2224559

by Mohammed Ibrahim

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Table of Contents

List of Figures 4
List of Tables 7
Introduction and Background Research 8
Component Research: 9
Specification and Project Aims 15
Planning 17
Solutions Considered 19
Solution 1: 19
Solution 2: 20
Comparison Table: 21
Choosing Solution: 21
Final Solution and Implementation 22
Detailed Specification: 22
Functional Specification Block Diagram 23
Parts List 24
Component wiring 25
Assembly 27
Software Configuration 28
Analysis of Test Results 30
Test 1 30
Test 2 30
Test 3 30
Test 4 30
Test 5 31
Test 6 31

Test 7 32
Discussion, Conclusions and Recommendations 33
Citation List 35
Appendices 37
Appendix A - Final Solution and Implementation 37
Component drawings 37
Transmitter Inputs 39
Assembly 40
Appendix B – Testing and Results 59
Test 1 – Wiring Check 59
Test 2 Part 1 – Input Channel Mapping: 63
Test 2 Part 2 – Switch Outputs 79
Test 3 Part 1 - Motor Mapping and Direction Check 84
Test 3 Part 2 – Failsafe Check 89
Test 4 Part 1 – VTX Output Power Check: 91
Test 4 Part 2 – VTX Channel Accuracy 92
Test 5 Part 1 – Initial PID and Flight Characteristics 98
Test 5 Part 2 – Current Draw: 100
Test 6 – Harmonic Analysis: 101
Test 7 - Final PID Test and Flight Characteristics After Tuning and Applying Filters: 105
Test 7 Part 1 – Final PID Test 106
Test 7 Part 2 – Final Harmonic Analysis: 109

Good detailed table of contents

List of Figures

Figure 1 - Transmitter Input Commands (GetFPV, 2018) 9
Figure 2 - Radio Receiver (GetFPV, 2018) 9
Figure 3 - Flight Controller Types (Liang, 2023a) 10
Figure 4 - Individual ESC (Nagel, 2022) and Brushless Motor 11
Figure 5 - 4s and 6s Battery (Liang, 2023b) 12
Figure 6 - FPV Camera, Video Transmitter/Receiver and Goggles (electronicsforu, 2018) 13
Figure 7 - Built Frame with Propellers Demonstration 14
Figure 8 - Closed Loop Diagram 15
Figure 9 - Project Gantt Chart 17
Figure 10 - 4 in 1 ESC (Nagel, 2022) 19
Figure 11 – 4 Single ESCs with PDB (iFlight Innovation Technology Ltd, 2024) 20
Figure 12 - Control and Video Transmission Block Diagram 23
Figure 13 - UNMANNEDTECH Requisition Form 24
Figure 14 - YOURFPV Requisition Form 24
Figure 15 - Completed Gantt Chart 33
Figure 16 - Flight Controller Wiring Diagram (DIATONE OFFICIAL, 2023) 37
Figure 17 – Speed Controller Wiring Diagram (DIATONE OFFICIAL, 2023) 38
Figure 18 - VTX/RX Wiring Diagram (TEAMBLACKSHEEP, 2023) 38
Figure 19 - Transmitter Inputs 39
Figure 20 – Assembly Step 1 40
Figure 21 – Assembly Step 2 41
Figure 22 – Assembly Step 3 42
Figure 23 – Assembly Step 4 43
Figure 24 - Assembly Step 5 44
Figure 25 - Assembly Step 6 45
Figure 26 - Assembly Step 7 46
Figure 27 - Assembly Step 8 47
Figure 28 - USB - C Connection to Laptop 48
Figure 29 - Configuration Step 1 49
Figure 30 - Configuration Step 2 49
Figure 31 - Configuration Step 3 50
Figure 32 - Configuration Step 4 50

Figure 33 - Configuration Step 5 51
Figure 34 - Configuration Step 6 51
Figure 35 - Configuration Step 7 52
Figure 36 - Configuration Step 8 52
Figure 37 - Configuration Step 9 53
Figure 38 – Configuration Step 10 54
Figure 39 - Configuration Step 11 55
Figure 40 - Configuration Step 12 ESC 1 56
Figure 41 - Configuration Step 12 ESC 4 57
Figure 42 - Configuration Step 13 Bound 58
Figure 43 - Configuration Step 13 Unbound 58
Figure 44 - Battery Terminals (+&-) Continuity Check 59
Figure 45 - Battery (-) to VTX UFL Connector 60
Figure 46 - Motor 2 Phase Balance Test 61
Figure 47 - Motor 1 Ground Check (Phase One to Motor Screw) 62
Figure 48 - Gimbal Calibration 63
Figure 49 - Gimbals Centred 64
Figure 50 - Channel 1 (Throttle) Minimum Value 67
Figure 51 - Channel 1 (Throttle) Maximum Value 68
Figure 52 - Channel 2 (Roll) Minimum Value 69
Figure 53 - Channel 2 (Roll) Maximum Value 70
Figure 54 - Channel 3 (Pitch) Minimum Value 71
Figure 55 - Channel 3 (Pitch) Maximum Value 72
Figure 56 - Channel 4 (Yaw) Minimum Value 73
Figure 57 - Channel 4 (Yaw) Maximum Value 74
Figure 58 - Channel 5 (AUX1) Switch Made 75
Figure 59 - Channel 6 (AUX2) Switch Made 76
Figure 60 - Channel 8 (AUX4) Switch Middle Position 77
Figure 61 - Channel 8 (AUX4) Switch Last Position 78
Figure 62 Test A- AUX1 Arm Switch Made (Motors Not Armed) 80
Figure 63 Test A - AUX2 Pre-Arm Switch Made (Motors Not Armed) 81
Figure 64 Test A - AUX1 (Arm) & AUX2 (Pre-Arm) Switches Made (Motors Armed at 10% idle) 82

Figure 65 Test B - AUX4 3 Position Switch Made to 3rd Position and ‘Flip After Crash Mode' Selected in OSD 83
Figure 66 - Motor 1 Selected....85
Figure 67 - Motor 2 Selected....86
Figure 68 - Motor 3 Selected....87
Figure 69 - Motor 4 Selected....88
Figure 70 - Motors Armed 89
Figure 71 - Motors Disarmed After Radio Turned Off 90
Figure 72 - VTX Transmitting at 25mW Output Power....91
Figure 73 - Channel Selection Menu 93
Figure 74 - Race Channel 1 94
Figure 75 - Race Channel 2 94
Figure 76 - Race Channel 3 95
Figure 77 - Race Channel 4 95
Figure 78 - Race Channel 5 96
Figure 79 - Race Channel 6 96
Figure 80 - Race Channel 7 97
Figure 81 - Race Channel 8 97
Figure 82 - Roll Axis Initial PID Performance....99
Figure 83 - Pitch Axis Initial PID Performance 99
Figure 84 - Yaw Axis Initial PID Performance....100
Figure 85 - Current Draw Approx. 30A Average 100
Figure 86 - Gyro [Roll] Frequency Spectrum 102
Figure 87 - Gyro [Roll] Frequency vs Throttle Spectrum....102
Figure 88 - Gyro [Pitch] Frequency Spectrum 103
Figure 89 - Gyro [Pitch] Frequency vs Throttle Spectrum 103
Figure 90 - Gyro [Yaw] Frequency Spectrum 104
Figure 91 - Gyro [Yaw] Frequency vs Throttle Spectrum 104
Figure 92 - Optimal PID Tune 105
Figure 93 - Stock PID Tune....105
Figure 94 - Applied RPM and Dynamic Notch Filter 105
Figure 95 - Gyro [roll] Final PID Tune....107
Figure 96 - Gyro [pitch] Final PID Tune....107
Figure 97 - Gyro [yaw] Final PID Tune 108

Figure 98 - Gyro [roll] Frequency Spectrum After Filtering.....110
Figure 99 - Gyro [roll] Frequency vs Throttle Spectrum After Filtering 110
Figure 100 - Gyro [pitch] Frequency Spectrum After Filtering.....111
Figure 101 - Gyro [pitch] Frequency vs Throttle Spectrum After Filtering 111
Figure 102 - Gyro [yaw] Frequency Spectrum After Filtering 112
Figure 103 - Gyro [yaw] Frequency vs Throttle Spectrum After Filtering.....112

Good extensive list of figures

List of Tables

Table 1 - Project Outcome Table.....16
Table 2 - Project Test Plan.....18
Table 3 - Solution Comparison Table 21
Table 4 - Electrical Hardware Requirements 22
Table 5 - Software Requirements.....22
Table 6 - Component Voltage, Terminal Locations and Identification Table 25
Table 7 – Gimbal (Analogue) Inputs.....25
Table 8 – Switch (Digital) Inputs.....26
Table 9 - Continuity Check.....59
Table 10 - Ground Check.....60
Table 11 - Motor Balance Test 61
Table 12 - Motor Ground Check.....62
Table 13 - Input Channel Mapping Checks 65
Table 14 - Switch Outputs Test 79
Table 15 - Motor Mapping and Direction Check 84
Table 16 - Failsafe Check 89
Table 17 - VTX Channel Accuracy 92
Table 18 - Initial PID and Flight Characteristics.....98
Table 19 - Harmonic Analysis 101
Table 20 - Final PID Test 106
Table 21 - Final Harmonic Analysis.....109

Good use of tables

Introduction and Background Research

A drone is an unmanned aircraft, also known as UAVs (Unmanned Aerial Vehicle) which can fly autonomously or be manually controlled using embedded systems. They generally work with onboard sensors to maintain flight. They are used in various different industries, such as firefighting, videography, delivery services, weather monitoring and agriculture. Two types of drones exist. Multirotor, such as quadcopters, and fixed wing. (TechTarget, 2023). *Correct citation*

The drone racing industry is currently a growing industry where pilots have the opportunity to compete in leagues. It turns flying drones in to a sport (Dean, 2021). The UK has a governing body called the BMFA (British Model Flying Association) for model flying. The BDRA (British Drone Racing Association) is a recognised body by the BMFA and is run by FPV (First Person View) pilots. They support clubs around the UK in organising racing events and have set rules (BDRA, unknown)*Correct citation*

Good background

Component Research:

To understand how a drone works, the components and software need to be understood. The components are as follows:

Radio Transmitter (TX) and Receiver (RX) – Radio transmitters (figure 1) use radio signals (typically at 2.4GHz) to transmit input commands wirelessly to a receiver (figure 2) which is connected to the drone. The receiver sends these commands to the flight controller board which will be talked about later. A typical radio transmitter has 8 inputs. 4 of these are throttle, pitch, yaw and roll and the rest are for switches (GetFPV, 2018). These drone commands are applied with hall sensors, which captures stick position values. See below:



Figure 1 - Transmitter Input Commands (GetFPV, 2018)



Figure 2 - Radio Receiver (GetFPV, 2018)

Flight Controller (FC)– This is the most important component when it comes to building an FPV drone. It is the brain of the drone. It receives the inputs from the receiver using UART communication. It uses a processor chip to run the software required for assigning inputs and outputs, measures data, controls motor speed and receives position feedback from the built-in gyro. They typically run open-source software called Betaflight, which allows the user to flash the flight controller with the correct firmware and apply their configuration where they can set the receiver protocol, assign inputs and outputs, adjust PID gains and filters in order to obtain a good tune. Below shows the types of flight controllers that are on the market (Liang, 2023a):

