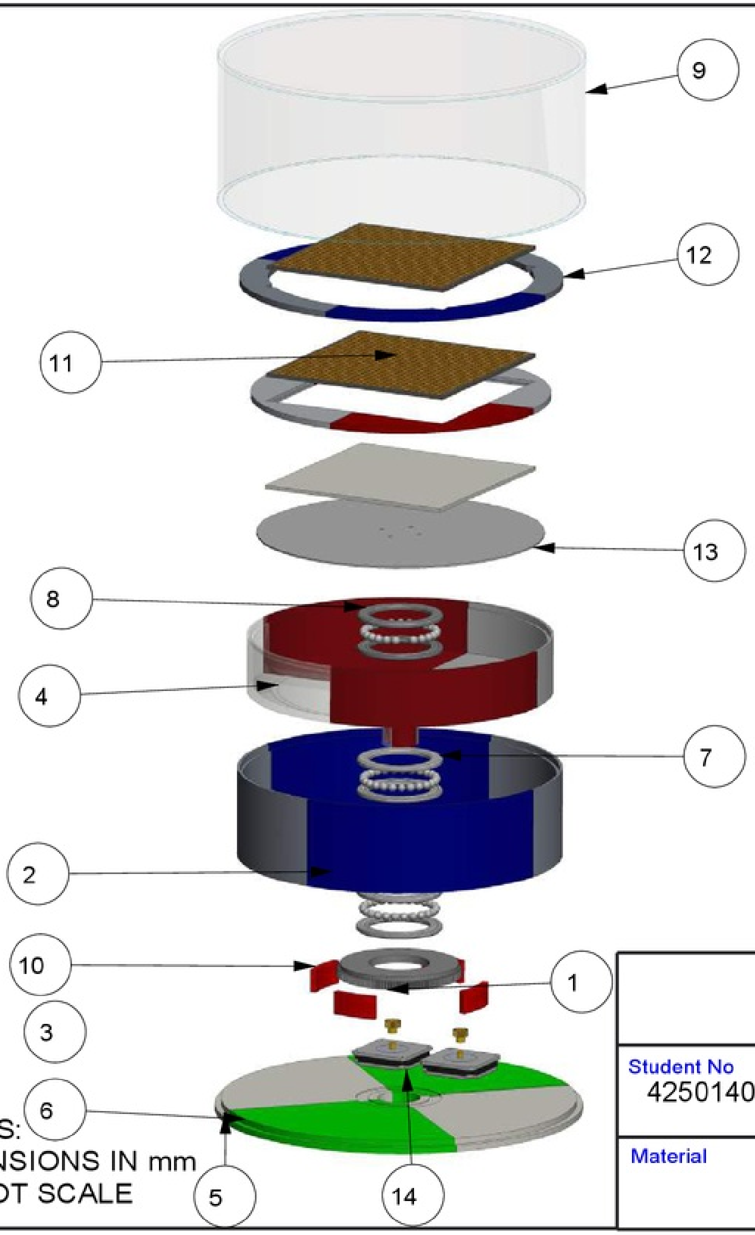
Student No	Drawn:	Date:	Descr:	
42501407	Elton D'Souza	Nov-07-16		
Material	Sheet: 1 of 1	Scale: 1:4	Drawing: DRAW3	Rev: A

6.4 Design 4

Design is a purely gear driven system attached to two of the shells. Each shell has a hollow shaft that comes down the centre, designed with such clearance that they can rotate within each other. For the outer shell the gear is attached to the outer section of the shaft while the inner shaft the gear is attached to the inner side. Stepper motors have been placed underneath to rotate the two shafts with direct gear driven system. To hold the shells in place again thrust bearings have been used. To hold the two shells a holder has been placed to hold the sections above the stepper motors. This design cannot be reduced down due to limitations of the stepper motor.



ITEM NO	PART NUMBER	QTY
1	128T_GEAR_	1
2	ANT1	1
3	ANTENNA1	2
4	ANTENNA2HOLDER	1
5	BASE	1
6	BASE2	1
7	BEARING	2
8	BEARINGCOMPLETE	1
9	COVER	1
10	HOLDER	1
11	LID1	1
12	LID2	1
13	METALSHEILD	1
14	STEPPER	2

NOTES:
DIMENSIONS IN mm
DO NOT SCALE

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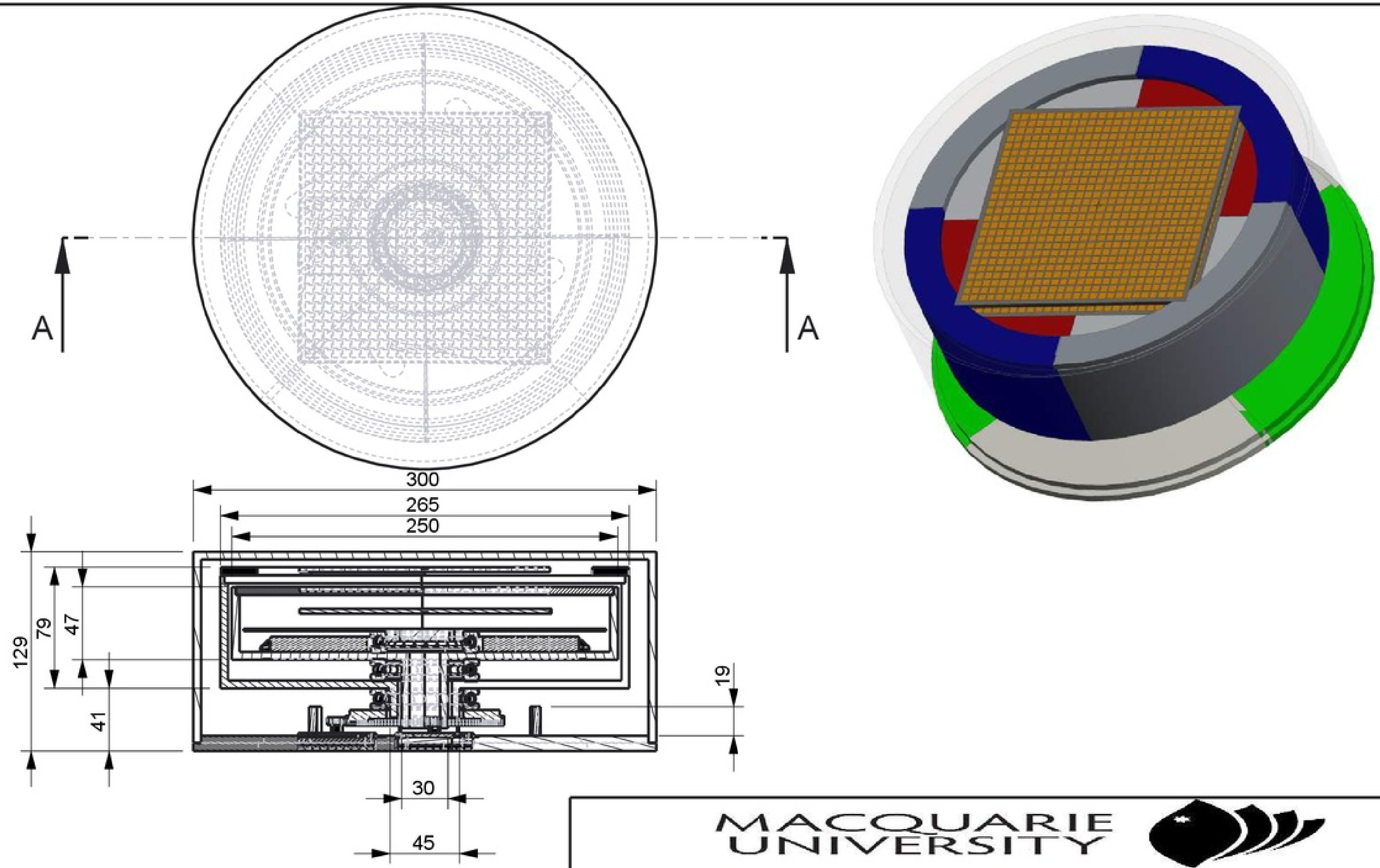
Student No 42501407	Drawn: Elton D'Souza	Date: Nov-05-16	Descr:	
Material	Sheet: 1 of 1	Scale: 1:5	Drawing: DRW0002	Rev: A



NOTES:
DIMENSIONS IN mm
DO NOT SCALE

SECTION A-A
SCALE 3:10

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Student No	Drawn:	Date:	Descr:	
42501407	Elton D'Souza	Nov-07-16	Design4 Section	
Material	Sheet: 1 of 1	Scale: 3:10	Drawing: DESIGN4	Rev: A

Chapter 7

Final design selection

7.1 System trade off analysis

The Boothroyd-Dewhurst Method is used to understand how the product cost is directly linked to the assembly time. This is helpful during the design selection it shows how long parts will take to fasten as well the manual handling time of each part. When put together it shows the total time to assemble the product. The higher the assembly time the higher the cost to produce. It is important to ensure that the DFA is as close to 100% as possible to ensure maximum efficiency of the assembly process. Tm determine the total time for assembly. This ideally should be as low as possible to reduce cost of assembly.

