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Automated Calorie Counting and Nutrition Detection App

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Nomenclature

Variables and functions

V	Voltage
I	Current
R	Resistance

Acronyms and abbreviations

GS	Ground Station
PQ	PocketQube
LEO	Low Earth Orbit
LOS	Line-of-Sight
PCB	Printed Circuit Board
EPS	Energy Power System
TX	Transmit
RX	Receive
GPS	Global Positioning System
GNNS	Global Navigation Satellite System
IMU	Inertial Measurement Unit
SU	Stellenbosch University
PQSU	PocketQube Stellenbosch University
RF	Radio Frequency
IC	Integrated Circuit

Abstract

English

The English abstract.

Afrikaans

Die Afrikaanse uittreksel.

1. Introduction

This project aims to design and implement a wireless communication system for a miniaturised satellite called a PocketQube (PQ). The PocketQube standard was created to define physical and electronic requirements for so-called ”nano satellites”. The goal of this is to allow for easy integration of various sub-modules into one physical enclosure. One common use-case of these satellites is to collect sensory information from the atmosphere. These can either be placed into orbit, are attached to a *high-altitude balloons* (e.g. a large, helium balloon). In this project, such a balloon will been provided by the department, and a communication system for this satellite balloon will be designed.

This project consists of the design of three sub-systems. The communication system to be designed will involve both a tracking ground station (GS), as well as a PQ ’unit’, that will use a custom link protocol. The general idea is that the GS will mechanically track the PQ while it communicates with it, enabling realtime data transmission and telemetry. An existing two-axis antenna mount has been provided for the GS, which a newly-designed PCB will be placed into. The GS will mechanically the balloon, allowing bi-directional wireless communication. The PQ unit should conform to the PQ standard and fit inside a provided housing. The third sub-system is the integration of a proprietary Radiosonde (atmospheric telemetry device) into the newly-designed communication system.

Literature will be consulted in order to investigate the various design approaches and decisions. Since the project focuses on system design and integration, a number of components and sub-modules will ultimately be combined to form the final system. Different electronic components and their specifications will be compared based on gathered project requirements. This will require trade-offs to be made, since the system design is limited in time, cost, form-factor and several other factors. This report documents the trade-offs and decisions made, with the goal of being of use to future designers of similar systems.

2. Problem

2.1 Overview

The requirements for this project are defined by analysing general, currently existing balloon-satellite systems, as well as taking into account the planned launch that this specific PocketQube will be used in, as shown in Figure 2.1. Further, the desired integration with the existing Radiosonde system (the iMet-54 device) is taken into account.

Generally, high-altitude balloons can drift to a height as much as 30 km above sea level [8]. For this project, the balloon is planned to be released from near Saldanha Bay (Western Cape, South Africa), where it will travel a maximum distance of around 200 km towards the Cederberg and land furthest in Worcester. From Cape Town, this is a maximum straight line distance of around 115 km.