Good explanation with corect citation

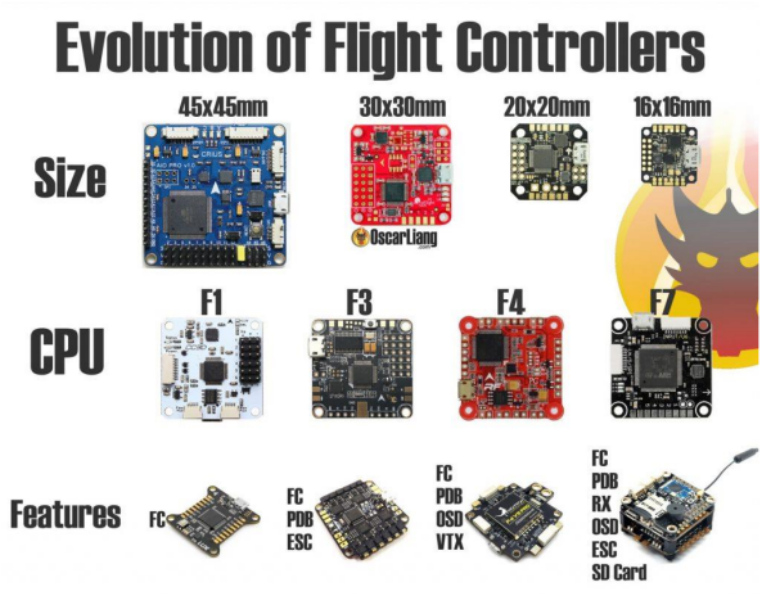


Figure 3 - Flight Controller Types (Liang, 2023a)

Electronic Speed Controller (ESC) and 3 Phase motors – ESCs take input signals from the flight controller and apply them to control motor speed. A gate driver is used to receive a low voltage signal from the microcontroller in the ESC and amplifies it. This is then sent to the MOSFETs. A single ESC has 6 of these connected to the 3-phase motor and they switch at a certain frequency depending on the throttle input, to mimic AC voltage required for a 3-phase motor. The micro controller uses back EMF provided from the motor in order to determine the position of the motor in relation to the stator. This is ideal for high-speed purposes. These are also software controlled, typically using BLHeli_32 in which various parameters can be altered (Nagel, 2022). Below shows an individual ESC and a typical brushless motor:

Good explanation with good technical content



Figure 4 - Individual ESC (Nagel, 2022) and Brushless Motor

Battery – lithium polymer (LiPo) batteries are known form their excellent power to weight ratio. Their chemistry also allows for high discharge, which provides the most power when it comes to a racing drone. They consist of individual cells, typically 4 (14.8V) and 6 (22.2V). This is an important factor to consider when it comes to purchasing an FC and ESC, as the number of cells, will increase the voltage being provided to the motors, and the ESC and motors need to be able to handle the amount of current being drawn. The FC uses a BEC to step down the voltage to provide the receiver, camera and video transmitter with power (Liang, 2023b).

Good explanation



Good supporting image

Figure 5 - 4s and 6s Battery (Liang, 2023b)

Analogue Video System – this type of video system is required when it comes to building a racing drone. It works with a camera, which captures light and sends this data to the video transmitter (typically at 5.8GHz) in which the antenna sends the waveform to video receiver on the goggles. This is then converted to an image which is displayed on the goggles, which the pilot can see in real time (electronicsforu, 2018).



Figure 6 - FPV Camera, Video Transmitter/Receiver and Goggles (electronicsforu, 2018)

Frame and propellers – A suitable frame will be used to house all of the components researched. It will be made from carbon fibre, as it is light, stiff, and less prone to resonance, compared to a plastic frame. Plastic propellers will be used and must be compatible with the size of the frame.

Frame resonance occurs when the natural frequency of the frame is excited. This is caused with motor and propeller vibrations and can cause damage to the frame (Kanevsky, 2022). Below shows a fully built frame with propellers:



Figure 7 - Built Frame with Propellers Demonstration

Specification and Project Aims

The specification for this drone is aimed to fulfil a racing specification. This includes the following:

- 25mW output power video transmitter (VTX) in the 5.8GHz range to ensure multiple pilots can fly at the same time without interference.
- Use 20x20 mounting for the Electronic Speed Controller (ESC) and Flight Controller (FC). This allows components to be mounted on a lightweight carbon fibre frame.
- Use 3-phase brushless motors. These motors are highly efficient when compared to brushed motors and last longer due to not having brushes that wear out over time.
- Must be a fast closed loop system involving PID with betaflight and BLHelli_32 software, which requires a near perfect tune due to constantly alternating motor speeds.
- High discharge batteries must be used to provide adequate current required for the motors.
- Use wireless data transmission at 2.4GHz via a transmitter, which the pilot registers their inputs.

See closed loop system below which demonstrates how it operates:

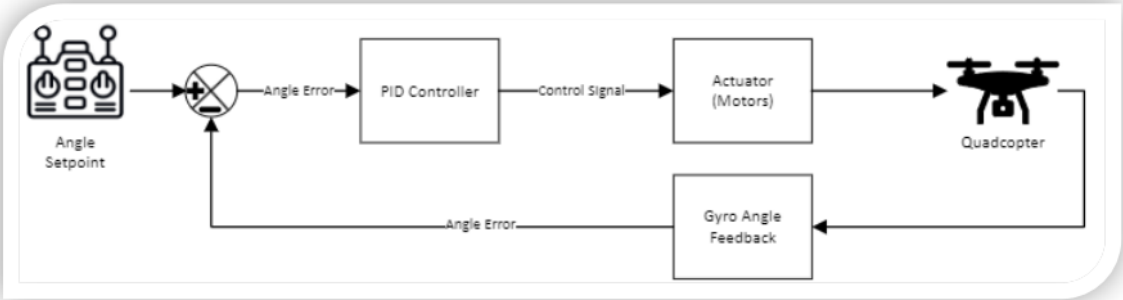


Figure 8 - Closed Loop Diagram

Good work

The project outcomes and sustainability were also considered in the following table and will be evaluated at the end of the project:

Table 1 - Project Outcome Table

Outcomes	
Location	This project will be based on in ColegSirGar graig campus and will be developed in place of residence.
Budget	The budget for this project is £1000
Health and Safety	A failsafe method must be implented to ensure safety of everyone in the operation area and motor testing must be done with propellers off to avoid injury.
Sustainability and Environmental Impact	Using reliable electrical components means they last longer and have impact on the environment. Such as using 3-phase brushless motors, as they are efficient last longer than DC motors. Batteries also have a big impact on the environment. 6 cell batteries will be chosen instead of 4 cell due to the fact they are less impacted on current draw due to having more cells. Hence, they last much longer.
User Requirements	A fast and responsive drone is required for the user, which means it must have a near perfect tune and do what the pilot asks it to do.
Timescale	A Gantt chart was created to ensure the project is completed in a certain timescale. See planning section of report.

Good use of table to identify outcomes

Planning

A Gantt chart was used to keep track of project progression and deadlines. Research of components required will be completed, a proposal and presentation will be done and one out of two solutions of ESCs will be chosen. The components will then be ordered and then built. The software will be configured, and the drone undergo a series of tests (see table 2, pg 18.). A comparison of when the tasks will be completed versus actual completion will be evaluated at the end of the project. The project will also be evaluated to see if it met the specifications. See below:

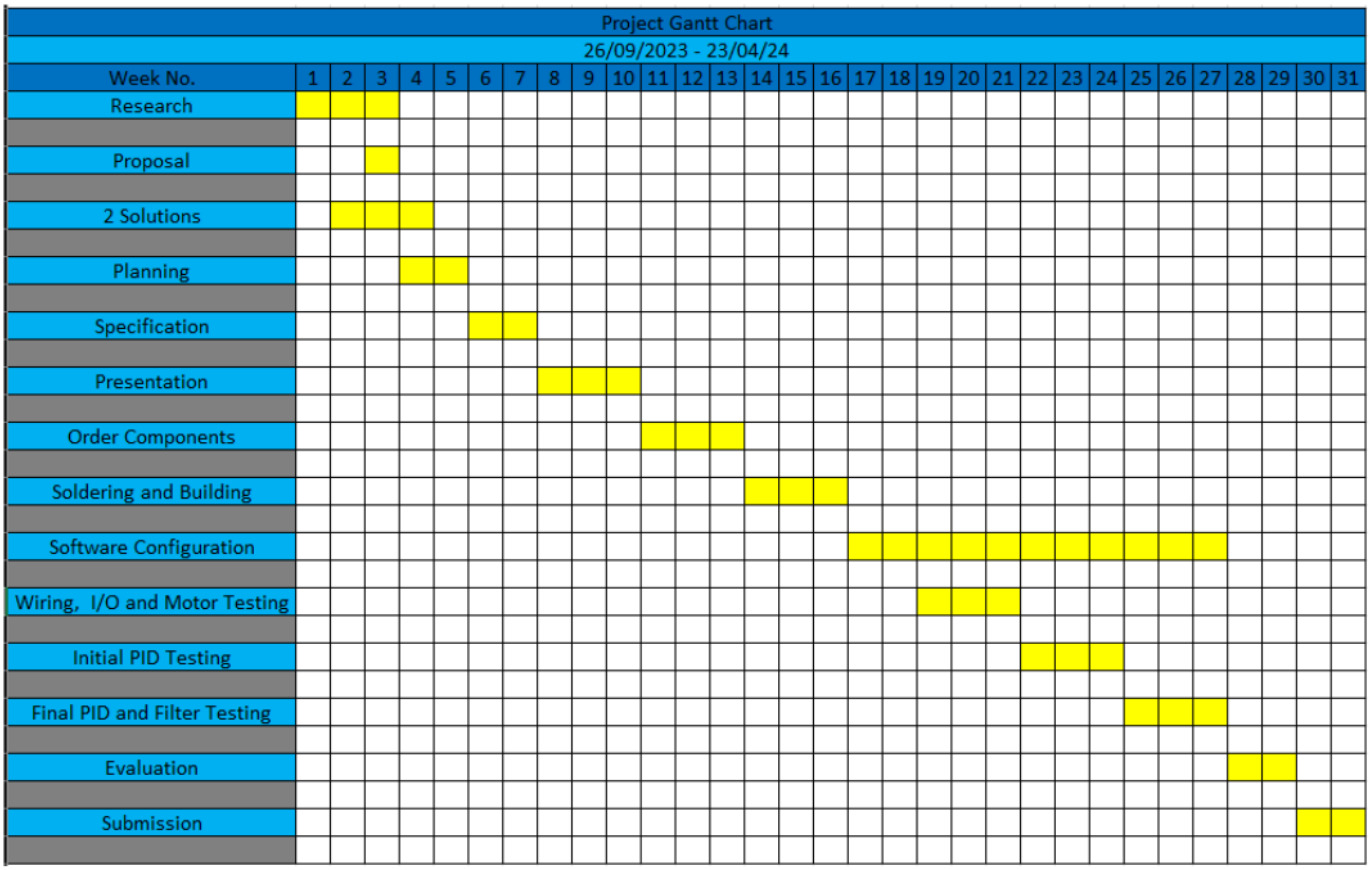


Figure 9 - Project Gantt Chart

Good detailed Gantt chart

Table 2 - Project Test Plan

Test	Brief Test Description
1. Wiring Check	Ensure that wiring is tested once all electronic components are soldered to ensure there aren't any solder splashes shorting out connections.
2. Input Channel Mapping	Inputs being sent from the transmitter to the receiver to be tested to ensure each input is mapped correctly with the correct range. The outputs of the switches should match what the drone is intended to do.
3. Motor Mapping, Motor Direction and Failsafe	Ensure the motors are rotating in the correct direction as per betaflight software requirements. A failsafe test is to also be conducted to ensure the motors stop rotating if the receiver has lost connection to the radio transmitter.
4. Video Transmission Output Power and 5.8GHz Channel Accuracy	The video output power should tested to be at 25mW to ensure live video will not bleed into other pilots' video receivers during a race also with the correct frequency.
5. Initial PID, Flight Characteristics and Current Draw Monitoring	Oscillations on all 3 axes of rotation should be tested to ensure each of their closed loop configurations are working correctly, with any parameter and filter adjustments to be made. The current being drawn from the battery should be monitored to ensure it doesn't exceed the ESC rating capacity.
6. Harmonic Analysis	Observe the types of harmonics produced from the same blackbox data as above.
7. Final PID Test and Flight Characteristics After Tuning and Applying Filters	The same test as number 5 but with applied filters and PID tuning parameters adjusted.