- Column 1: Part description
- Column 2: The number of times an identical part is used at this level of the assembly. For example if for this particular part of the assembly you have to screw in the same screw 6 times, this number is 6. Screws and Washers are separate parts.
- Column 3: Determine the component symmetry (alpha or beta) see appendix C for table In order to calculate the Man handling time see appendix D for table
- Column 4: Determine the Handling code from the component symmetry and from the ease of assembly (based on number of hands needed, size of component, need for additional aids), see appendix D for table
- Column 5: Determine the Handling time based on the code chosen, see appendix D for table
- Column 6: Assess the ease of insertion, consider all attributes, i.e. alignment need to hold down the part, insertion resistance, see appendix E for table
- Column 7: Insertion time see appendix E for table

Table 7.1: Design 1

Number	Part Description	Number of items	A+B symmetry	Manual handling code	Manual handling time	Manual insertion code	Manual insertion time	Total assembly time	Theoretical number of parts
1	InnerShell	4	0+90	09	2	79	12	56	1
2	Belts	2	90+90	68	6.5	81	9	31	1
3	Stepper Motor	2	0+0	40	2.18	29	5	14.36	1
4	Screws	4	0+360	30	3.06	0	1.5	18.24	1
5	Axel	2	0+90	40	2.18	83	6	16.36	2
6	Pulley	2	0+180	10	1.43	83	6	14.86	2
7	Antenna Holder	2	360+0	09	2	10	2.5	9	2
8	Outer Shell	1	0+20	09	2	83	6	8	1

Table 7.2

Nm	11
Tm	167.82
DFA	19.66

Table 7.3: Design 2

Number	Part Description	Number of items	A+B symmetry	Manual handling code	Manual handling time	Manual insertion code	Manual insertion time	Total assembly time	Theoretical number of parts
1	Antenna Holder	2	360+0	09	2	10	2.5	9	1
2	Inner Shell	1	360+0	09	2	79	12	14	2
3	Outer Shell	1	360+0	09	2	79	12	14	2
4	Gear 16t	1	360+0	01	1.5	29	5	6.5	1
5	Gear128t	1	180+0	01	1.13	79	12	6.5	1
6	Bearing	3	180+0	01	1.13	79	12	13.13	1
7	Magnet	2	360+0	01	1.13	0	1.5	39.39	1
8	Magnet Holder	1	180+0	01	1.13	79	12	5.26	2
9	Stepper Motor	2	360+0	40	2.18	29	5	14.36	1

Table 7.4

Nm	12
Tm	128.77
DFA	26.96

Table 7.5: Design 3

Number	Part Description	Number of items	A+B symmetry	Manual handling code	Manual handling time	Manual insertion code	Manual insertion time	Total assembly time	Theoretical number of parts
1	Antenna Holder	2	360+0	09	2	10	2.5	9	1
2	Inner Shell	1	360+0	09	2	79	12	14	2
3	Outer Shell	1	360+0	09	2	79	12	14	2
4	Gear 16t	1	360+0	01	1.5	29	5	6.5	1
5	Gear128t	1	180+0	01	1.13	79	12	13.56	1
6	Bearing	3	180+0	01	1.13	79	12	39.39	1
7	Magnet	2	360+0	01	1.13	0	1.5	5.26	1
8	Magnet Holder	1	180+0	01	1.13	79	12	13.13	2
9	Stepper Motor	2	360+1	40	2.18	29	5	14.36	1
10	Cover	1	180+0	08	4.1	83	6	10.1	1

Table 7.6

Nm	13
Tm	139.3
DFA	27.99

Table 7.7: Design 4

Number	Part Description	Number of items	A+B symmetry	Manual handling code	Manual handling time	Manual insertion code	Manual insertion time	Total assembly time	Theoretical number of parts
1	Antenna Holder	2	360+0	09	2	10	2.5	9	1
2	Inner Shell	1	360+0	09	2	79	12	14	2
3	Outer Shell	1	360+0	09	2	79	12	14	2
4	Gear 16t	1	360+0	01	1.5	29	5	13	1
5	Gear128t	1	180+0	01	1.13	79	12	13.13	1
6	Bearing	3	180+0	01	1.13	79	12	39.39	1
7	Magnet	2	360+0	01	1.13	79	12	13.13	1
8	Magnet Holder	1	180+0	40	2.18	29	5	14.36	2
9	Stepper Motor	2	360+0	08	4.1	83	6	10.1	1

Table 7.8

Nm	12
Tm	1401.11
DFA	25.69

7.2 Selection Matrix

There are currently are 4 designs which have been created, in order to choose which one to develop further a selection matrix table has been created to compare each choice on specific areas according to the requirements.

Table 7.9: Selection Matrix

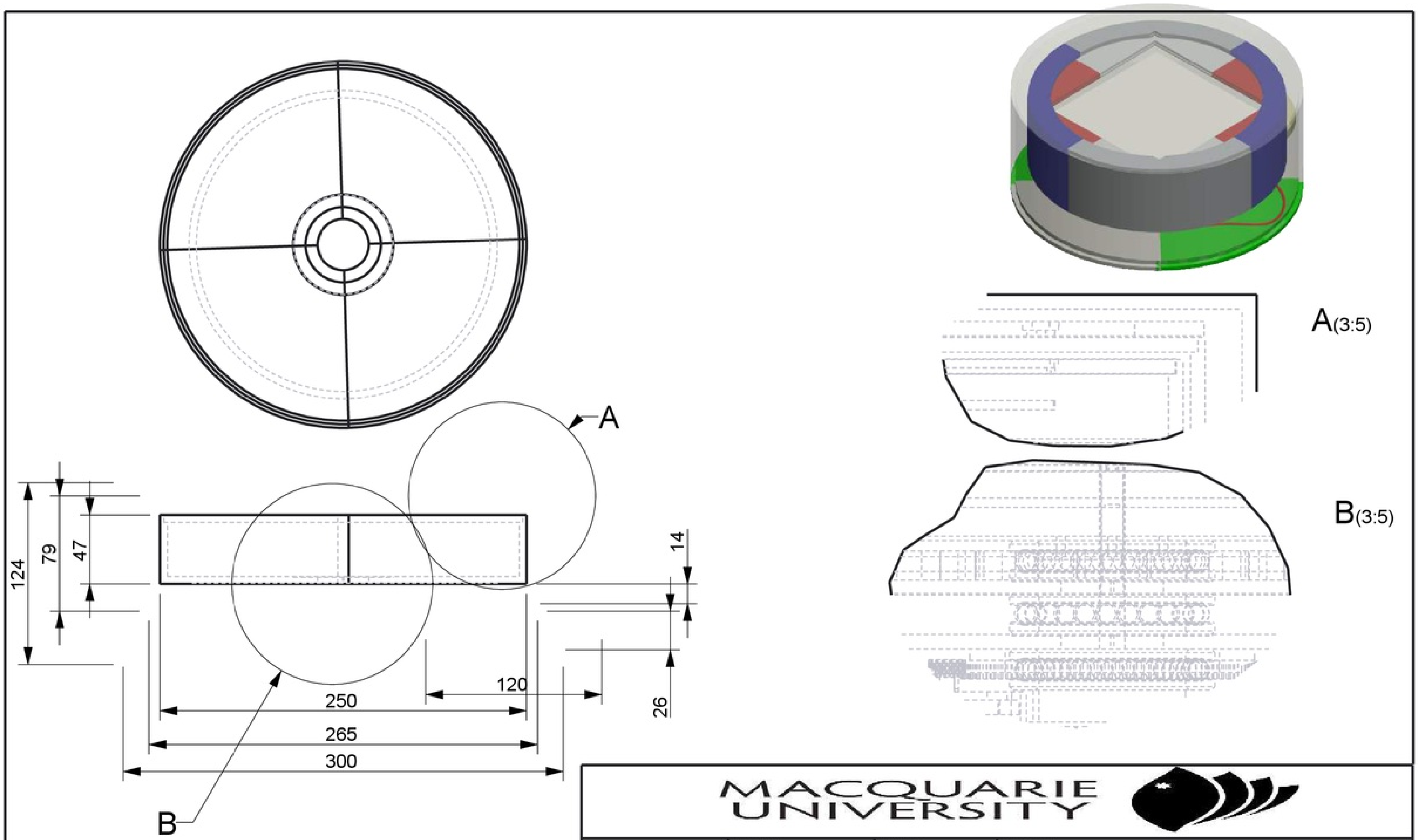
	Design Concepts				Current Market		
Selection Criteria	1	2	3	4	AMCAS	Thinkom	Gimbal (reference)
Thinness	+	+	+	+	+	+	0
Accuracy	+	+	+	+	+	+	0
Portability	+	+	+	0	0	-	0
Ease of assembly	-	+	+	0	0	-	0
Durability	0	0	0	0	0	+	0
Ease of Use	0	+	+	0	+	0	0
+'s	3	5	5	3	3	3	0
0's	1	1	1	2	3	2	6
-'s	2	0	0	0	0	1	0
Net score	2	5	5	3	3	1	0
Rank	5	1	1	3	3	6	7
Continue	N	Y	Y	N	N	N	N/A