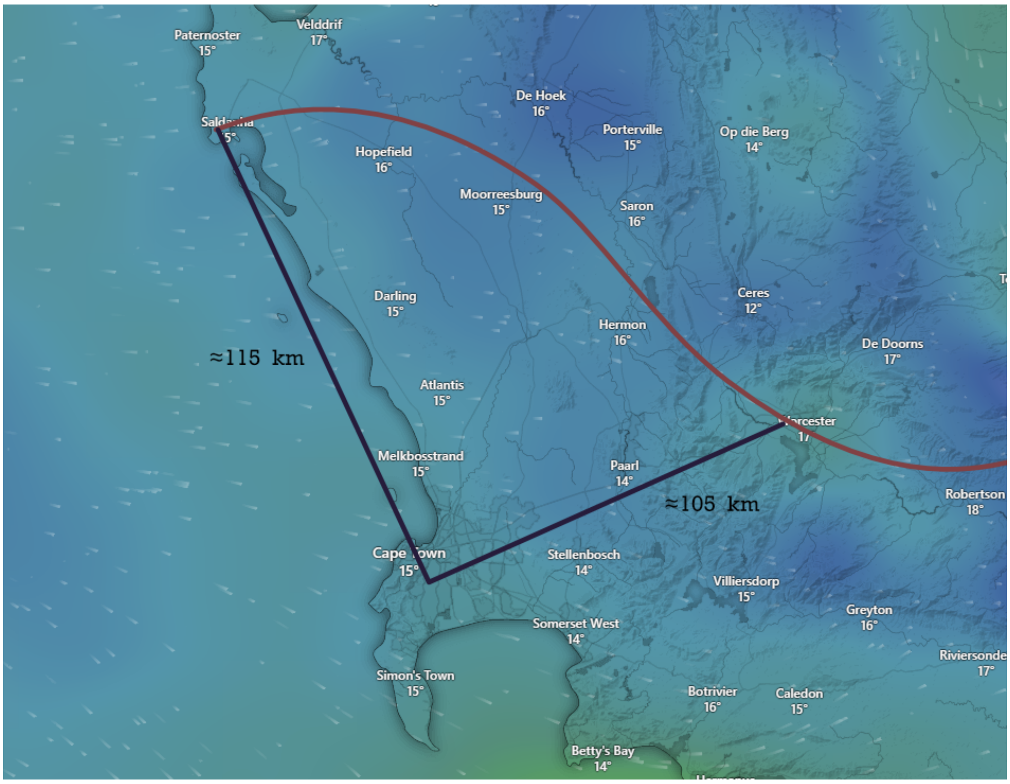

Figure 2.1: Balloon Path and Distances

2.2 Requirements

The general requirement of the system is that continuous, wireless communication should be established and maintained between the ground station and a balloon-satellite carrying a PocketQube payload. The antenna mount of an existing ground station has been provided. Further, communication with the existing Radiosonde should also be possible. From this information, and after supervisor consultation, slightly more specific user requirements are gathered and listed:

1. Wireless communication data between the GS and the PQ should be retrievable, as well as data from the priorietary Radiosonde.
2. The communication system should be capable of the range covered in Figure 2.1.
3. The PQ unit should conform to the *SU-modified* PQ9 standard (which has been provided), and integrate with other prototype units. This standard is hereby refered to as PQSU.
4. The PQ unit should remain operational for ”a few hours”.
5. The GS electronics should integrate into an existing antenna mount.

The system will undergo a *flight-readiness review* to determine if it has met the requirements before launch. To match the features of the existing, proprietary Radiosonde system [9], an additional requirement that the slant range should be no less than 250 km will be imposed. Further, although these are the minimum requirements for the Saldanha launch, choices could be made such that the communication system is even more general-purpose, and can potentially be used for low earth orbit (LEO) applications as well. In this case, the orbital height should be increased to between 160 km and 1000 km [10]. As the project progresses, if supporting such a distance will not significantly increase the time, complexity, or cost of the system, it could be catered for as an expansion to the core requirements.

2.3 Specifications

For specification definition, further calculations should be done. This will allow a list of more detailed, system-level specifications to be created. First, the required communication conditions (link distance, atmospheric effects etc.) are established. Then, power and voltage requirements are expanded on. Finally, system integration is considered.

Typicall balloon satellites reach a maximum height of around 30 km [8]. They rise at a vertical speed of around 20 km/h, and can travel horizontally as fast as 200 km/h when falling. However, a typical distance for such a balloon is 200 km, and therefore an average speed of around 100 km/h will be designed for given the average flight time of longer than 2 hours. At this height, a line-of-sight (LOS) calculator reveals that the horizon is around 600 km, meaning that the antenna could theoretically be placed on sea level. Further, the earth's curvature is found to be negligible at this distance, meaning pythagoras can be used to calculate an LOS distance of 120 km. If LEO heights are to be considered, the curvature of the earth should be taken into account. At a height of 160 km, an LOS distance of 1400 km is required, and at 1000 km, an LOS distance of around 3500 km is required. Since this is much further than the required slant range of 250 km, it will not be designed for initially. However, as mentioned, this could potentially be added as a project expansion.

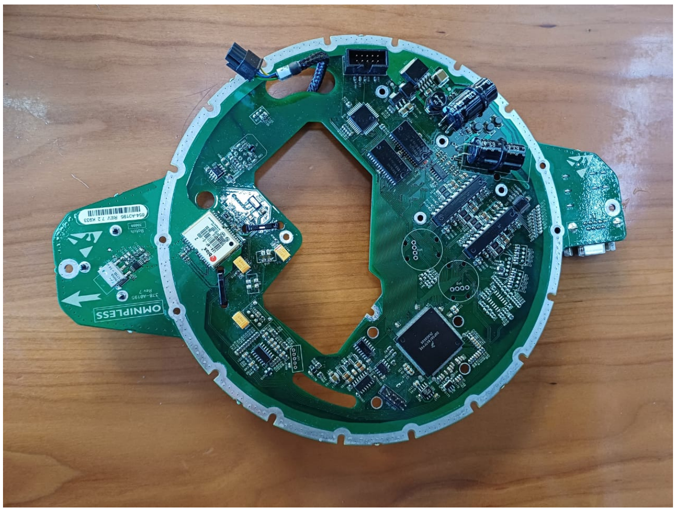

Figure 2.2: Existing Antenna Mount PCB

The PQ9 standard stipulates a 3V minimum bus voltage. This must therefore be used directly to power the PQ unit circuitry. As mentioned, the PQ unit will be integrated with other *prototype* units into a single PocketQube. Since this is a prototype launch, there is risk of the EPS malfunctioning. Further, a power connection is also needed during development for modularized testing. A simple on-board battery at least matching the standard's voltage, as well as a battery source selector, will therefore be included in the design. This can be used for testing and deployment, however this battery cell could potentially be removed if the EPS is found to meet the *flight-readiness* tests. It should be noted that high-altitude balloons generally remain air-bound for 2-3 hours, where they eventually pop.