Good informative test plan

Solutions Considered

Solution 1:

The first solution to consider is using 4 in 1 Electronic Speed Controllers to control the motors. This means using a single board to control all 4 motors. The advantages of using a 4 in 1 board means that there is significantly less wiring, due to 4 ESCs being integrated into one board, which also makes it lighter. 4 in 1 ESCs are also the most feasible when it comes to manufacturing. A lot of manufacturers produce more 4 in 1 ESCs and provide adequate support, such as DSHOT communication, which is a digital protocol that is used to send throttle values to the motors instead of PWM and is significantly faster and more reliable. It also supports RPM filtering. This filters out harmonics proportional to motor speed being seen by the gyro and will result in less oscillations, hence better flight stability. The disadvantage of using 4 in 1 ESCs however, is if that one fails, the whole board requires replacement even if the other ESCs still work, which then means it will cost more to replace the whole board. They can be subject to fail under extremely heavy load or vibrations, which can burn out the MOSFETs. Another disadvantage is if one ESC does fail and the board needs to be replaced, the entire drone needs to be taken apart and built again. This means there would also be a significant amount of de-soldering to do. The figure below shows a typical 4 in 1 ESC:

Good explanation and supporting image

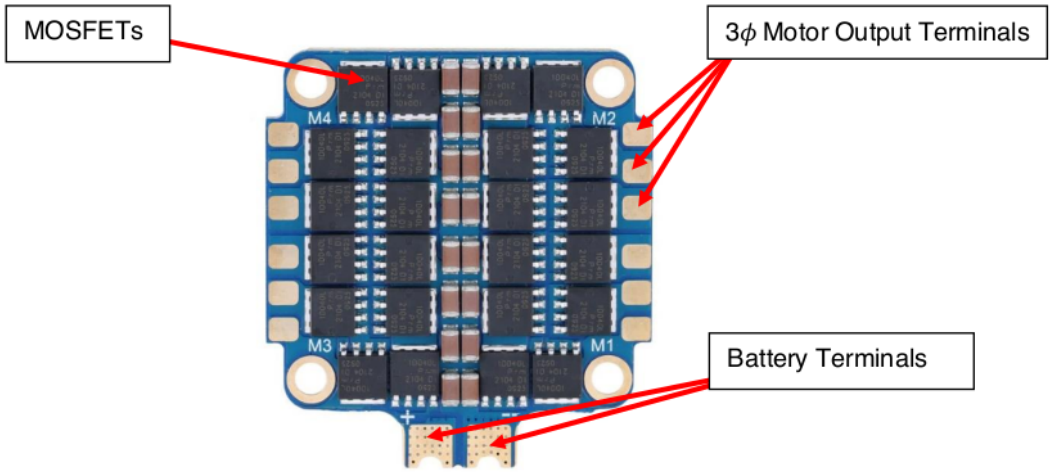


Figure 10 - 4 in 1 ESC (Nagel, 2022)

Solution 2:

The second solution to consider is using individual ESCs instead of a 4 in 1 board. Doing this means that if one of them fails, that single ESC can be easily replaced, which is ideal in racing conditions. This is also makes it more cost effective than a 4 in 1 ESC. Individual ESCs also receive sufficient airflow, due to being mounted on the arms of the frame under the propellers, hence they are better cooled. The disadvantage of individual ESCs however, is there aren't that many available to purchase. They also require a power distribution board, which requires more wiring. This and the ESCs being mounted on the arms can possibly cause more vibrations, which will result as noise going to the gyro, however some individual ESCs also use DShot communication. The figure below shows the wiring configuration for individual ESCs to the power distribution board:

Good explanation and supporting image

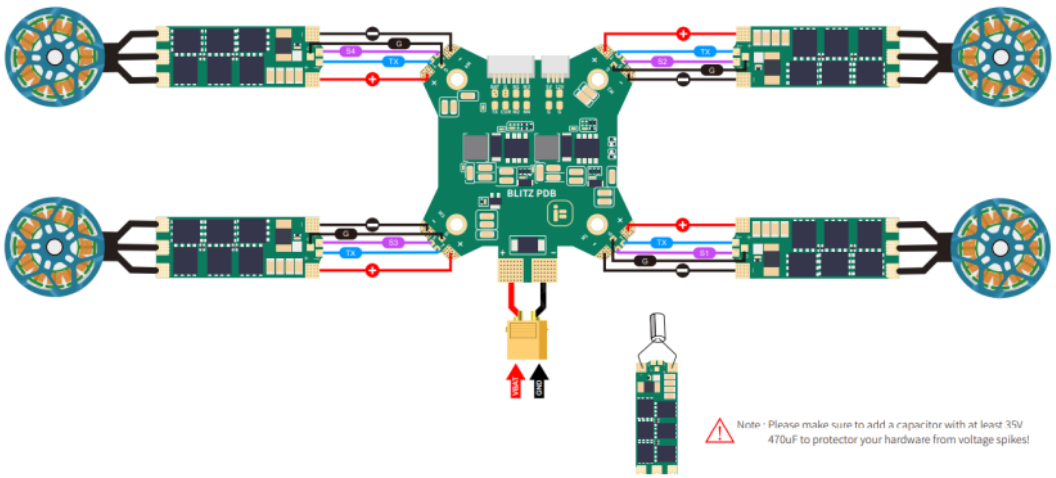


Figure 11 – 4 Single ESCs with PDB (iFlight Innovation Technology Ltd, 2024)

Comparison Table:

Table 3 - Solution Comparison Table

	Diatone MAMBA5 Reactor 66 BLHeli_32 ESC 66A 6S	Succex-E 45A Slick BLHELI_S ESC (Single)
Cost	£57.20	ESC - 4 x £12.84 PDB - £12.99 Total - £64.35.
Product Support	4 in 1 ESC have become more popular and more support is available.	Individual ESCs aren't as commonly used and are less supported.
Current Capacity	Maximum continuous current draw of 66A per esc.	Maximum continuous current draw of 45A.
Maintenance	Harder to maintain due to being mounted under the flight controller which means there's restricted access.	Easier to maintain due to being mounted on the arms of the frame and is not covered by anything.
Reliability	More reliable at a higher continuous current of 66A, which means it can handle the motors pulling more current.	Reliable enough to be able to handle the current at 45A.
Software	Uses BLHeli 32 software and uses a 32-bit processor which adds higher performance and advanced features, such as ESC telemetry, which allows the ESC to send data back to the flight controller (which is used for RPM filtering), current draw monitoring etc.	Uses BLHeli S software which uses a 16-bit processor, but isn't as high performing as a 32 bit one. This type of ESC can use DShot, but extra steps are required to take advantages of it, and separate software is required to enable extra features.

Good table of comparison to evaluate the options

Choosing Solution:

After analysing both solutions, solution 1 was chosen. Even though the cost of replacing one ESC would cost the whole board, the initial cost of purchasing one is cheaper than purchasing 4 individual ESCs and a power distribution board. There is also far less complicated wiring, due to all four ESCs being integrated into one board. The board is also mounted in the centre of the frame, which less susceptible to vibrations and collisions. This makes it more reliable. Its higher current rating also makes it more reliable. It is also easier to setup in terms of software, as RPM filtering and telemetry data is all integrated.

Good argument made for final solution

Final Solution and Implementation

Detailed Specification:

Table 4 - Electrical Hardware Requirements

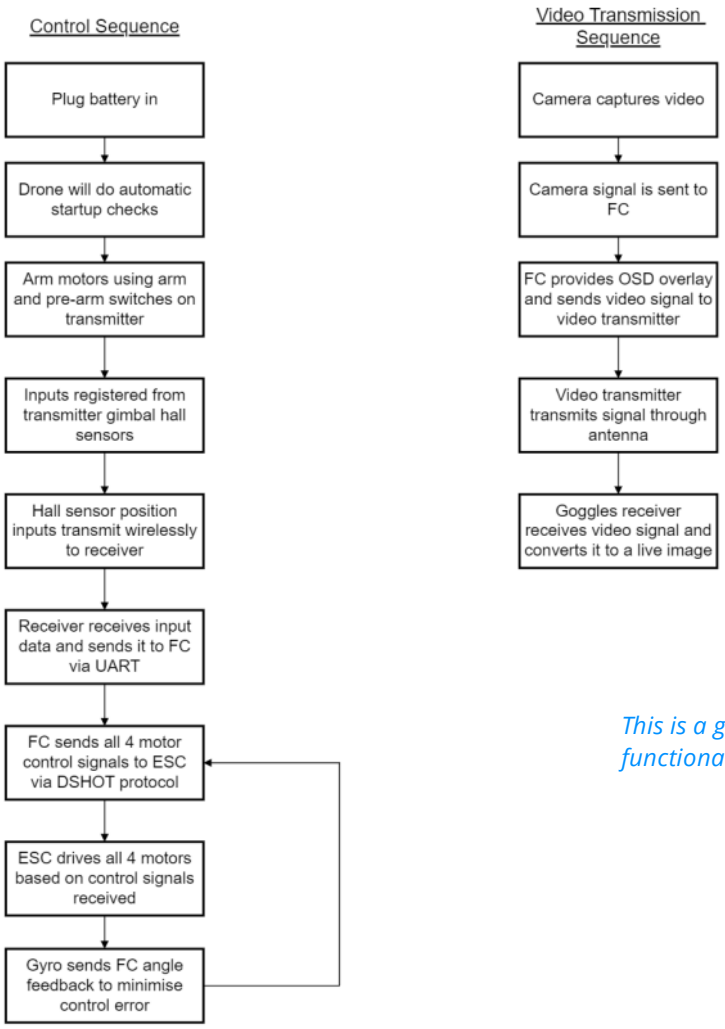
Electrical Hardware	Function and Specification
Flight Controller (FC)	Use an F7 processor chip to be able to process PID loops at 8KHz.
Electric Speed Controller (ESC)	Must be rated at least 45A to be able to handle high motor currents.
Motors	2207 size and 1960 KV to be able to handle 6 cell battery current.
Receiver	Use CRSF protocol to be compatible with the transmitter.
Video Transmitter	Must operate at 25mW to be able to race with other pilots.
Camera	To capture video and send this data to the video transmitter.
VTX Antenna	To transfer video in the 5.8GHz band to the video receiver on the goggles.
Frame	Must be lightweight and have 20x20 mounting for the ESC, FC and VTX/RX.
Battery	Must be a 6 cell 1300-1500mAh.

Table 5 - Software Requirements

Software Requirements	Function
Betaflight	To run all the I/O with an F7 chip at 8KHz PID loop frequency and at least one UART for the receiver. It must also be able to perform a failsafe as a safety requirement.
BLHeli_32	To run the ESC and be capable of using RPM filtering if required.

Functional Specification Block Diagram:

To better understand how the drone functions, a block diagram was created. A block diagram was also created to understand how the video transmitter functions. See below:



This is a good method to identify functionality of separate systems

Figure 12 - Control and Video Transmission Block Diagram

Parts List:

See below for electrical hardware costs. This made the total budget come to £355.60.