Table 7.10: Weighted Matrix

		Design 2		Design 3		Gimbal (Reference)	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted score
Thinness	30%	4	1.2	5	1.5	3	0.9
Accuracy	30%	3	0.9	3	0.9	3	0.9
Portability	5%	4	0.2	4	0.2	3	0.15
Ease of assembly	5%	4	0.2	4	0.2	3	0.1
Durability	25%	3	0.75	3	0.75	3	0.75
Ease of Use	5%	3	0.15	3	0.15	3	0.15
	Total Score	3.4		3.7		2.95	
	Rank	2		1		3	
	Continue	No		Develop		No	

From the selection matrix developed it is clear that design 3 is the best method to develop. Mainly due to fitting the requirement of being smaller and reduced maintenance on the system. However due to constraints in building the prototype design 2 has been selected. The close similarities of one another should be easily transferable. OptoFab at the hearing hub have a 3d printed that is able to print 220mm diameter. As a first working prototype it would be effective to build design 2 rather design 3. It is important to note that design 3 should be built for prototype 3.

7.3 Detail design



NOTES:
DIMENSIONS IN mm
DO NOT SCALE

MACQUARIE UNIVERSITY				
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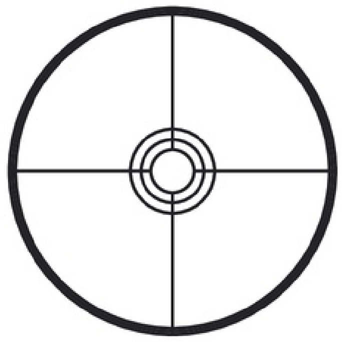

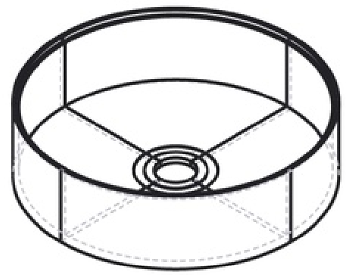

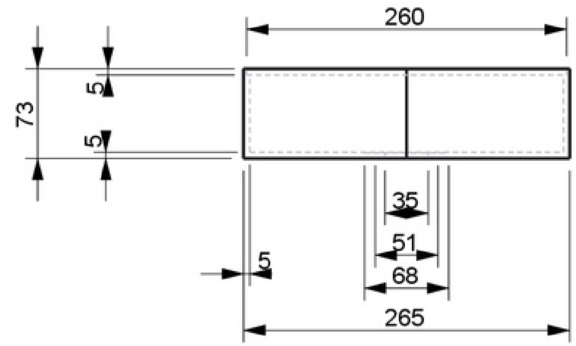

NOTES:
DIMENSIONS IN mm
DO NOT SCALE

MACQUARIE UNIVERSITY

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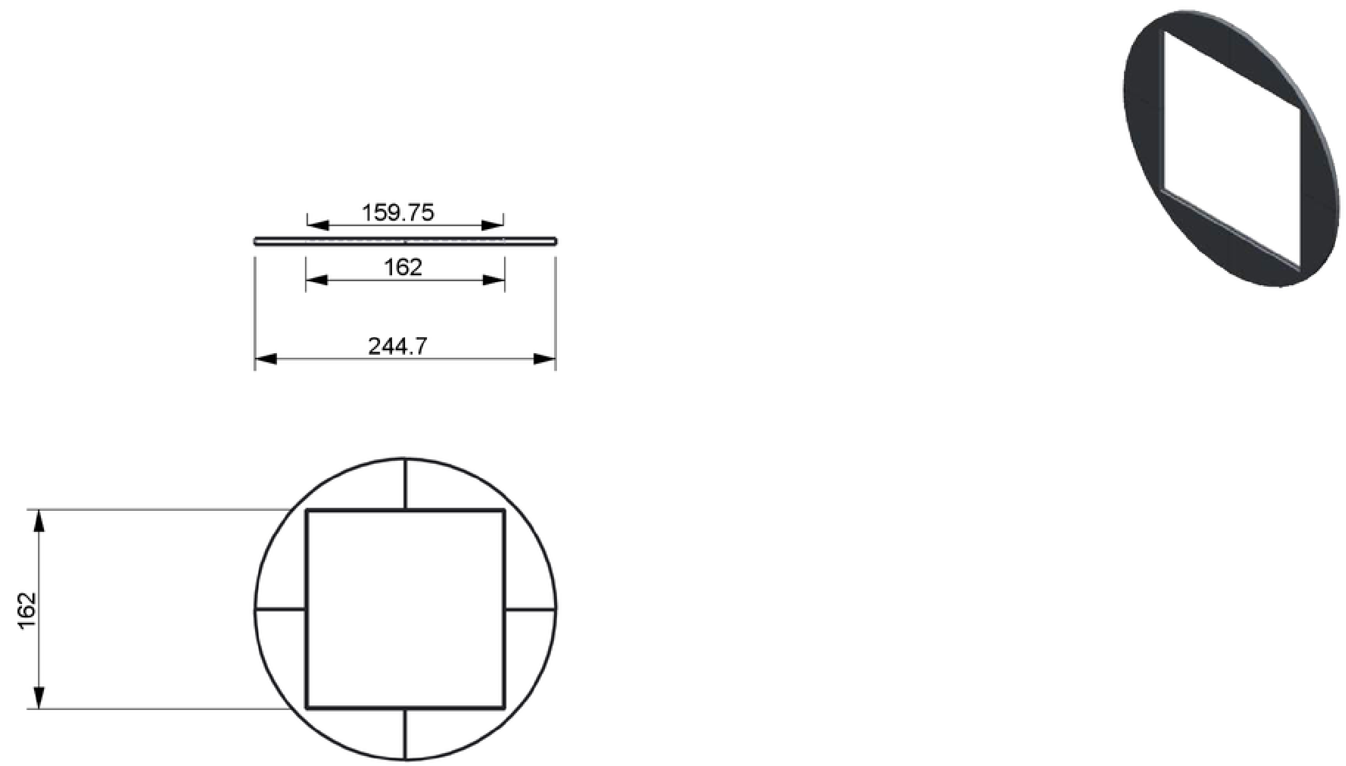

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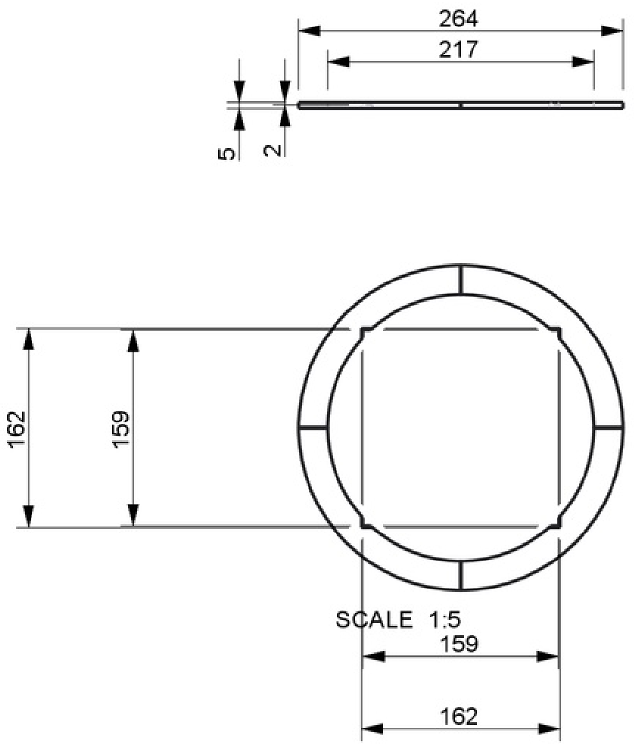