Both designed PCBs integrate into the relevant systems. The PQ9 standard clearly defines the dimensions of such a PCB (e.g. 42 mm x 42 mm outer dimensions) and the design should conform to this. The old antenna mount made use of an existing circular PCB with mounting holes and two support ”wings”, as shown in 2.2. The new GS PCB should conform to this form factor. Lastly, the system should drive the existing stepper motors in the antenna mount.

Further investigation finally leads to the following general system-level specifications:

1. The system should be capable of a slant range of 250 km.

2. The system should be designed to operate at a data rate of 9600 baud at the specified range. This data rate is a typical satellite telemetry value as in [11].

3. The system should allow for iMet-54 Radiosonde data to be retreived, assuming that the priorietary protocol can be reverse-engineered. This data is GFSK modulated at a pre-selected frequency of between 402 to 405 MHz [12].

4. A single antenna should be used for both the custom and proprietary protocol on the GS, meaning the custom communication frequency should be as close to 405 MHz as possible (to minimize required antenna bandwidth).

5. The PQ unit should follow the PQSU standard, stipulating:

   - A 42 mm square outer PCB dimension
   - A 4 mm component height above, and 2 mm below.
   - A 20-pin header interface, catering for RS-485 and I2C communication, and providing 3.3 V and 5 V power lines.

6. The PQ unit should include a battery capable of lasting 4 hours at nominal current draw.

7. The GS should be capable of tracking the balloon at 110 km/h at a distance of 90 km away (10 % headroom).

8. The GS PCB connecting to the existing antenna mount, which has a diameter of 20 cm, with equi-spaced mounting holes, wings etc. as in Figure 2.2.

9. The GS should control two 4218S-15 bipolar stepper motors, which have a maximum current of 0.50 A per phase, each being driven at 24 V.

10. The GS should provide a USB-C connection to allow a PC to monitor the data in realtime. This should be capable of receiving all data from the link in realtime.

3. Background

3.1 PocketQube

The PocketQube standard is a fairly new set of protocols and specifications defining a modularized nano-satellite system. The term *modularized* in this context refers to the ability for different ”modules” or PocketQube units, each with their own set functionality, to be connected to a common *backplane* and integrate seamlessly. *Integration* here refers to both the mechanical spacing of each module, as well as the electronic communication between the modules.

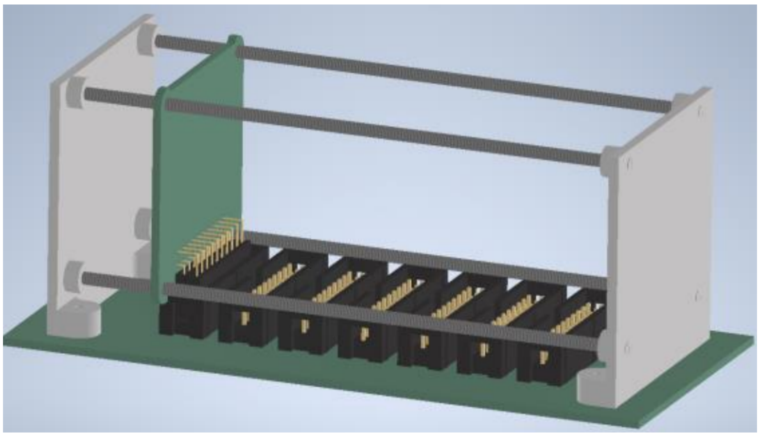

Figure 3.1: A PQSU Enclosure [1]

As an example, a PocketQube enclosure could contain three units: a communication module, a sensor pack, and a battery system. These modules can then be connected onto the backplane via headers, and placed inside a single enclosure, such as that in Figure 3.1. This ”nano-satellite” can then be ”launched” through any means.

3.2 Antennas

There are various antenna types to consider for this communication system. A highly-customized antenna design is out of the scope of this project, and therefore only common designs with tunable parameters, or existing designs in literature, will be considered. Ultimately, the following characteristics will be used to compare the various options:

- Radiation pattern (qualitative shape)
- Gain (relative to an *isotropic* source)
- Bandwidth (relative to resonant frequency)
- Beamwidth (width of *main lobe*)
- Dimensions

3.2.1 Half-Wave Dipole

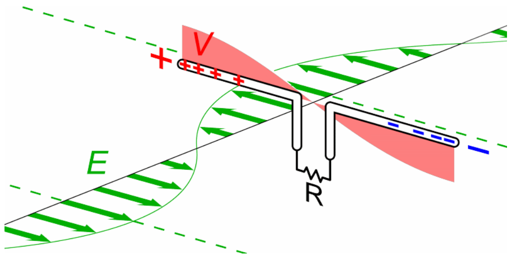

Figure 3.2: Dipole Antenna Illustration [2]

The half-wavelength (0.5λ) dipole anntenna is arguably the simplest and most common type of antenna. It consists of two conductive elements operating in opposite phase, as depicted in Figure 3.2. It is considered *omni-directional* i.e. it radiates relatively equally in all directions. Its gain is relatively low, at around 2.15 dBi [7]. Further, it does not radiate in the direction of the conductor.