Cais Gan / Requested by:	Robert Jenkins			Deliver To/ Danfonwch Colegsirgar G30			
Dyddiad / Date:	14/11/2023			Cyfeiriad / Address :	Graig Campus, Sandy Rd, Llanelli SA15 4DN		
Cyfeirnod Mewnol / Internal Ref:							
Supplier Name:	YourFPV						
Supplier Tel No:	None						
Supplier Web Site	https://yourfpv.co.uk/						
Os ydych yn defnyddio cyllidebau gwahanol, rhannu yn briodol / If using different budgets, please split appropriately							
Value	Analysis Code	Cost Centre	Project Code	Manylion Cyswllt / Contact Details			
				Ymholiadau i: / Enquiries to:			
				Rhif Ffon / Phone			
NWYDDAU A GWASANAETHAU CAIS / GOODS AND SERVICES REQUEST					VAT - Enter a Z where there is no VAT VAT - Enter an S where there is VAT		
Cyfeirio / Reference	Manylion / Details			Rhif / Quantity	Pris Uned / Unit Price	VAT	Swm / Total
HNC Project	MAMBA MK4 F722 MINI Flight Controller (20x20mm) SKU: YFPV - JH60907			1.00	£ 48.10		£ 48.10
	Diatone MAMBA5 Reactor 66 BLHeli32 ESC 66A 6S SKU: YFPV - JH61299			1.00	£ 57.20		£ 57.20
	RCINPOWER GTS V4 1960KV | 2207 BRUSHLESS FPV DRONE MOTOR SKU: YFPV - 14042258			5.00	£ 21.95		£ 109.75
	RushFPV Cherry Stubby 5.8G Antenna (SMA)(RHCP) SKU: YFPV - DC7R-B			1.00	£ 10.20		£ 10.20
	DOGCOM 1500mAh 160C 6S 22.2V FPV lipo battery SKU: YFPV - 14041855			1.00	£ 36.20		£ 36.20
LLOFNOD DEILYDD Y GYLLIDEB		DYDDIAD		Cludiant / Postage & Packing			£ 4.09
BUDGET HOLDER SIGNATURE		DATE		Cyfanswm / Total			£ 265.34

Figure 14 - YOURFPV Requisition Form

Supplier Tel No:	None						
Supplier Web Site	https://www.unmannedtechshop.co.uk/						
Os ydych yn defnyddio cyllidebau gwahanol, rhannu yn briodol / If using different budgets, please split appropriately							
Value	Analysis Code	Cost Centre	Project Code	Manylion Cyswllt / Contact Details			
				Ymholiadau i: / Enquiries to:			
				Rhif Ffon / Phone			
NWYDDAU A GWASANAETHAU CAIS / GOODS AND SERVICES REQUEST					VAT - Enter a Z where there is no VAT VAT - Enter an S where there is VAT		
Cyfeirio / Reference	Manylion / Details			Rhif / Quantity	Pris Uned / Unit Price	VAT	Swm / Total
HNC Project	Foxeer Predator 5 Nano – 4ms Latency WDR Racing FPV Camera SKU:76F-6A0-0D5			1.00	£ 30.99		£ 30.99
	TBS Tracer Sixty9 (RX + Unify VTX) SKU: 876-5DF-5E0			1.00	£ 49.90		£ 49.90
	XT60 Connectors Yellow/Black (Pack of 10) SKU: 2FC-FF8-D61			1.00	£ 3.49		£ 3.49
LLOFNOD DEILYDD Y GYLLIDEB		DYDDIAD		Cludiant / Postage & Packing			£ 5.88
BUDGET HOLDER SIGNATURE		DATE		Cyfanswm / Total			£ 90.26

Figure 13 - UNMANNEDTECH Requisition Form

Good evidence of inventory

Component wiring:

Each component's supply voltage, terminals and their location were then listed due to the likelihood of fault finding. The speed controller provides supply voltage to the rest of the components, hence why it isn't listed. See the table below:

Table 6 - Component Voltage, Terminal Locations and Identification Table

		Terminal Location	
Component	Supply Voltage	Flight Controller	Speed Controller
Flight Controller	VBAT/VCC	Micro JST Harness	VCC, GND, S1, S2, S3, S4, T, C
Receiver and Video Transmitter	5.5-36V	9V, GND, VTX, RX4, TX4	
Camera	5V	5V, GND, CAM	
Motor 1	VBAT/VCC		Motor 1
Motor 2	VBAT/VCC		Motor 2
Motor 3	VBAT/VCC		Motor 3
Motor 4	VBAT/VCC		Motor 4

A table was then created for the hall sensor inputs being sent from the transmitter gimbals. These were shown in figure 1. See below:

Table 7 – Gimbal (Analogue) Inputs

Inputs	Function
Channel 1	Throttle
Channel 2	Roll
Channel 3	Pitch
Channel 4	Yaw

Good use of tables

Another table was created for the input switches on the transmitter:

Table 8 – Switch (Digital) Inputs

Inputs	Function
Channel 5	Arm/Disarm Switch
Channel 6	Pre-arm Switch
Channel 8	Beeper/Flight Mode Switch

The terminal drawings for the components in table 6 and input functions for tables 7 and 8 can be seen in appendix A, pg.37-39.

Assembly:

After observing the component drawings, the drone assembly begun. It was completed in the following steps (see appendix A, assembly section, pg. 40 for each step):

1. The frame was assembled, and m3 mounting screws were added.
2. The battery connector was soldered onto the ESC with a noise absorption capacitor in parallel to it.
3. The motors were secured to the frame with m3 screws and soldered to the ESC terminals. Their direction will be setup in the software.
4. The flight controller was mounted on top of the ESC with vibration damping mounts and also plugged into the ESC as per the ESC diagram.
5. The VTX/RX board connections were soldered onto the flight controller.
6. The camera connections were soldered and was secured in its mount.
7. The VTX/RX connections were then connected from the flight controller and the board was mounted on top of it. All of the boards were then secured with m3 bolts.
8. The VTX/RX antennae were secured to their UFL connections. These antennae were then mounted to the frame and the assembly was complete.

Assembly method is identified

Software Configuration:

Once the assembly stage was complete, the software configuration stage begun. The Betaflight firmware on the board had already been installed from factory, which means it only required configuration. It is running the latest version 4.3.0 with some features pre-set. BLheli_32 version 32.9 was also pre-installed on the ESC from factory.

The drone was connected to the laptop with a USB-C connection from the flight controller. The software can be configured, without battery voltage.

Once the software could see the serial connection, the configuration was done in the following steps (see appendix A, pg.48 for all step evidence):

1. The accelerometer/gyro was first calibrated on a level surface in order for it to read the correct angle on each axis of rotation.
2. The receiver port was configured. Since it was wired to TX4 and RX4, UART 4 was selected.
3. The gyro update frequency and PID loop frequency was set to 8kHz, which will give the drone slightly better flight characteristics, due to the PID loop having a fast update frequency.
4. The maximum, minimum and warning cell voltages were set, which will be displayed on the video OSD.
5. The receiver mode was set to serial (UART), as this is the method the receiver uses to communicate. The protocol was set to CRSF as this is the brand/protcol of the receiver. The channel mapping was also set to TAER1234, which is the order the channels are set on the transmitter.
6. The switch inputs were set up with reference to table 8. The drone can only take off once the pre arm and arm switches are made. Channel 8 switch is used to toggle between normal flight mode, beeper which will sound the motors if the drone is lost and flip after crash mode, which reverses the motor directions to flip the drone over after a crash.
7. DSHOT600 was selected to communicate with the ESC and telemetry was enabled to allow ESC RPM data transfer.
8. The VTX table was located from TBS's official website (TEAMBLACKSHEEP, 2023) and transferred to the software through a JSON file. This tells the video transmitter what bands, channels and output power to operate with. RACEBAND will be used for this build.
9. The OSD was setup to fulfil the pilot's needs. The OSD includes the band, channel and output power the VTX is set to, the average cell voltage of the battery, flight timer and low battery warnings, which tells the pilot to land the drone.

10. The failsafe was set up to ensure the motors disarm if radio connection is lost.
11. Next, the ESC software was set up, but before doing so, a wiring check was completed first, as the battery needed to be plugged in to power the ESC (see test 1 for results). Once the wiring check was complete, all four ESCs were setup in the software. The motor timing for each ESC was set to 23 degrees to account for motor demagnetisation. The “demag compensation” had also been set to high which will better compensate if a motor stalls. The PWM frequency was set to 48kHz locked instead of the pre-set 24kHz. Note that this type of PWM frequency is separate from input signal PWM. A higher PWM frequency allows for smoother motors at higher throttle due to the MOSFET duty cycle being updated twice as fast.
12. The motor direction for ESC 1 and 4 were reversed, as motor 1 and 2 need to be spinning opposite to 2 and 3, as per betaflight software requirements.
13. The drone was then ready to be bound to the transmitter. This was simply completed by powering up both the transmitter and the drone. The receiver came from factory in binding mode, which was displayed by a red LED on the board. The transmitter module was then bound by pressing the yellow button and once they were bound, both the LEDs on the transmitter and the drone turned green.

Good detailed explanation

Analysis of Test Results

Testing was conducted as per the testing plan in table 2. (See appendix B, pg.59 for detailed test descriptions and results for each test):

Test 1:

The wiring check completed okay with no fails, which indicated the drone can be safely powered up without component failure. The motors also tested to be balanced, which means they will perform as expected. They also tested to have no continuity between the phases ground, which was expected. (pg.59-62)

Test 2:

The gimbals were first calibrated on the radio. Channels 1 – 4, (gimbal commands) showed a value of 1500 when the sticks were centred, and the remaining switch channels showed at 1000 when off which was correct. This showed the gimbals were correctly calibrated and all the switches where not made. All inputs then tested to be assigned correctly as seen from the betaflight screenshots, and the outputs worked as expected. (pg.63-83)

Test 3:

The motors tested okay and were assigned correctly when selecting which one to spin up in the betaflight software. They all rotated in in the correct direction as per software requirements. (pg.84-90)

Test 4:

The output power of the video transmitter was tested using an RF meter and it showed that it was transmitting at the required output power of 25mW. Each channel was being received correctly when channels 1-8 were selected from the transmitter menu (figure 73). There was some minor interference on the spectrum analyser on the lower band channels, but not significant enough to cause problems for other pilots operating on the other channels. (pg.91-97)

Test 5:

From analysing the blackbox data, tuning will be required, especially on the roll axis as oscillations occurred on a number of occasions, some being caused by motor noise without setpoint change and some with poor tuning parameters where the setpoint is changing. Damping should be increased. The pitch axis performed well without any significant oscillations during the flight. Damping could also be increased. The yaw axis performed as it should without any significant oscillations and may only require more damping. There was also no phase delay and feedforward didn't need adjusting. The current draw, shown in the OSD averaged around 30A which was a great result and didn't draw too much battery current. The motors also felt slightly warm after landing, which was normal. (pg.98-100)

Test 6:

From the results shown on the gyro frequency spectrum for each axis, it can be seen that the maximum motor noise produced occurs at around 500Hz, except for the yaw axis at around 300Hz. From the frequency vs throttle spectrum on each axis, it can be seen that two exponential curves are generated and their frequency increases as the throttle does. The maximum noise produced by the motors is also shown on these graphs, as the brighter parts show the maximum motor noise at 500Hz for roll and pitch and 300Hz for yaw. Both the roll and pitch axis spectrums also show a notch, which is likely to be the frame's resonant frequency. The 0Hz region of the frequency graphs have very high amplitude, but these can be ignored as these are the flight movements of the drone. (pg.101-104)

Test 7:

Following from test 5 the final PID tuning parameters were set after numerous flights were carried out to achieve the optimal tune. The final parameters have more damping on roll and pitch, less proportional on yaw, and more integral on all axes. Following from test 6, the filters were applied. The RPM filter was enabled set to two harmonics, as two could be seen with one starting at around 100Hz. This filter should eliminate the majority of noise occurring. The dynamic notch filter was also enabled with two notches as there were two spikes found at two different frequencies within all axes, which range from 250-600Hz. This filter will then hunt for notches found within this range. Once these filters were applied, a final flight test was completed. (pg.105)

From the PID test results, the drone performed very well and the blackbox data showed the control loop for each axis functioned as expected, with the gyro correctly following the setpoint with minimal phase delay and no oscillations, except for the yaw axis, to which oscillations are expected due to no damping control. The filters also played a significant part of its performance and filtered out noise, stopping it from giving the gyro false readings. The RPM filter filtered out harmonics increased with throttle and the dynamic notch filter filtered out frame resonance. (pg.106-112)

A good structured test method

Discussion, Conclusions and Recommendations:

Overall, the project managed to meet all of the expected outcomes discussed in the specification and was even completed 2 weeks before the deadline. Using the Gantt chart helped a lot as it played a significant part in the test planning, especially due to the extensive testing taking a majority of the time to complete but was completed early, as weather was accounted for when creating the Gannt chart, in case it rained and flight testing could not be carried out, so more time was given for this. The software was also completed throughout the testing stages, such as when tuning. An initial harmonic analysis test was also added to the test table after test 5 and was not included in the Gantt chart. This sudden change was done as the harmonics needed to be analysed first before analysing them after they had been applied in the final test. This however did not affect time constraints.