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DO NOT SCALE

MACQUARIE UNIVERSITY				
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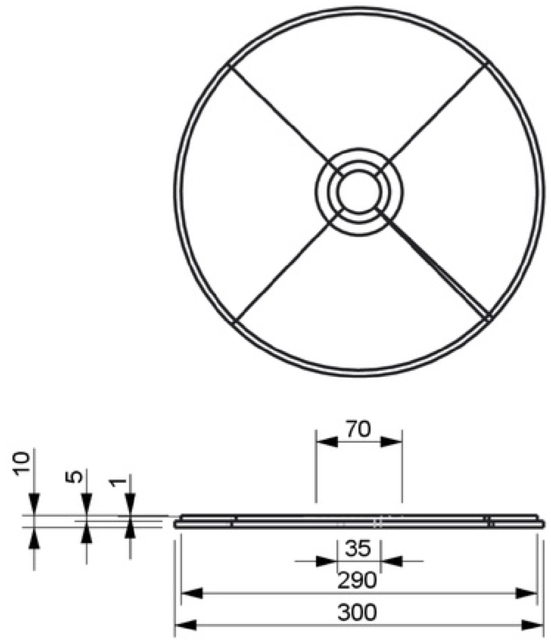

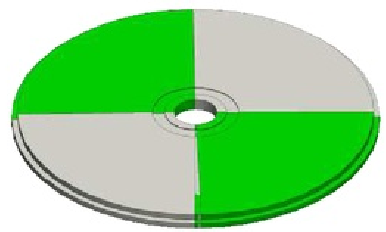

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42501407	Elton D'Souza	Nov-05-16		
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MACQUARIE UNIVERSITY

NOTES:
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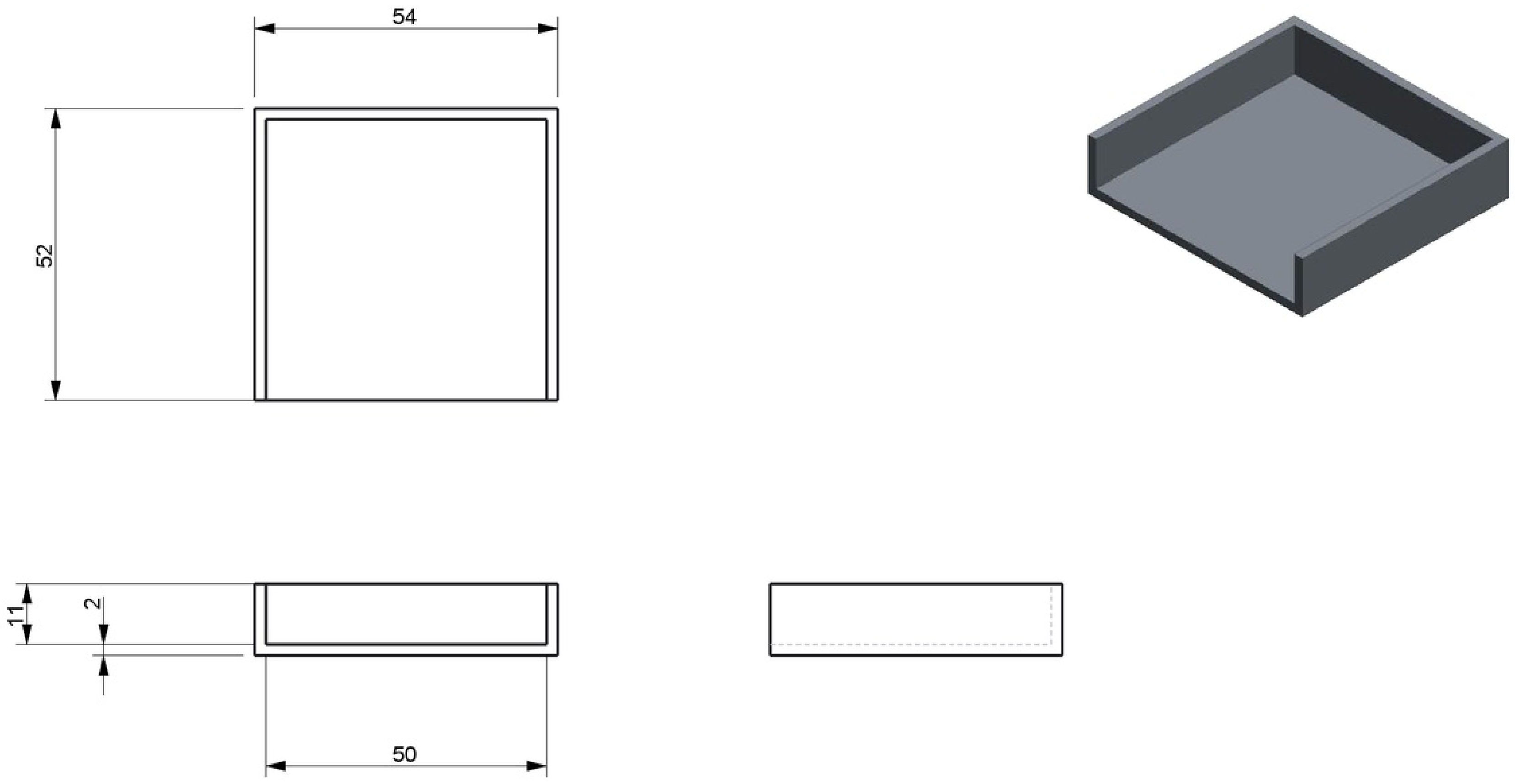

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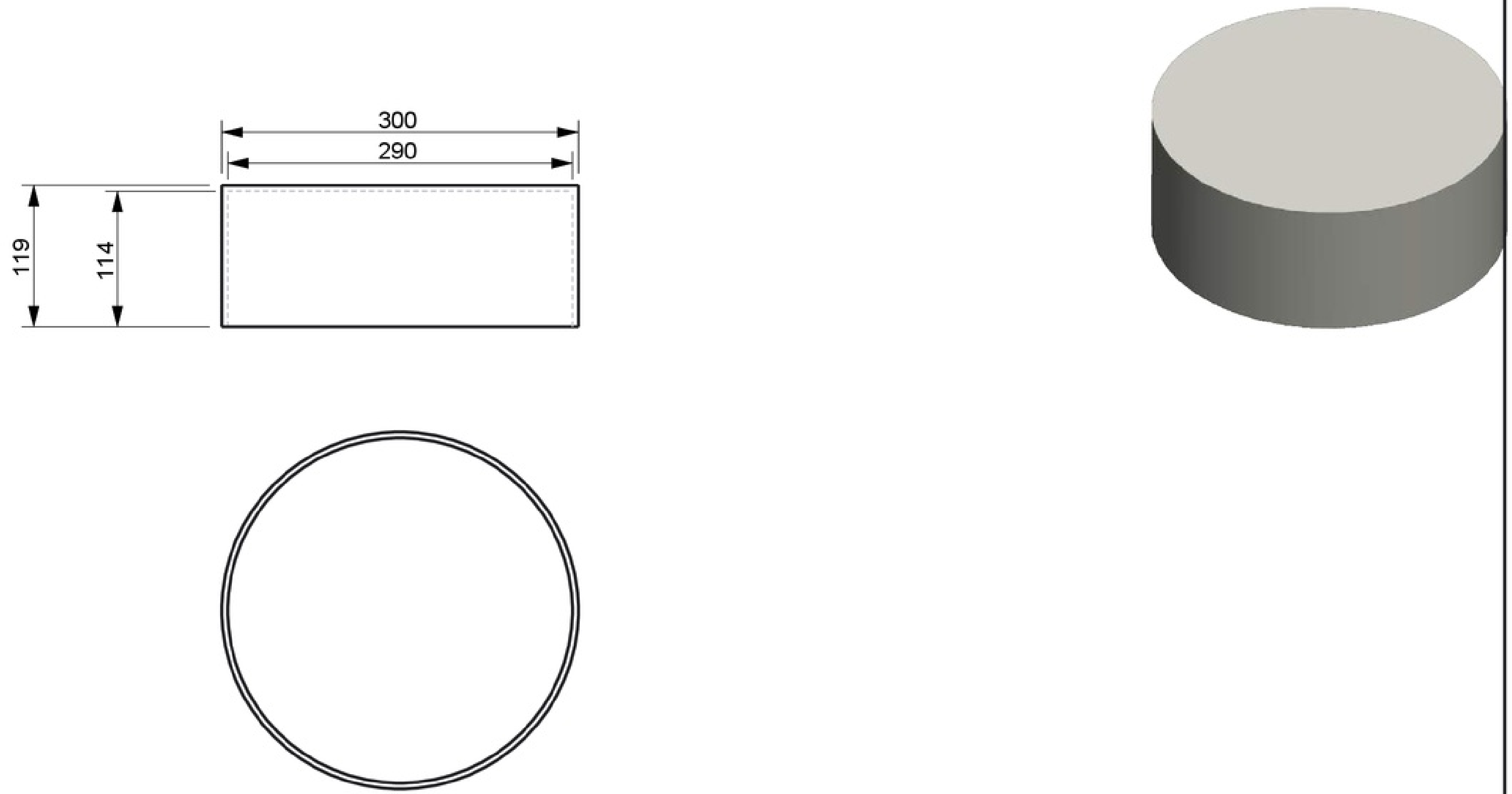