3.2.2 General Dipole

Dipole antennas can, in general, be any length. However, a change in length results in a change in the antenna's characteristics. In general, smaller antennas result in lower gain and lower efficiency, but a larger beamwidth at the resonant frequency. The obvious advantage of these designs is that the size of the dipole can be decreased. However, if size is a constraint, *monopole* antennas are generally employed.

3.2.3 Quarter-Wave Monopole

The working principle of monopole antennas makes use of the electromagnetic theory of *imaging*. Essentially, if an infinite ground plane is placed below one half of a 0.5λ dipole antenna, then the electromagnetic waves react with the ground plane in a way which causes propogation similar to a half-wavelength dipole. They are extremely useful when size is a constraint, however have the disadvantage of requiring a ground plane. A *whip* antenna is a form of monopole antenna designed to be flexible so that it does not break as easily, and often placed inside a plastic enclosure, as in Figure 3.3.

Figure 3.3: Whip Antenna in Plastic Housing

3.2.4 Helical

Figure 3.4: Helical, Unidirectional Antenna

Helical antennas are coiled windings of wire, where the circumference of the coil has some direct relationship with the desired wavelength. Commonly, a circumference of $C = 1.0\lambda$ is used. Both *omni-directional* and *unidirectional* variants are possible, depending on the size of the antenna relative to the operating wavelengths. These generally arise from an antenna operating in *normal mode* or *axial mode*, respectively. Figure 3.4 depicts a unidirectional variant. These antennas have the major advantage of a small size, due to the *circumference* being more related to the wavelength as opposed to the antennas length itself. Further, they have several design parameters that can influence the antennas functionality, such as number of turns, wire width, and turn pitch angle. They also are able to receive either linear or circularly polarized signals, making them more flexible.

3.2.5 Patch

A *patch* antenna (also collequially known as a *PCB* antenna) is simply a rectangular PCB trace sized correctly to allow for radiation. Typically, a simple square or rectangular shape can be used. They allow for small profiles at the cost of efficiency [7], and can be integrated onto a PCB using normal trace techniques.

3.2.6 Array

It should be noted that multiple antennas can be combined in what is known as an *array* configuration. This allows complete manipulation of the design due to *constructive* and *destructive* interference, meaning directivity can be increased or decreased. Common variations of this concept reside in *Yagi-Uda* and *Patch Array* antennas.

3.2.7 Yagi-Uda

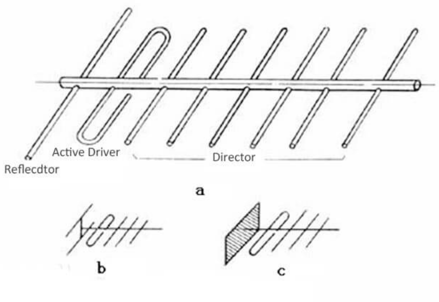

Figure 3.5: Yagi-Uda Antenna [3]

Although not strictly an antenna array, *Yagi-Uda* antennas are one of the most popular directive antennas available. A number of conductors are stacked in a specific configuration to "steer" the electromagnetic waves using interference. Only one of the conductors in the array is actually fed with a signal - the rest are merely *passive* elements used for increasing the directivity. An example of such an antenna is shown in Figure 3.5.

3.2.8 Microstrip

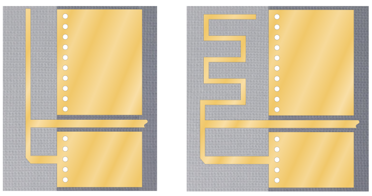

Figure 3.6: Inverted-F Patch Antennas [4]

Microstrip antennas generally refer to any planar, PCB antenna, and can be considered a generalization of a patch antenna. Many designs exist (which are often derived from non-planar antennas) and allow for a diverse selection of desired characteristics. A few examples include:

- A *patch array*, which has increased directivity.
- An *inverted-F* design, which has a small form factorer and a nearly full 3D omni-directional radiation pattern.
- A *ring antenna*, which has a uni-directional, and an even smaller form factor than the inverted-F antenna [13].
- A *helical patch* antenna, which is simply a "zig-zag" helical shape flattened onto a PCB.

Many variations on these designs exist, and the literature may be further consulted in the design phase. A multi-frequency inverted-F design is illustrated in Figure 3.6.

3.2.9 Summary

The following table presents a general summary of the investigated antennas. Note that a number of these parameters can vary due to the design (e.g. a thicker dipole results in larger bandwidth), however typical values have been chosen for an initial comparison. A thickness of 1mm has been chosen arbitrarily for dimensions which do not contribute to an antenna's form factor.

Type	**Gain (dBi)**	**Radiation**	**Bandwidth (frac.)**	**Beamwidth (°)**	**Dimensions (mm)**
0.5λ Dipole	2.15	Omnidirectional	0.1	78	1 x 1 x 172
Whip	1.76	Omnidirectional	0.1	78	1 x 1 x 86
Helical	2-10	Either	0.56	60	4.4 x 4.4 x 25
Patch	5-7	Unidirectional	0.03	65	346 x 346 x 1
Yagi-Uda	10+	Unidirectional	0.02	30-60	172 x 1 x 500+

Table 3.1: Comparison of Common Antennas and their Typical Characteristics [7]

3.3 Satellite Tracking

There are various tracking methodologies used to track balloon satellites in order to maintain a wireless communication link from the ground. Ultimately, all of these methods provide a single output to a ground station system: the direction in which to ”steer” its antenna mount. Each method is compared and expanded on below.