THre are significant points that affect the progress explained here

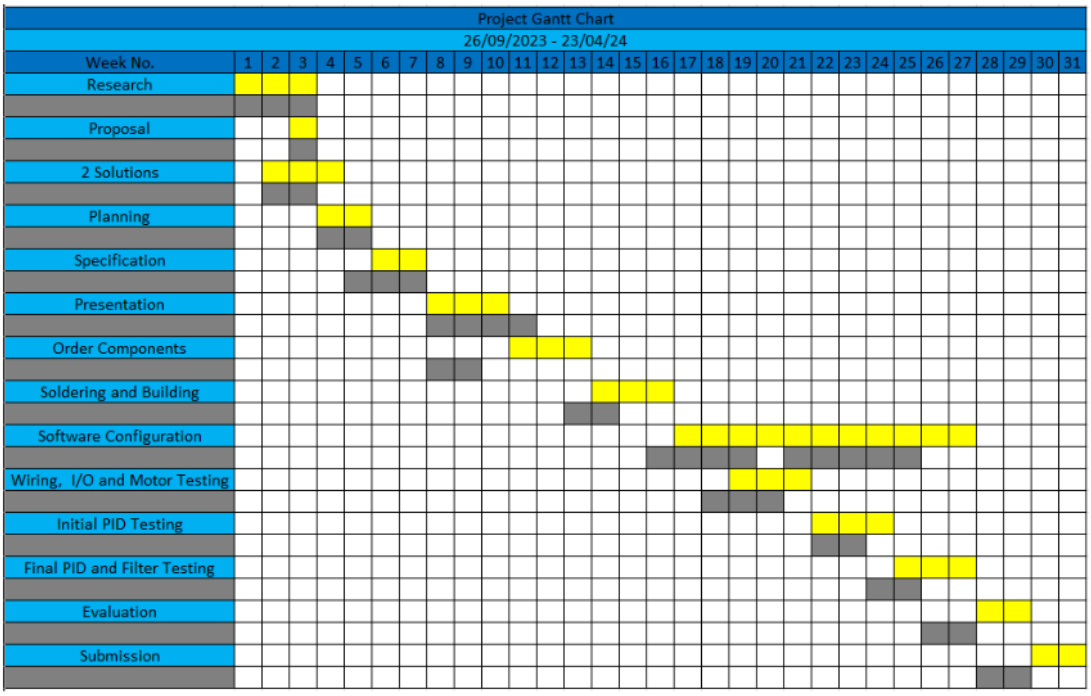


Figure 15 - Completed Gantt Chart

Excellent work with the Gantt chart comparison

The drone functioned correctly as a closed loop system and a VTX output power of 25mW was achieved. All components were correctly ordered without any alternate substitutes required. As per the project outcome table 1, using 3-phase brushless motors and 6 cell batteries ensured the drone was sustainable by these being everlasting compared to brushed DC motors and 4 cell batteries. The project also met the budget at £355.60, which was significantly lower. The user requirements were also met by the drone having a fast response and tuned perfectly. All of the testing carried out ensured the drone was fit for purpose. There was one fail on the initial flight PID test due to being unstable on the roll axis but was tuned and tested again, which then passed. The video transmitter also performed as expected and clear video was seen throughout all of the flight testing. The motors also did not draw too much current during flights and ensures reliability. The failsafe procedure also functioned as expected.

A recommendation that can be made is to use separate boards for the receiver and video transmitter instead of both on integrated into one board. This would make mounting more difficult, however if one were to fail, either the receiver or video transmitter can be replaced, which will save cost.

Good explanation

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Good number of sources

Appendices

Appendix A - Final Solution and Implementation

Component drawings:

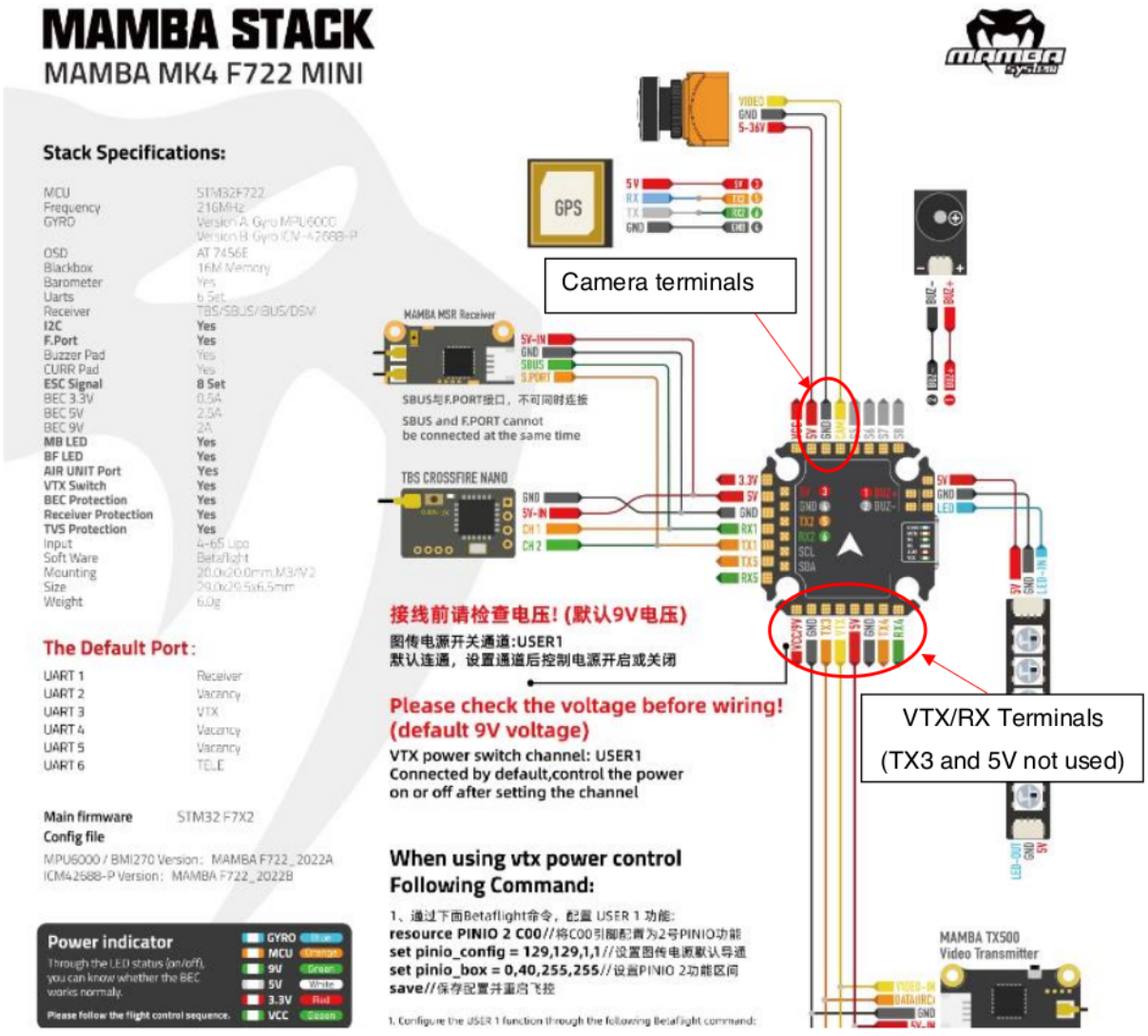


Figure 16 - Flight Controller Wiring Diagram (DIATONE OFFICIAL, 2023)

This is an informative diagram

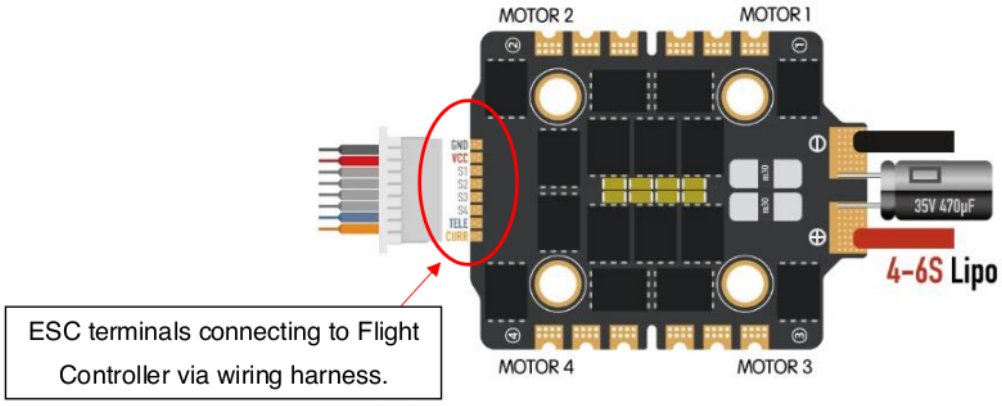


Figure 17 – Speed Controller Wiring Diagram (DIATONE OFFICIAL, 2023)

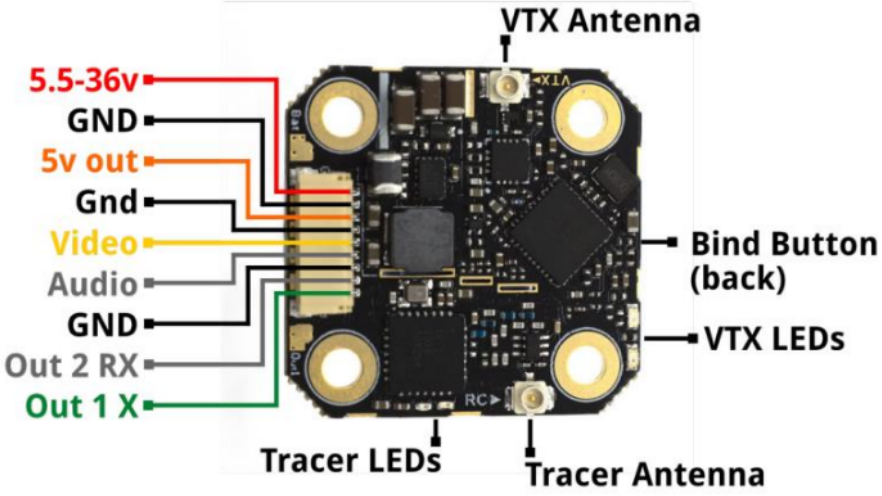


Figure 18 - VTX/RX Wiring Diagram (TEAMBLACKSHEEP, 2023)

Transmitter Inputs:



Figure 19 - Transmitter Inputs

Good evidence

Assembly:

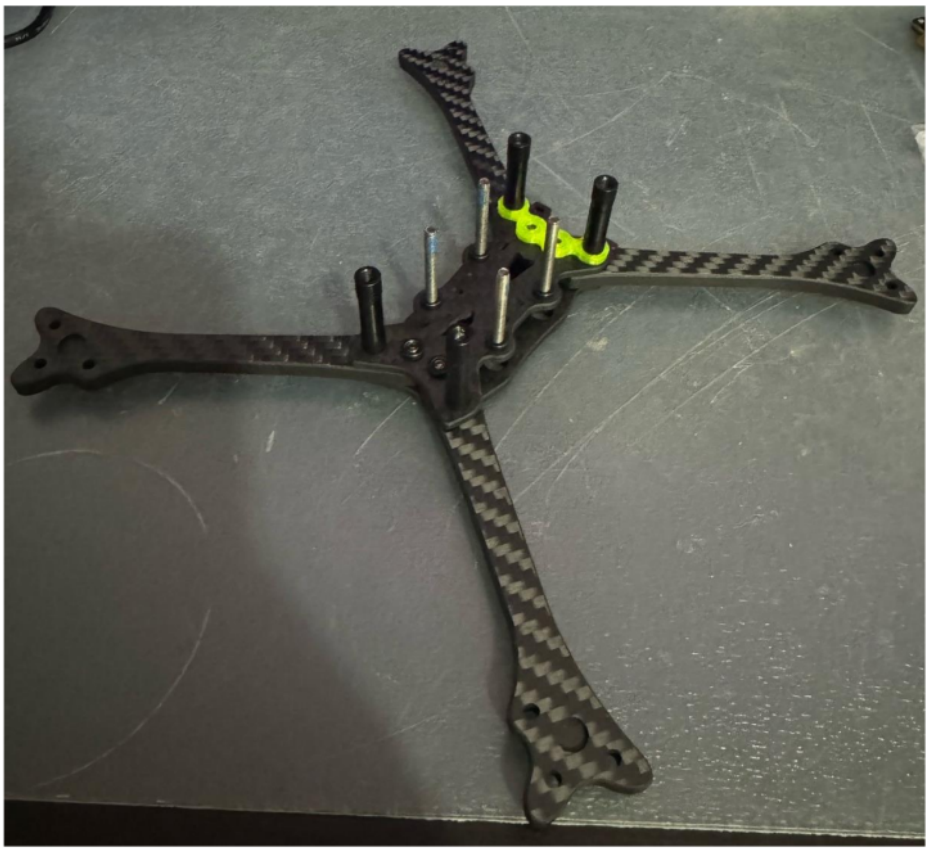


Figure 20 – Assembly Step 1

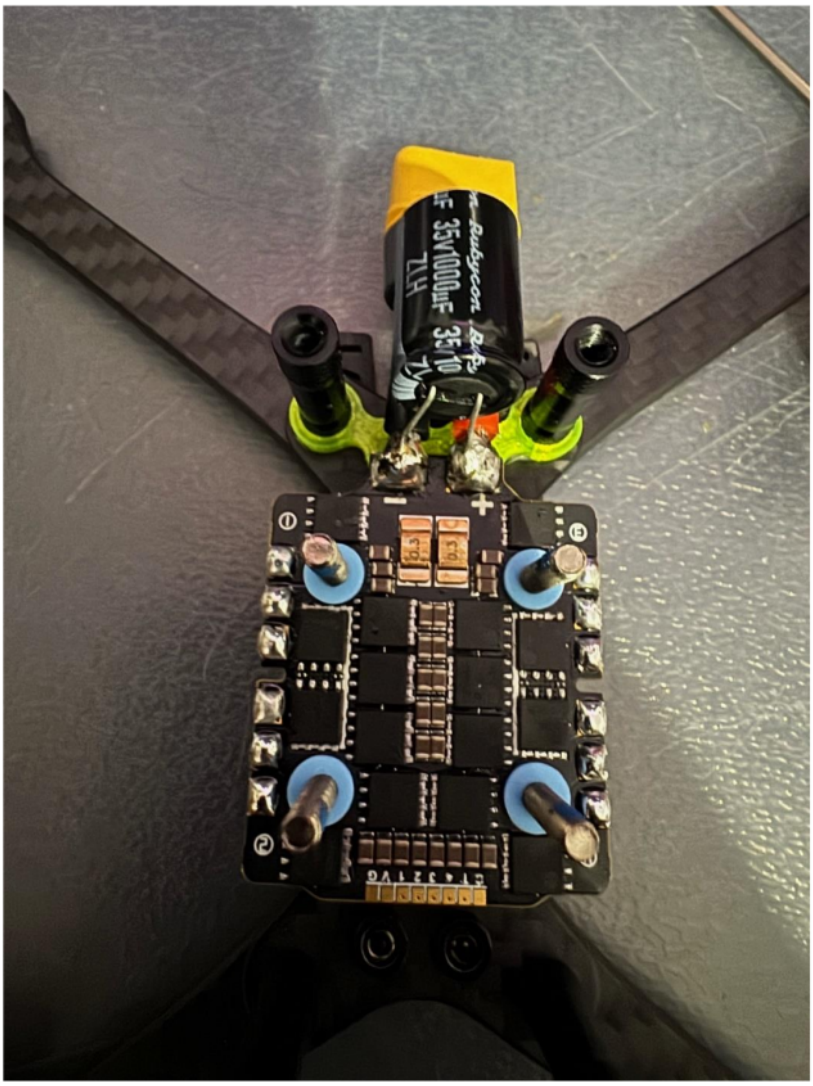


Figure 21 – Assembly Step 2

Good evidence

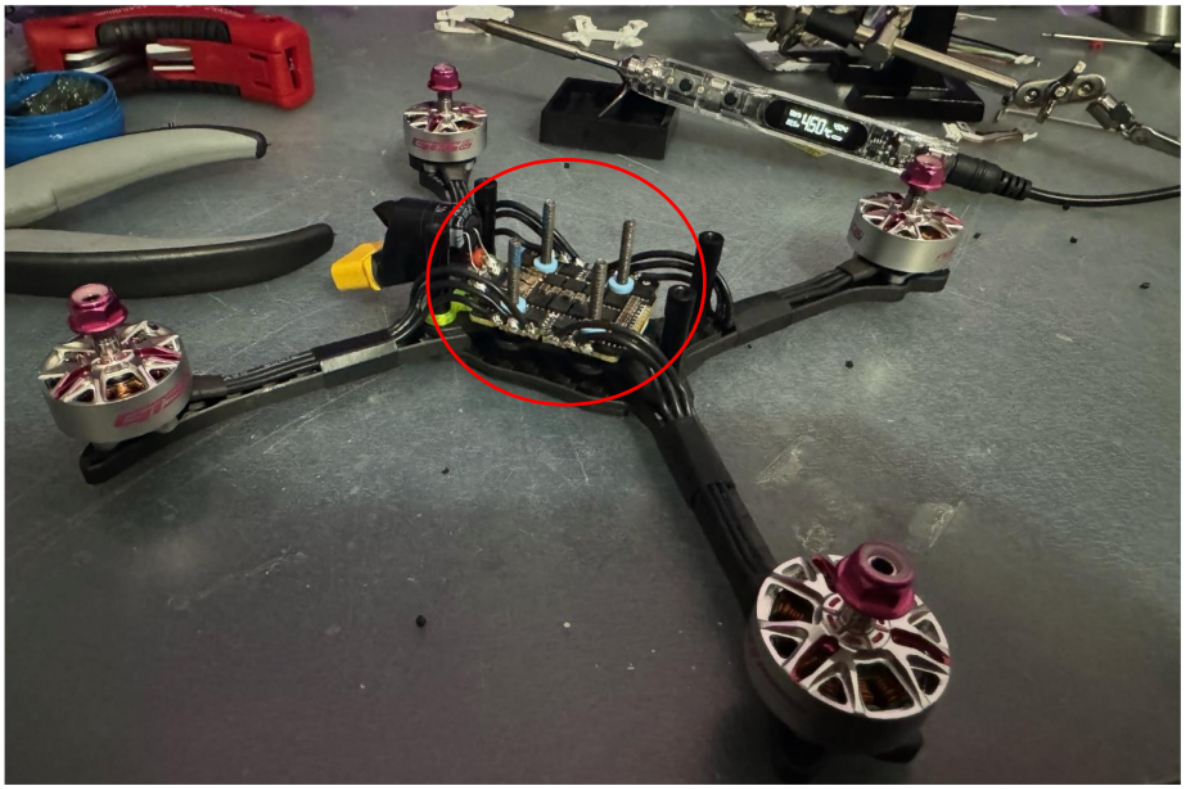


Figure 22 – Assembly Step 3

Good evidence showing components fitted

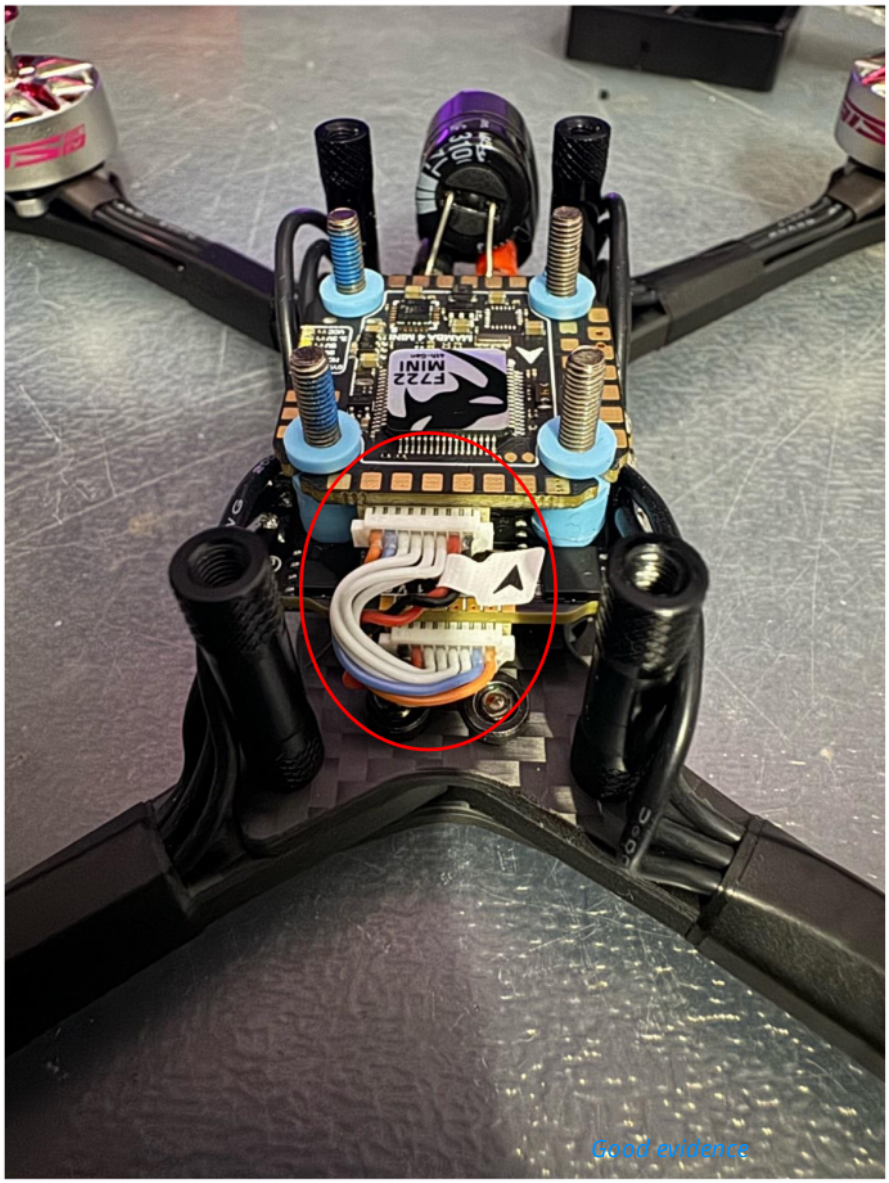