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MACQUARIE UNIVERSITY

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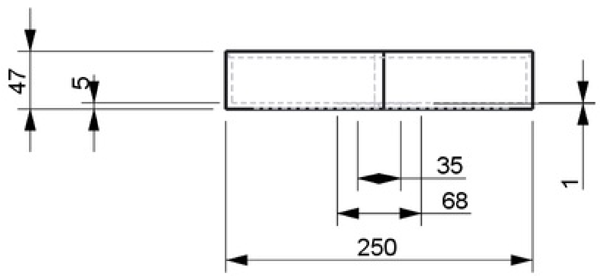

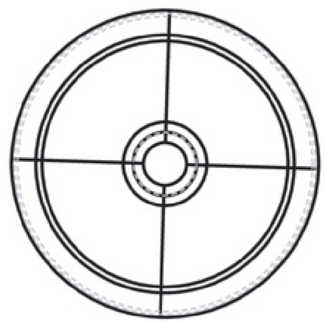

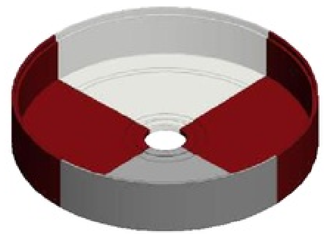

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Student No 42501407	Drawn: Elton D'Souza	Date: Nov-05-16	Descr:	
Material	Sheet: 8 of 8	Scale: 1:5	Drawing: MANUFACTURING	Rev: A

Chapter 8

Prototype Build

8.1 Calculations

In order to select the correct stepper motor for the prototype we have to understand how much torque is required to turn the system. Equations for moment of inertia, angular acceleration and the torque equation are used to determine this.

$$I = \frac{1}{2}mr^2 \tag{8.1}$$

$$= \frac{1}{2}0.2X0.15^2$$

$$= 0.00225kg/m^2$$

$$\alpha = \frac{\Delta\omega}{\Delta t} \tag{8.2}$$

$$= \frac{60rpm}{60s}X\frac{2\pi rad}{1revolution}$$

$$= 2\pi rad/s$$

$$\alpha = \frac{\omega f - \omega i}{\Delta t} \tag{8.3}$$

$$= \frac{2\pi - 0}{1}$$

$$= 6.28rad/s^2$$

$$T = I\alpha \tag{8.4}$$

$$= 0.00225kg/m^2X6.28rad/s^2$$

$$= 0.01413Nm^2$$

8.2 Material Selection

8.2.1 Stepper motor

A stepper motor was needed for this application in order to turn the antennas at precise movements. Stepper motors are used over normal motors as the stepper motor is able to rotate to a degree of accuracy of 1.8degrees. This can be further improver through micro-stepping using a stepper motor driver. A driver from little bird electronics was sourced duel to the ability to rotate two motors independently from one another. The stepper motor driver is able to micro step at 1/32th of a step. The stepper motor which was chosen was looked at from the calculations of the torque require to turn the system. It was calculated earlier that the amount of torque need to turn the structure would be $0.01413Nm^2$. Abiding by the design constraints a Sanyo Pancake Stepper Motor:Bipolar, 200 Steps/Rev, 5011mm,4.5V, 1 A/Phase was chosen. From the data sheet in appendix the stepper motor has a holding torque of $0.1Nm^2$ which is more that enough to turn the current system.

8.2.2 Housing

In the mass production the housing structure would be made up of a number of materials from metals to plastics. It would be quite similar to the materials used in the prototype. However the prototype has been made out of materials that are cheap and fast to make. using 3d printing to print the housing structure there was only 2 main materials that were going to be chosen. This was either PLA or ABS plastic. PLA was opted for a better decision due to the ability to print over larger surface areas without warping. PLA also has environmental benefits since it is derived from natural sources rather than ABS with is petroleum based.

8.2.3 Bearing

For this project thrust bearings were needed to allow for the rotation of the shells within each other. The better option for the prototype would have been plastic bearings however there was no manufacturer that sold plastic thrust bearings. The reason for choosing plastic over metal is due to the design of the system. The system uses magnets which are rotated around the bearing. Due to the strong magnetic field produced by the magnets the bearings would not only become magnetised over time but eddy currents are induced in the metal. Since eddy currents are induced in the metal the bearings resist movement and thus don't function as well.

8.2.4 Gears

Metal gear

8.2.5 Gluing

To connect two section of ABS plastic, you can fuse the material together using acetone, however when using PLA plastic there is no perfect solution in finding the best glue. Before buying the adhesive material a simple tensile test on the instron was done to understand some of the glues that could be quite strong. Two pieces of pla was stuck with adhesive. In figure 9.1 a stress strain plot was plotted and the results were shown. Based on the results Loctite Gel Control was the most effective with the highest ultimate tensile strength at 4MPa. Based on the results Loctite Gel Control was chosen and bought.

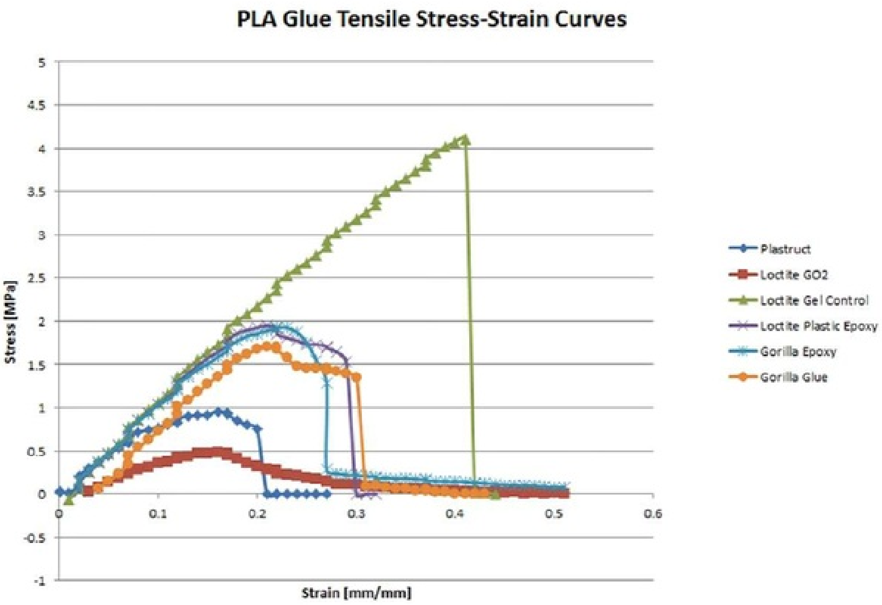


Figure 8.1: Tensile test to measure different adhesive types on PLA plastic

8.3 Construction Techniques

Two techniques have been used in the construction of prototype 1. 3d printing has been used to build the sections of the shell while an adhesive had been used to combine the parts together. Figures 9.2 show 3d printing process used while 9.3 shows the glue to fuse the parts together.

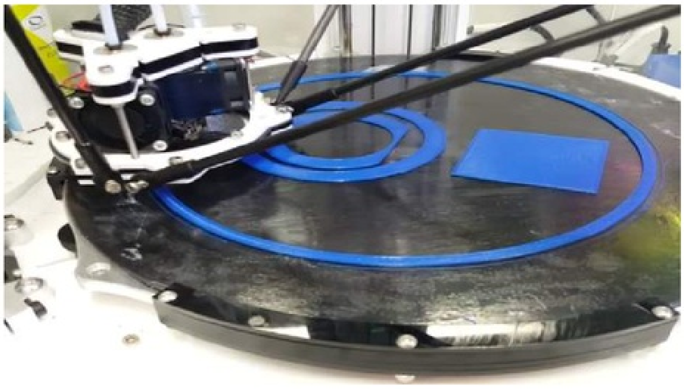


Figure 8.2: 3d printing the assembly

Figure 8.3: Loctite Gel Control

8.4 Prototype

The prototype was built at OPTOFAB at the hearing hub using their 3d printer. The maximum size of the 3d printer was 220mm diameter x400mm high. Unfortunately this size was a little to small for the project so the design was cut into 4 pieces. There was in total 26 pieces used in the 3d print which was conducted over a period of 3 weeks.