3.3.1 Open-Loop

The simplest method to track a balloon satellite is using simple ”open-loop” control. In this method, information about the flight path of the balloon is fed into the system, and the ground station is simply pointed in that direction, with the ”hopes” of maintaining a connection. This information can simply be a pre-calculated, predicted path of travel, or a continuously re-estimated path based on continous weather data. *HABHug.org* is an organisation with a high-altitude path predictor [14].

An advantage of this method is its extreme simplicity in implementation. It has several disadvantages, however, including being vulnerable to prediction inaccuracies, as well as the difficulty experienced in re-acquiring the communication link once it is lost. Further, the ground station generally still a requires GPS receiver and IMU, however this could theoretically be excluded if it is to be placed in a fixed position.

3.3.2 GPS Relay

This method makes use of GPS location information to close the tracking loop. The weather balloon payload should carry a GPS receiver and a radio transmitter. The tracking functions in a four-step process, explained below and depicted in Figure 3.7:

1. The precise position of the payload and the ground station is determined using data received from GPS satellites.
2. The position is *relayed* to an external network (satellite or ground -based) using a radio transmitter.
3. The ground station receives the location from the external network (e.g. via the internet).
4. The ground station calculates the direction to point based on its own GPS location, and the GPS location of the payload.

The major disadvantage of this method is the additional PocketQube hardware required. Not only does it need an antenna capable of communicating with one of the external networks, but it requires a GPS receiver, and a ground-station system if realtime data collection is needed. This type of tracking works well if the satellite is physically close to the external network satellites, or if the ground station does not need to communicate in realtime, but merely needs access to location of the satellite (e.g. in a homemade cellphone balloon satellite

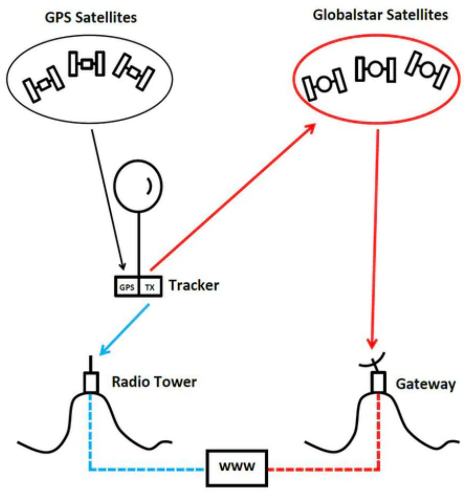

Figure 3.7: GPS Relay Tracking [5]

launch). A further disadvantage of this method is the need for a paid subscription to access the external network.

3.3.3 Radio

Radio tracking can be done when the satellite itself transmits radio waves. Techniques which provide simple direction pointing make use of the electromagnetic signal strength to point the ground station correctly. To initially find the satellite, the entire sky can be scanned or an initial guess can be provided. From there, periodic *radius scanning* can be used to track the signal within a certain portion of the sky, or more advanced techniques such as *conical scanning* can be used.

3.4 PCB Design

Printed circuit board (PCB) design is considered a skill and art in and of itself. Since this project will require basic PCB design techniques related to simple circuits, as well as potentially RF circuits (depending on decisions made in the design process), an initial review of literature and techniques should be done. An overview of the most relevant, core concepts is presented below.

3.4.1 Layers

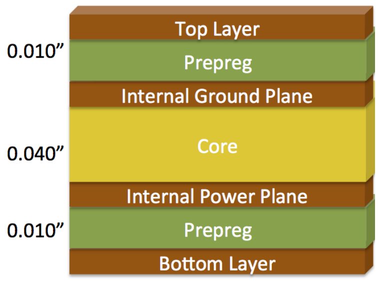

Figure 3.8: Common 4 Layer PCB Stackup [6]

A PCB is made up of multiple layers. 2-layer and 4-layer PCBs are considered the most common. For a 2-layer board, there are two layers of copper on both the top and bottom of the board. For 4-layer boards, 2 extra copper layers lie in between the outer layers and are therefore not exposed to air. These inner layers are general used for *ground planes* or *power planes*. The purpose of each layer and how they are distributed is called the PCB *stackup*. Figure 3.8 shows a common 4-layer PCB stackup. [15]

3.4.2 Traces

The traces connect various components on the different layers. They are created by removing the copper which surround them, resulting in a single conducting path. For digital design, generally only the thickness of the trace is important, and is determine by the current handling requirements of that signal. For radio frequency *RF* design, the type of material in between traces, distance between traces, thickness of the trace etc. should all be taken into account. This is due to the fact that they influence the *characteristic impedance* of the resulting *transmission lines*.