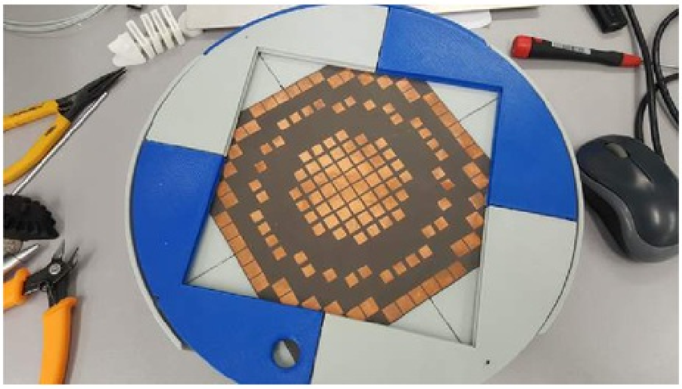


Figure 8.4: Copper antenna fitted to the design

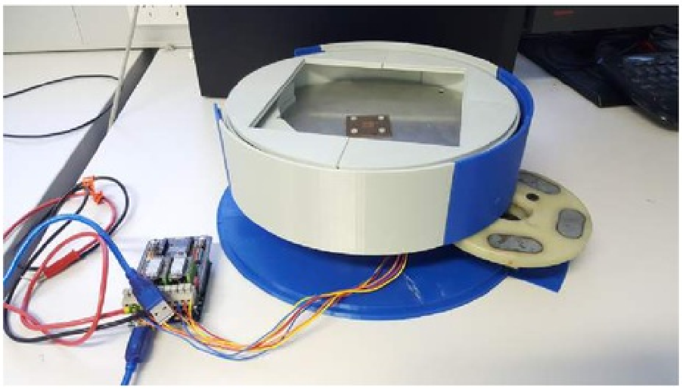


Figure 8.5: The overall system design

8.5 Cost of Prototype

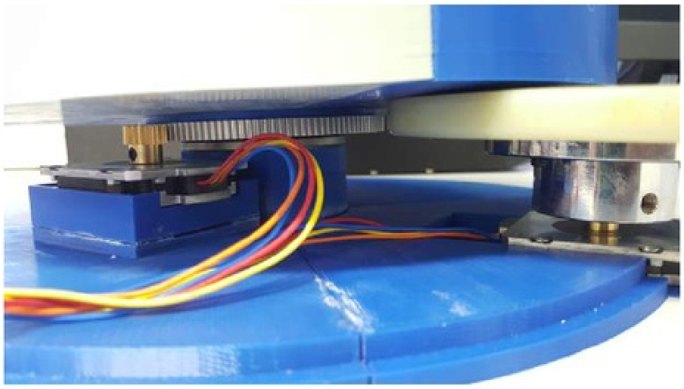


Figure 8.6: Gearing driving the outer shell

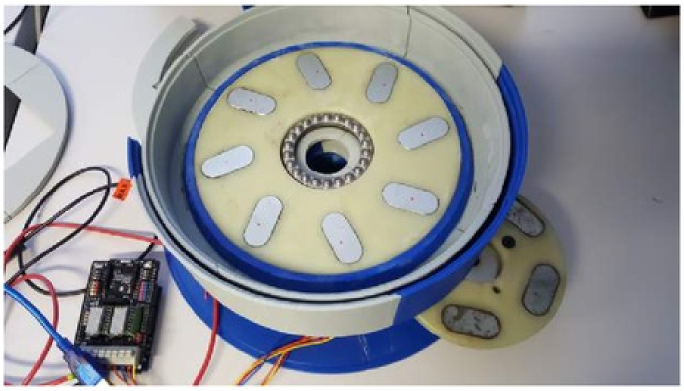


Figure 8.7: Magnet in the system with the bearing in the centre

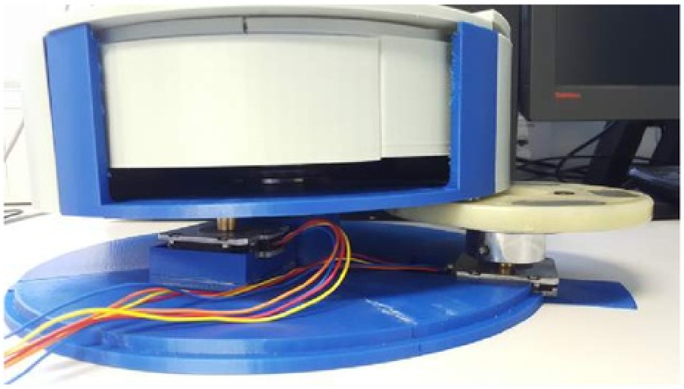


Figure 8.8: stepper motors connected to the shell

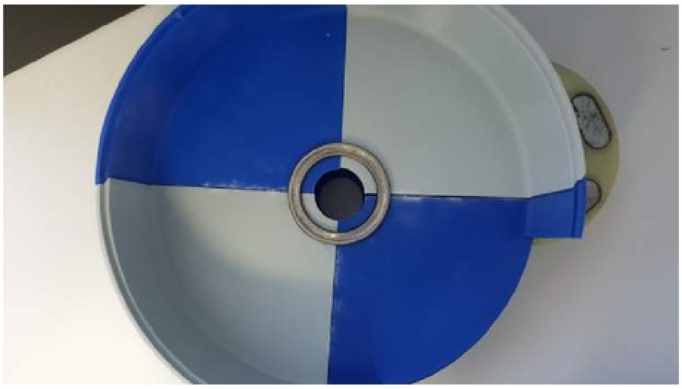


Figure 8.9: Gluing the bearing race way to the shell

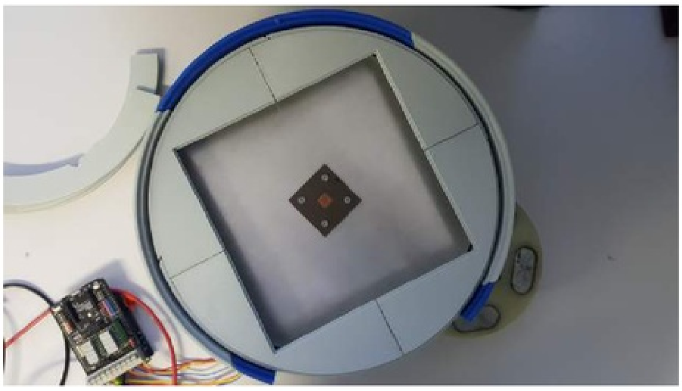


Figure 8.10: Clearance factor of the inner vs outer shell

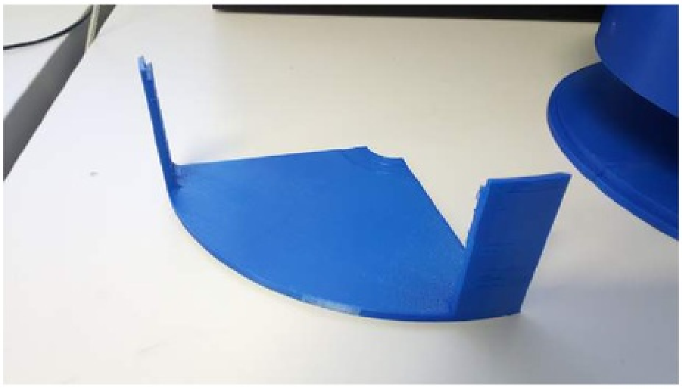


Figure 8.11: A quarter of a material saving sectioned shell

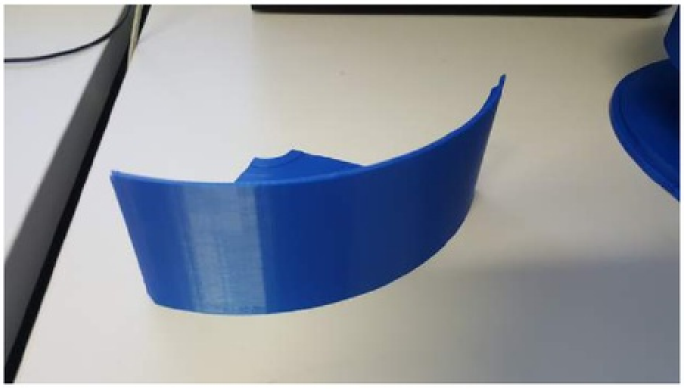


Figure 8.12: A quarter of a sectioned shell

Table 8.1: Prototype Costs

item	Part	Description	Qty Needed	Unit Price	Actual Cost	Source	Lead Time
1	Stepper Motor	Sanyo Pancake Stepper Motor: Bipolar, 200 Steps/Rev, 5011mm, 4.5V, 1 A/Phase	2	69.83	139.66	Little Bird	3 weeks
2	Driver	Dual Bipolar Stepper Motor Shield for Arduino (A4988)	1	30.03	30.03	Little Bird	3 Weeks
3	3d Printing	PLA plastics 3d pinter	2 rolls	35.00	70.00	OptoFab	1 week
4	3d Printing	Training	-	-	30.00	OptoFab	0
5	Wires	Extension Wires	2 sets	18.36	36.72	PC Case Gear	4 days
6	Metal Shield	Metal Shield Cut, Magnet Bore	0	0	120.00	Mets	3 days
7	Bearing	Bearings	3	32.625	65.25	VXB Bearing	4 weeks
9	Gears	128T + 16T x2 gears	1	108.64	108.64	Servo City	4 weeks
				Total	$600.30		

Chapter 9

System design and feasibility

9.1 Design for reliability

Throughout design there are a number of reliability tools that can be effectively used to understanding the failure in a design. Reliability is important in a system to understand when will the system be likely fail and what effects or step can be taken to ensure the system is constantly running. Understanding the reliability can help mitigate expensive costs as well as schedule important maintenance strategies which can improve the life of the system. Since time is critical in reliability it is often expressed at meantime between failure (MTBF) or mean time to failure (MTTF). As part of the iterative process of the system there are a few reliability methods that can be effectively used such as failure mode effects and critically analysis (FMECA) and a faulty tree analysis (FTA). Here we will be focusing on FMECA.

9.2 Design for maintainability

In order for the system to be continuously running it is important that maintenance is scheduled at correct times over it's life time. Maintenance can be broken down into two categories:

1. Corrective Maintenance This is an unscheduled maintenance in the system which is done to restore a system fault. This included the initial detection of failure, fault isolation, disassemble, readjustment/alignment and final checkout of the systems performance.

2. Preventative Maintenance Schedule maintenance is done to ensure that the current level of performance is still being provided. An inspection, detection, servicing of impeding failures through periodic item replacement.

9.3 Design for expandability

In the design specifications, it has been expressed that the system was to be able to work in conjunction with other designs where another antenna system can be added. Building expandability to the system allows for future work to be added in at a reduced cost.

9.4 Design for sustainability

Sustainable design has been considered through the whole project. In this design that has been chosen a modular system of parts has made it very easy to replace during periods of failure of that particular component. Such examples if a bearing was to fail the internal structure could be pulled apart quite easily thus replacing the failed bearing. Another sustainable feature that has been incorporated is the reduction in material used. Designs have been made for prototype 2 to be not only thinner but use 60 percent less plastic than prototype 1. This would not reduce the reliant on petrol driven resources but also help with disposability of the product during the end life cycle.

Chapter 10

Testing

The current design of the multi-rotational antenna has been built as a prototype 1 to illustrate that turning two antennas independently is a feasible option. The current model is made up of 3d printed parts that have been glued together using epoxy to form a circular body. The epoxy glue was tested to ensure the highest strength was taken. In all there are 26 parts that make up the final prototype. To power the rotation of the antenna system two stepper motors had been selected to rotate the antennas at precise measurements. Since the antennas are each unidirectional the antennas need to be rotated with extreme precision to ensure that the signal of the receiver is maintained at its strongest point. The current stepper motors have been chosen to be able to turn on a degree of accuracy of 1.8 degrees. This would ensure that the antenna system can work over long distances and/or even be able to connect to satellites. An Arduino was connected with a power supply unit to provide the code and the voltage to control the direction in which the stepper motors turned to.