3.4.3 Vias

Vias are holes on boards that (generally) pass a signal from one layer to another. They allow for a circuit's components to be distributed across layers, therefore providing flexibile in laying traces. *Untented* (uncovered) vias can be soldered to for e.g. *through-hole* components, whereas *tented* vias are used to prevent the via from being soldered to [16]. *Stiching vias* are a large number of vias placed in a spaced-out pattern, which result in a stronger connection, allow for better thermal management, and reduce crosstalk and EMI [17].

3.4.4 Copper Pours

Copper pours are large areas of copper on a PCB. They are typically used for large exposed ground planes and power planes where power distribution or electrical shielding is necessary.

3.4.5 RF Design

The design of PCB circuits involving higher frequencies is significantly more complex. Not only is the layout of components more critical, but the length of traces, the placement of ground planes, and many complex considerations need to be made. Some of this process can be significantly simplified by making use of RF *modules*. These are typically isolated components with an RF *shield* providing a single functionality.

The following list encompasses a short summary of some considerations that *may* be applicable in this project. It should be noted that many of these points are *only* applicable if RF traces and RF ICs are designed directly (as opposed to using an RF module). This is known as a ”chip-down” design. The trade-off of using such modules will be made in the design phase.

- Ensure proper grounding with thick enough traces and V_{cc} bypas capacitors near RF integrated circuits. If the ground is not on the same layer as the IC, multiple vias should be used [18].
- If a high-frequency signal is to be routed on a trace, its characteristic impedance should either be *controlled* or *matched* appropriately. In other words, if two $50\,\Omega$ RF pins on two different ICs are to be connected together, either the trace itself should have a $50\,\Omega$ impedance, or impedance matching should be done so that the transition between characteristic impedances does not cause reflections. [18]
- Take care of *crosstalk* and electromagnetic *isolation*. Use *RF filters*, *RF shields* and *stitching vias* to minimize these effects.
- Keep RF lines as far as possible from each other, and route high-speed digital signals on a different layer from the RF lines entirely. Layers should be dedicated to a continuous ground plane and power plane - typically layers 2 and 3 for a 4-layer board, as shown in Figure 3.8. [19]
- Apply curved bending or *mitering* when transmission lines are required to change direction abruptly. [19]

4. System Design

4.1 Overview

This chapter encompasses the system-level design. The approach is to make design choices that allow for modularity with regards to component integration and testing. The specific details of the circuit design and interconnects will be not be discussed, however initial high-level design choices will be made. This include decisions for the overall system, the PocketQube unit, and the ground station unit.

4.2 High-Level System

There are various decisions to be made regarding the entire communication system. A complete high-level system block diagram illustrating the decisions discussed below is shown in Figure 4.1. Note that the yellow blocks are external (i.e. already-provided systems).

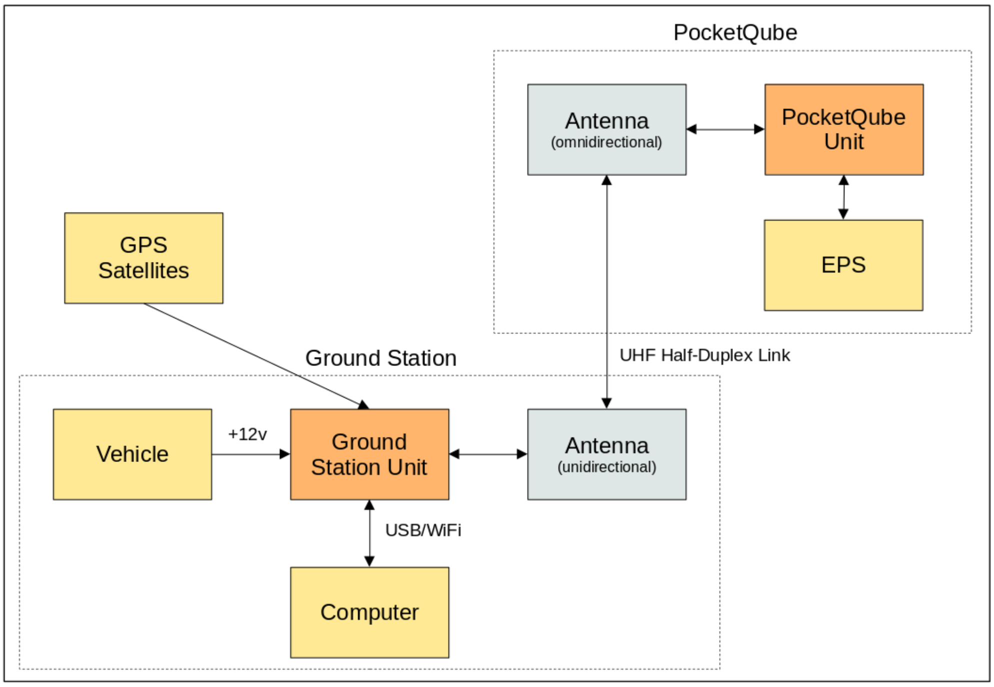

Figure 4.1: Complete High-Level Diagram of Communication System

Firstly, since this project is consists (to a large degree) of system-level design, components integrated into modules (e.g. an ”RF module”) will be used as much as possible to simplify the integration. Only if no modules are found to meet the system requirements, should a more custom solution be developed.