Design Review and issues This current design has been a 1/4th of a scale version to the actual design. A larger antenna would not only mean a greater data volume but also a greater range. The prototype currently made was able to show that the system can work using the design concept however after testing the antenna housing there is a few issues that was found. Some of the issues faced was, warping, magnetic interference and gearing. Since the material was printed in PLA plastic there was some issues with alignment of the parts. This mismatch allowed the parts not being precisely level and a slight wobble is has been detected in the testing. It is also important to note it was found that the 3D printer used by OptoFab had a 0.5 degree error in the print. So when 4 circles was printed 2 degrees was extra and a new print had to be conducted with a reduced angle. So it would fit. Using magnets was a good design choice in the design and allowed for the design to be slimmed further down than even current commercial models. One of the issues that was experienced during testing was the changing magnetic flux which could be seen as one magnet turned the other. As the magnets turned and stopped there was a slight movement in the secondary magnet. This phenomena may be due to the fact that a couple of factors were playing a part here. One of them was the 3d print not being 100%. Cross hatching is used in 3d prints to support the internal structure without printing a solid piece. This method allows not only weight saving by time saving as well. Though since there was a cross hatching the material was not uniform and as the antenna housing turned this unbalanced material changed the strength of the magnetic flux which then creates a wobble effect when spun around.

Chapter 11

Future System Improvement

The design has been chosen because its ability to be versatile in different situations. This particular design utilising a combination of magnets and gears could be rearranged so that the overall system height can be reduced 60% of the current size. The current prototype is already thinner than any current product in the market making highly desirable to prospective buyers. Given that current applications of the systems are fitted in passenger planes, with further development in trains and eventually cars where aerodynamics is important, thinner systems would be highly important.

In design 3 you can see that magnets which can be re orientated into the same plane. Having it in the same plane reduces the height of the overall product. Introducing the outer shell with gears would also further reduce the product size. This design would have been constructed but due to manufacturing constraints this was not a feasible option.

Another improvement would improving material usage through the model. As costs of systems increase over a period of time to ensure that this product is economically viable removing material where it is not needed yet holding structural integrity would be important. The material forming the antenna holders can be designed into small cylindrical parts. These cylindrical parts would form the support to hold the antennas without the need of walls. This would reduce the material weight by 80%. Further study would have to be conducted into determining the correct diameter of the part to ensure there is no buckling of the sections.

11.1 Bearings

The bearings which have been used are made from chrome steel which do become magnetised over time from the permanent magnet which are inducing a magnetic field. When the bearings spin they are inducing magnetic currents also known as eddy current which are opposing the movement of the race ways. This increases the amount of torque which the stepper motors need to turn the antennas. One improvement would be using a bearing that is made from non-ferrous material. A combination of plastic bearings or bearing s that have glass balls and plastic would be an ideal solution. The costs would indeed increase due to lack of availability however this would increase the life of the product by putting less strain on the stepper motors. Another design improvement that could be made is the introduction a 3 tier thrust bearing. The current prototype uses 3 thrust bearings however condensing that to 1 thrust bearing with 3 tiers would not only reduce cost but also time to build and assemble the product since there is less parts.

11.2 Current stepper

In the prototype stepper motors were used to ensure a highly precise movement of the antenna system to 1.8 degrees of movement. A stepper motor driver is used to further do micro stepping in which the movement of the stepper motor can be reduced even further. The current design has a 1/16th stepper motor driver which can move the stepper motor every 0.1125 degrees. Sourcing a new driver that can move 1/32th of a micro step would increase the accuracy to 0.056 degrees of movement. The current stepper motor is a small stepper motor that can move of torques of 0.1 but since the current magnets oppose the bearings which was not foreseen this has added a level of restricted movement. A larger stepper motor would be ideal however going bigger would mean that the overall system size would be increased. Gearing the current stepper motors down would increase the current mechanical advantage yet keeping a slim profile.

11.3 Gears

Currently the system is using a simple spur gear design. One of the issues with spur gears is the amount of backlash in it. The design should be redesigned by utilizing a worm gear. This not only reduced backlash but also acts as a safety feature to the stepper motor by not turning backward. If a stepper motor is spun the wrong direction current can be induced in the coil and be sent to the stepper motor driver effectively burning it out.

11.4 Scalability

Given that this first design is a prototype of r a model that is to be around 4 times bigger it is expected that most of the items could be able to scale up. In the current design, due to the ability to source materials industrial rated products have been added such as magnets and bearing s which have been over engineered for the design. The materials chosen can with stand operating temperatures stated in the technical specifications.

Mass production scale is possible however a prototype of a 1:1 scale should be made to ensure smooth construction and understanding manufacturing procedures. Things that should be looked at is clearance, manufacturing constraints and shipping costs which would all play a part in the overall project design. The project would be well suited to high volume transportation's such as planes trains and buses. A smaller version of the design could be introduced into cars.

Chapter 12

Conclusions

As the project moves into the next phase of the feasibility the initial prototype design proves that this project is possible and can be easily made. It is important to note that costings of materials and handling time would be the most expensive part of the project. Reducing number of parts would not only mean reducing the cost of mass manufacture but increasing the reliability of the system.

Chapter 13

Abbreviations

AWGN	Additive White Gaussian Noise
BC	Broadcast Channel
BS	Base Station
CSI	Channel State Information

Appendix A

Stepper Motor Data Sheet

2-phase stepping motor

50mm sq. (1.97inch sq.)

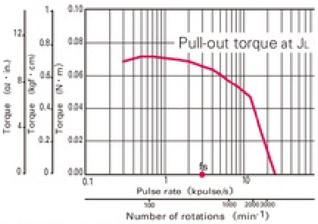
SS250□
1.8° / step Bipolar winding

Bipolar winding・Lead wire type

Model		Holding torque at 2-phase energization	Rated current	Wiring resistance	Winding inductance	Rotor inertia	Mass (Weight)
Single shaft	Double shafts	[N・m (oz・in) MIN.]	A/phase	Ω /phase	mH/phase	[×10⁻⁴kg・m²(oz・in²)]	[kg (lbs)]
SS2501-5041	**-5011**	0.1 (14.16)	1	4.5	1.8	0.026 (0.142)	0.09 (0.20)
SS2502-5041	**-5011**	0.215 (30.44)	1	5.9	3.2	0.049 (0.268)	0.15 (0.33)

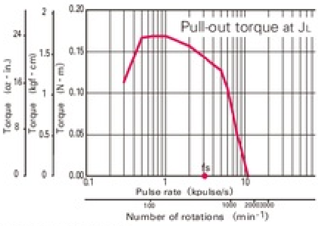
■ Pulse rate-torque characteristics

● SS2501-50□□



Constant current circuit
Source voltage : DC24V・operating current : 1A/phase,
1-2-phase energization (half-step)
JL = [0.01x10⁻⁴kg・m² (0.055 oz・in²) Pulley barancer system]
fs: No load maximum starting pulse rate

● SS2502-50□□



Constant current circuit
Source voltage : DC24V・operating current : 1A/phase,
1-2-phase energization (half-step)
JL = [0.01x10⁻⁴kg・m² (0.055 oz・in²) Pulley barancer system]
fs: No load maximum starting pulse rate

The date are measured under the drive condition of our company. The drive torque may very depending on the accuracy of customer-side equipment.

Appendix B

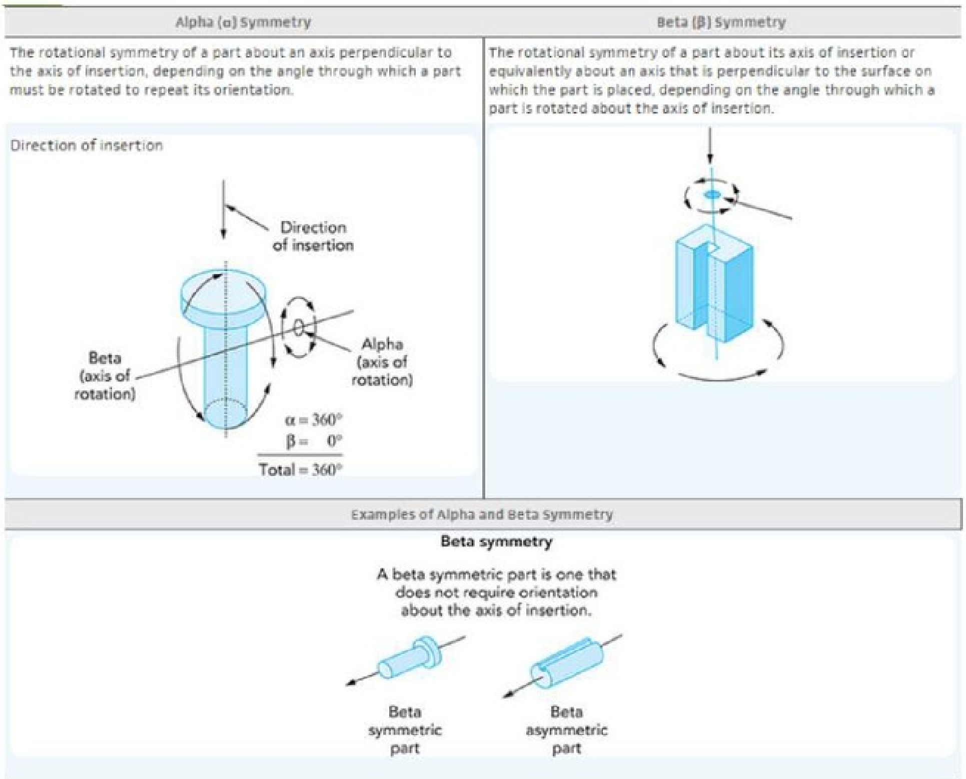
Ardunio Code

```
/*
This code is for testing the 2 stepper motors
The rotation velocity can be adjusted by the code switch
Microcontroller: Arduino UNO
*/
int M1dirpin = 4;
int M1steppin = 5;
int M2dirpin = 7;
int M2steppin = 6;
void setup()
{
  pinMode(M1dirpin,OUTPUT);
  pinMode(M1steppin,OUTPUT);
  pinMode(M2dirpin,OUTPUT);
  pinMode(M2steppin,OUTPUT);
}
void loop()
{
  int j;
  delayMicroseconds(2);
  digitalWrite(M1dirpin,LOW);
  digitalWrite(M2dirpin,LOW);
  for(j=0;j<=5000;j++){
    digitalWrite(M1steppin,LOW);
    digitalWrite(M2steppin,LOW);
    delayMicroseconds(2);
    digitalWrite(M1steppin,HIGH);
    digitalWrite(M2steppin,HIGH);
    delay(1);
  }
```

```
}
```

Appendix C

α and β symmetry in BDM



Appendix D

Manual Handling Code

MANUAL HANDLING — ESTIMATED TIMES (seconds)

Key

ONE HAND — parts can be grasped and manipulated by one hand without the aid of grasping tools

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha + \beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \leq (\alpha + \beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \leq (\alpha + \beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha + \beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS — parts can be grasped and manipulated by one hand but only with the use of grasping tools

			parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
			parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
			parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
			thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
			0	1	2	3	4	5	6	7	8	9
$\alpha \leq 180°$	$0 \leq \beta \leq 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
$\alpha \leq 180°$	$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
$\alpha = 360°$	$0 \leq \beta \leq 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
$\alpha = 360°$	$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g., sticky, delicate, slippery, etc.)(1)				
		$\alpha \leq 180°$			$\alpha = 360°$		$\alpha \leq 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary)(2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present ther handling difficulties (1)			
		$\alpha \leq 180°$	$\alpha = 360°$	$\alpha \leq 180°$	$\alpha = 360°$	$\alpha \leq 180°$	$\alpha = 360°$	$\alpha \leq 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Appendix E

Manual Insertion

MANUAL INSERTION — ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
			0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
					plastic bending or torsion			rivetting or similar operation				
						not easy to align or position during assembly			not easy to align or position during assembly			
			easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
			0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately	part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

Appendix F

Consultation Meetings

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
1	5/8/16	Met with Usman about the details of the project and design		
2	9/8/16	Met with Nazmul about formulating a meeting with Karu & Rahel.		
3	19/8/16	Met with Raheel, Karu Usman about the project details and further research		
4	23/8/16	Meeting Nazmul was cancelled (Department meeting)		
5	30/8/16	Meeting with Nazmul was postponed. (Nazmul was sick)		
6	5/9/16	Met with Nazmul for the concept designs. Meeting with Karu to be made		
7	13/9/16.	Design has been approved by Karu to be made.		
8	4/10/16	Seen Nazmul about project approval.		
9	11/10/16	Showed Nazmul 3D printed parts		
10	18/10/16	Showed Nazmul the working design of the antenna		
11	25/10/16	Meeting next week has to be made for thesis		
12.	1/11/16.	Meet Nazmul for thesis		

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