It is know that open-loop path-predicted tracking is adequate for high-altitude balloons. In this sense, the ground station requires at least a GPS connection, as well as some form of intertial measurement unit (IMU) for beem steering. The path data will be uploaded to the ground station via USB or WiFi and an external device, such as a laptop, personal computer or smartphone (referred to as the system’s *computer* onwards). Further, this computer will be used to monitor the link and record the data.

The requirement to communicate with the existing Radiosonde should be considered. According to the iMet54’s datasheet [12], it operates at a centre frequency of between 402 and 405 MHz, selected in 1 MHz increments. Ideally, for a simpler design, one antenna should be designed on the GS supporting both the custom and proprietary communication communication protocols.

If very long-range communication is to be supported, a highly-directive antenna will most likely be needed and, as mentioned in Section 3.2, these antennas are usually large in size. Although the possibility of a high-gain design in the 400 MHz band will be investigated, it is probable that this may be limited by the size and weight constraints of the existing antenna mount. Further, for longer-range communication, it is desirable to utilize radio signal-strength tracking on the ground station, as well as to add a GPS to the PocketQube unit itself. Given the above considerations, it was decided for the detailed design to follow a phased approach:

- **Phase 1:** The design of a single ground station antenna in the 400 MHz band, allowing for close-range testing of both the custom and proprietary protocols. Only open-loop tracking will be implemented.
- **Phase 2:** The addition of a physically smaller, high-gain 868 MHz band antenna for long-range custom protocol communication. Signal-strength tracking, as well as GPS on the satellite, may be added.

In this way, close-range system requirements are met in Phase 1, and longer range support can be added in Phase 2, if time allows. This phased-approach is also made possible due to the choice to use modular components, easily allowing e.g. a 400 MHz module to be swapped for an 868 MHz module with minimal re-design.

Half-duplex communication will be designed for, since full-duplex is unnecessary for this type of link. This is due to the nature of the link itself i.e. the command-response pattern used when receiving data from satellites. It is also decided that the ground station will be powered via +12V from a nearby vehicle, and the PocketQube will be powered from an on-board EPS (another PQ unit). Finally, both sub-systems will be designed such that testing without a vehicle/EPS is also possible.

5. Detailed Design

5.1 Components

The first step in the detailed design process is to select components for the various sub-systems. Components for both the ground station and PQ unit will be selected in one step, as there is little reason to separate the two process.

5.1.1 GPS

5.2 PocketQube Unit

Since the components have been selected, the design of the PQ unit PCB can be done. This unit includes the microcontroller, integration with the PQ9 9-pin bus, a simple power module, and the control of the GPS and RF modules.

The power consumptions of the various on-board components are found in Table 5.1 below.

Component	**State**	**Current**
ATmega328	Active	0.2 mA
RA-02	TX	93 mA
	RX	12.15 mA
	Idle	1.5 mA

Table 5.1: Current Consumption of PQ Unit Components

This results in a maximum current level of around 100 mA, although will typically be less since TX will not be continuously occuring. (e.g. around 40-50 mA). The Panasonic CR2450 is a 3 V, 620 mAh coin cell which, even at maximum current, will allow the system to last 5 hours. This meets the specification and will therefore be used.

The bus requires one unit of the PocketQube to control the reset line. This will need to be included in the RF unit so that the entire PQ can be reset via a tele-command. This, however, introduces complications in that the PQ9 specification requires the reset line to be driven for at least 20 ms, whereas the ATmega328 will reset after a 2.5 µs pulse. A

5.3 Link Budget

For any communication system, a link-level design or *link budget* should be conducted. The goal of this step is to determine the power requirements of the commuication system, taking into account transmitter power, antenna characteristics, receiver sensitivity, and any attenuation involved.

Given the travel path in Figure 2.1, and a height of 30 km, the minimum and maximum elevation angles are around 15 and 17 degrees respectively.

Transmitter Power +18 dBm (RA-02)

GS Gain +1.2 dBi

Satellite Gain +1.2 dBi + G (if directive antenna is used)

Receiver Sensitivity Target of around 9600 bps: +118 dBm (LoRa, SF 6, 125 kHz, CR2, 7812 bps) +120 dBm (LoRa, SF 7, 250 kHz, CR2, 9115 bps) +119 dBm (LoRa, SF 8, 500 kHz, CR2, 10417 bps) Target of maximum sensitivity: +139 dBm (LoRa, SF 12, 62.5 kHz, CR1, 146 bps) +147 dBm (LoRa, SF 12, 62.5 kHz, CR1, 24 bps) Target of maximum speed: +116 dBm (LoRa, SF 7, 500 kHz, CR2, 18230 bps) (high) +111 dBm (LoRa, SF 6, 500 kHz, CR2, 37500 bps) (very high) +109 dBm (GFSK 40 kHz, 38400 bps) (very high) +108 dBm (OOK, 32000 bps) (very high)

Free space loss -133 dB (250 km) -153 dB (2500 km)

Polarization mismatch -3 dB

Helical parameters Disc diameter = 762 N Gain (dBi) Length (mm) 3 10.55 520 4 11.80 693 5 12.77 866 8 14.81 1385 10 15.78 1732 15 17.54 2598

Budgets Range Speed Budget Close Medium 18dBm + 1.2dBi + 1.2dBi + 119dBm - 133dB - 3dB = +3.4dB margin Close High 18dBm + 1.2dBi + 1.2dBi + 116dBm - 133dB - 3dB = +0.4dB margin Close Very high 18dBm + 1.2dBi + 1.2dBi + 108dBm - 133dB - 3dB = -7.6dB short Far Low 18dBm + 1.2dBi + 1.2dBi + 139dBm - 153dB - 3dB = +3.4dB margin Far Medium 18dBm + 1.2dBi + 1.2dBi + 119dBm - 153dB - 3dB = -16.6dB short Far High 18dBm + 1.2dBi + 1.2dBi + 116dBm - 153dB - 3dB = -19.6dB short Far Very high 18dBm + 1.2dBi + 1.2dBi + 108dBm - 153dB - 3dB = -27.6dB short

Therefore: - A simple half-wave dipole will work for close-range medium-speed LoRa, and far-range high-speed LoRa - Around 10 dBi antenna gain is needed for high-speed close-range applications (leaving 2.4 dB margin) - Around 20 dBi antenna gain is needed for medium-speed far-range applications (leaving 2.4 dB margin)

5.4 Ground Station Antenna

5.4.1 Mechanical Integration

The existing antennna mount is shown in Figure 5.1. Azimuthal and elevation stepper motors are connected directly through Gear A and B respectively. Gear A rotates the centre shaft to provide azimuthal steering, whereas Gear B rotates through Gear D and E to allow a change in elevation (pointing angle).

The black plastic platform is triangular and has three mounting holes. The new ground station's antenna should therefore be mounted onto this platform. It is important to consider the forces/torques involved, as well as the stepper motor holding torques, in order to determine the maximum weight and acceptable form factor of the new antenna.

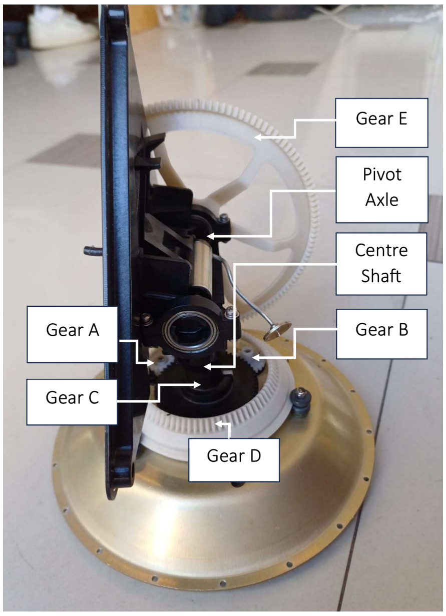

Figure 5.1: The existing Antenna mount

The azimuthal motor need not be considered, as all torques from the mount to its base are perpendicular to the central shaft. The holding torque of the elevation motor, however, will constraint the antenna design. The holding torque of each motor is 0.25 Nm. The gearing ratio resulting from Gear B having 20 teeth, Gear D having 80 teeth, and finally Gear E having an equivalent of 140 teeth, results in a 7x torque increase. This provides a holding torque of around 1.75 Nm at the pivot axle.

The centre of gravity of the antenna, as well as its weight, will affect the motor's ability to hold it in place. The horizontal distance between the pivot axle and the mount in the upright position is measured to be 40mm. Therefore, in the worst-case (when the mount is upright as in Figure 5.1) a planar antenna could weigh up to $\frac{1.75}{(9.8\times0.04)} = 4.46\,\text{kg}$. In general, the *mass-distance* factor of the antenna (mass times distance of centre of gravity from mount) should not be more than 0.18 kg.m, which will be more limiting for protruding antennas.

6. Conclusion

The conclusion

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A. Appendix A

Week 01 (24/07 to 30/07): Problem formulation; requirements gathering Week 02 (31/07 to 06/08): Initial research; component selection Week 03 (07/08 to 13/08): System-level design; initial system layout; components ordered Week 04 (14/08 to 20/08): PCB design without traces; initial circuit design Week 05 (21/08 to 27/08): Component prototyping; Full PCB design; initial antenna design; Week 06 (28/08 to 03/09): Mechanical design; Custom protocol investigation; PCB ordered Week 07 (04/09 to 10/09): (Test week) Week 08 (11/09 to 17/09): Initial build Week 09 (18/09 to 24/09): Software design; initial testing Week 10 (25/09 to 01/10): Software design; debugging Week 11 (02/10 to 08/10): Reporting Week 12 (09/10 to 15/10): Design improvement Week 13 (16/10 to 22/10): Testing Week 14 (23/10 to 29/10): Reporting Week 15 (30/10 to 05/11):