Figure 23 – Assembly Step 4

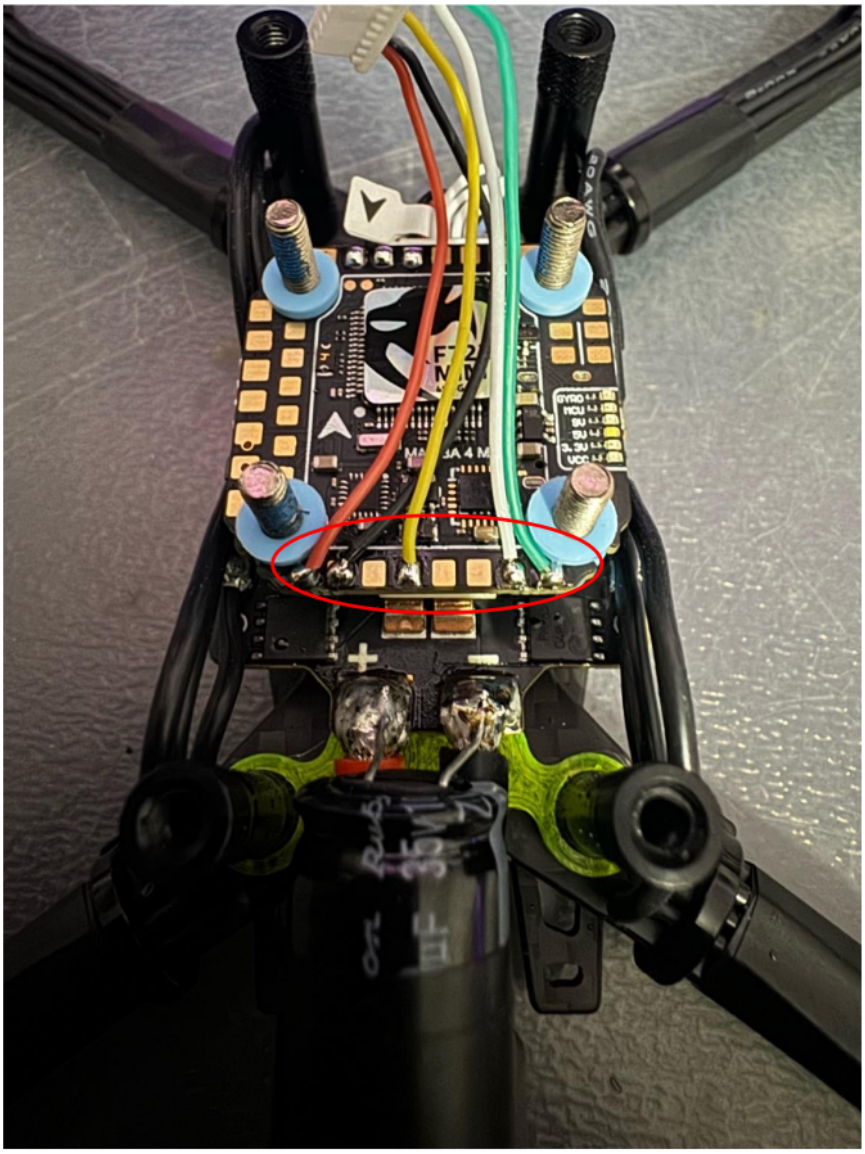


Figure 24 - Assembly Step 5

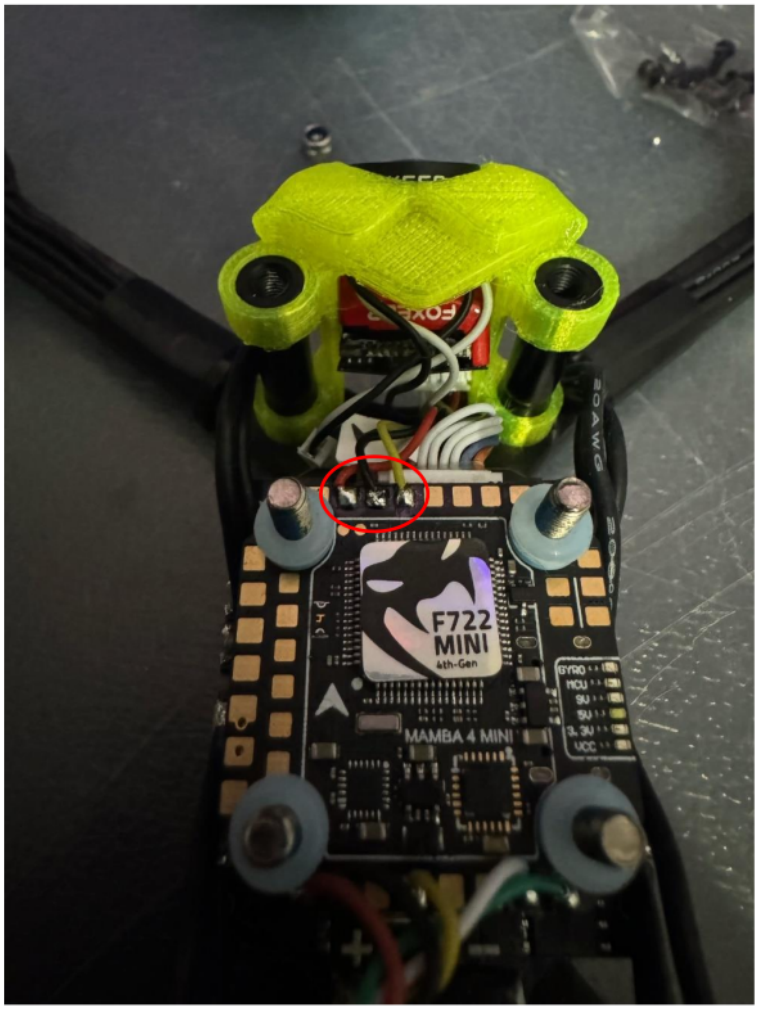


Figure 25 - Assembly Step 6

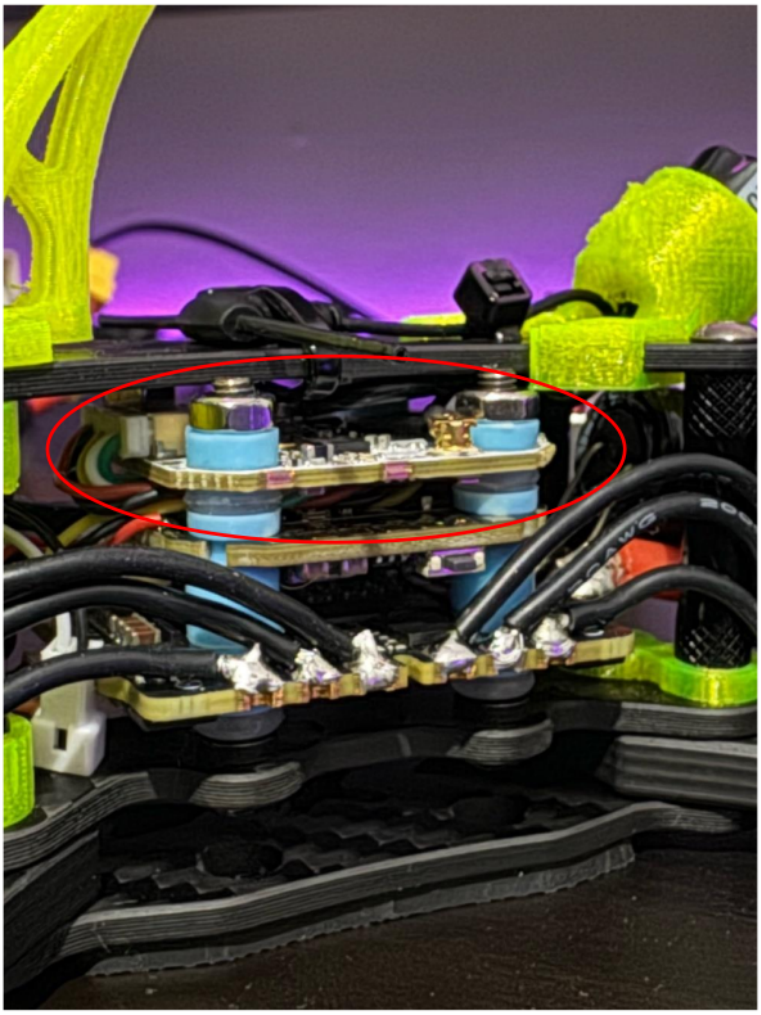


Figure 26 - Assembly Step 7



Figure 27 - Assembly Step 8

Software Configuration:



Figure 28 - USB - C Connection to Laptop

Good evidence of software setup

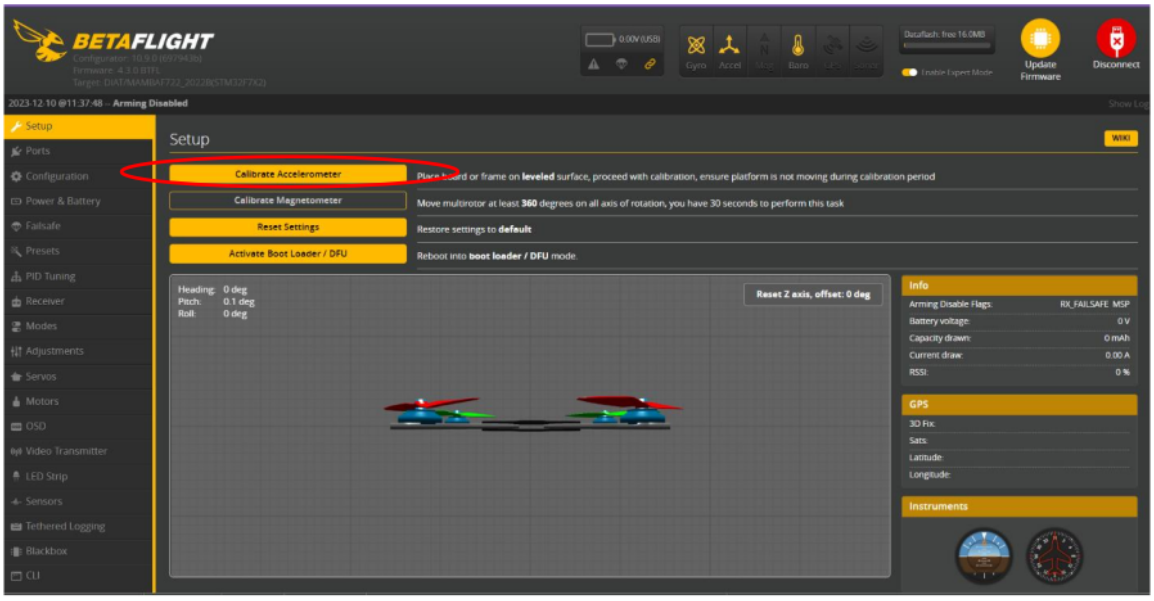


Figure 29 - Configuration Step 1

Good evidence fo configuration

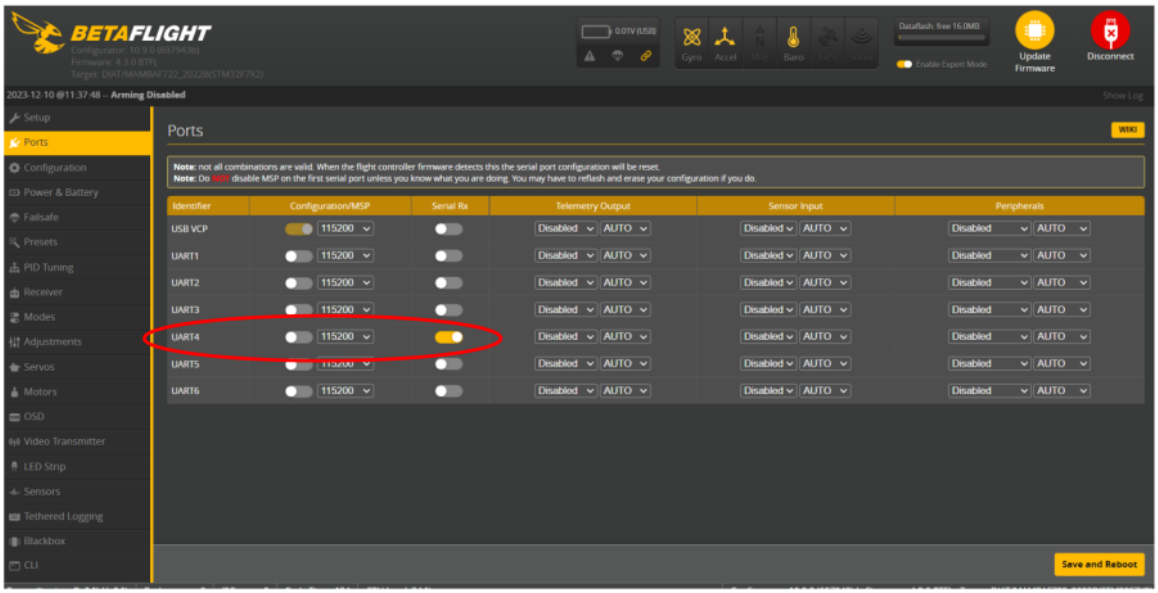


Figure 30 - Configuration Step 2

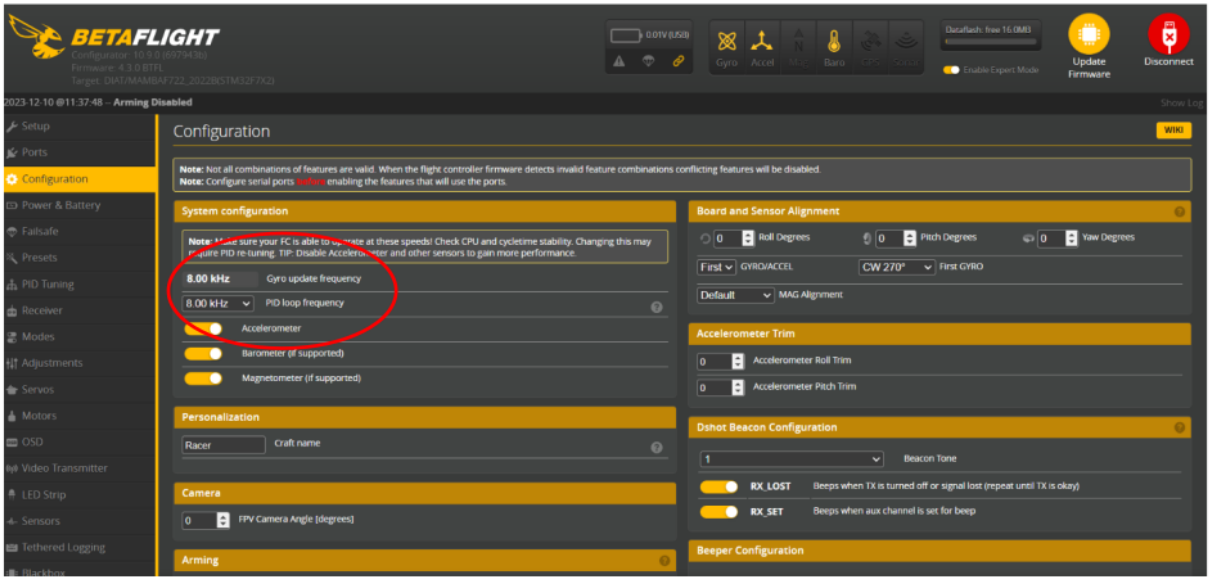


Figure 31 - Configuration Step 3

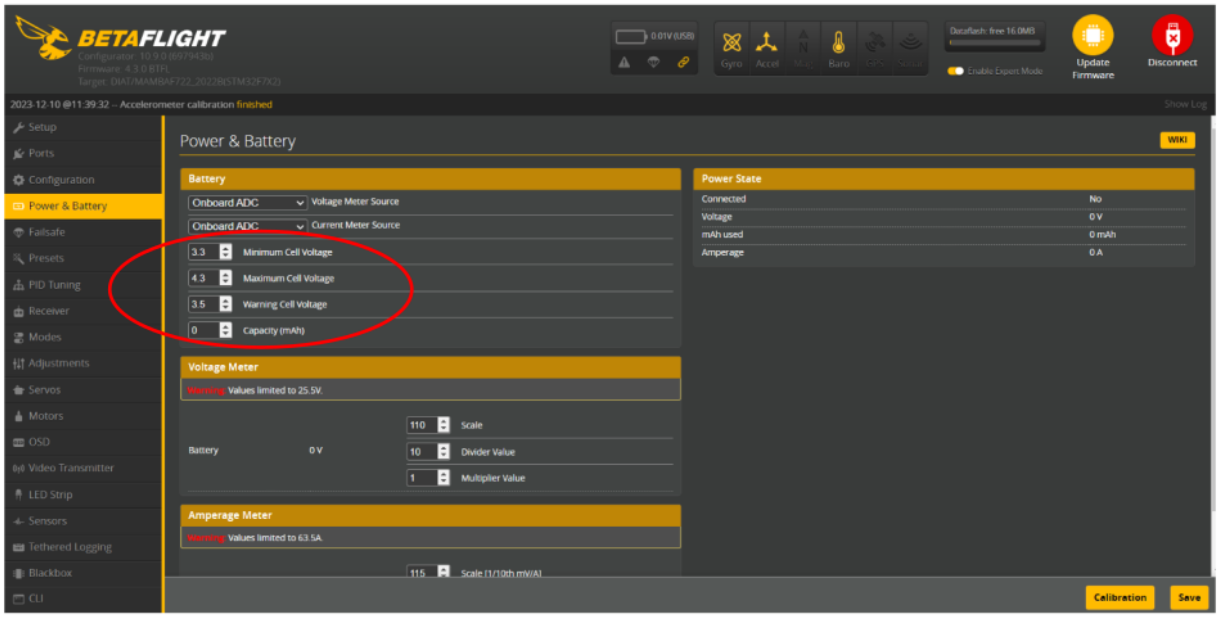


Figure 32 - Configuration Step 4

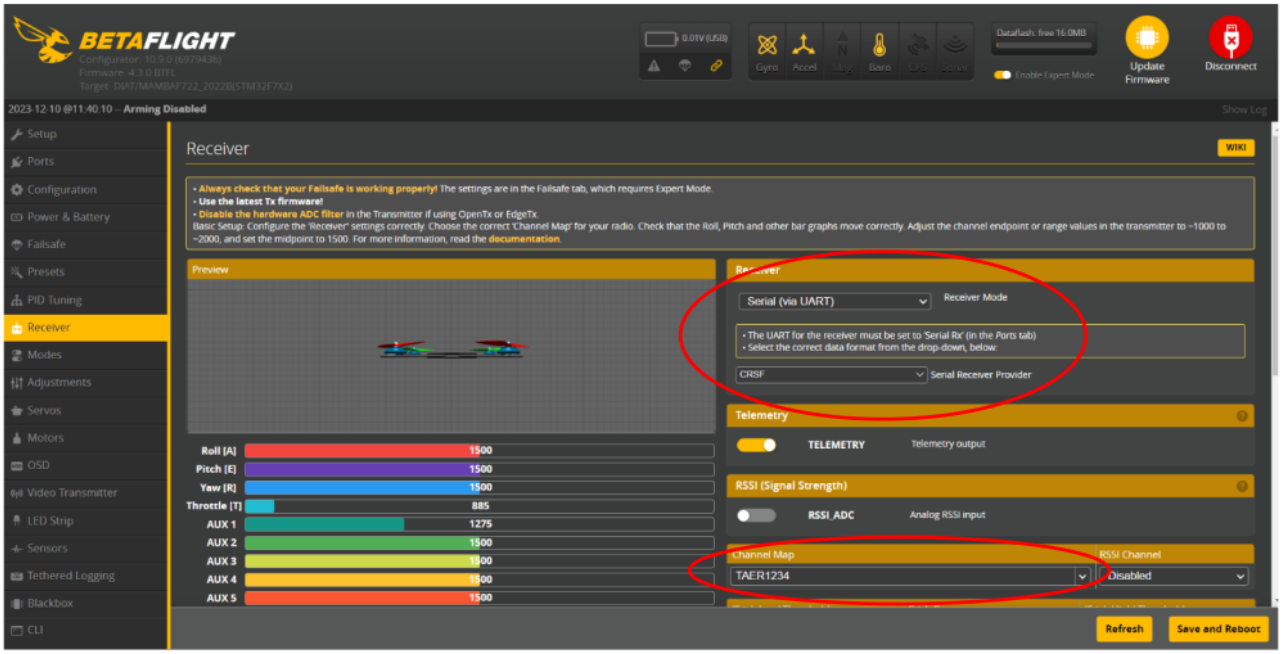


Figure 33 - Configuration Step 5

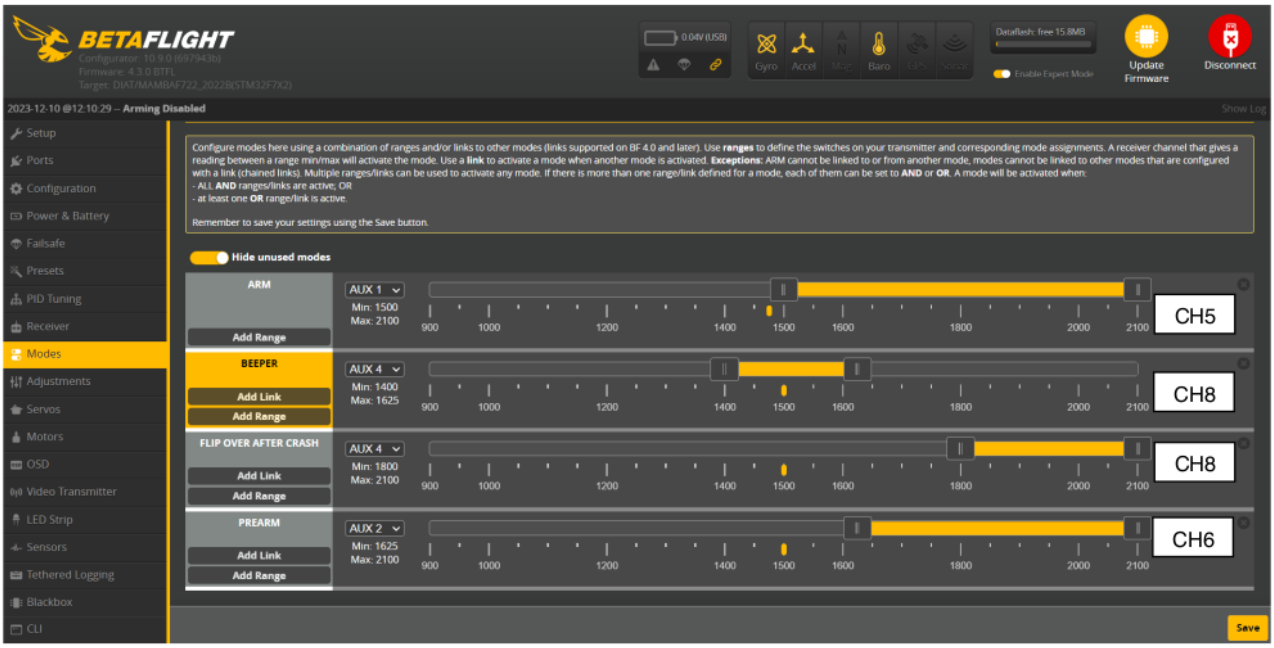


Figure 34 - Configuration Step 6

Good evidence of configuration comlexity

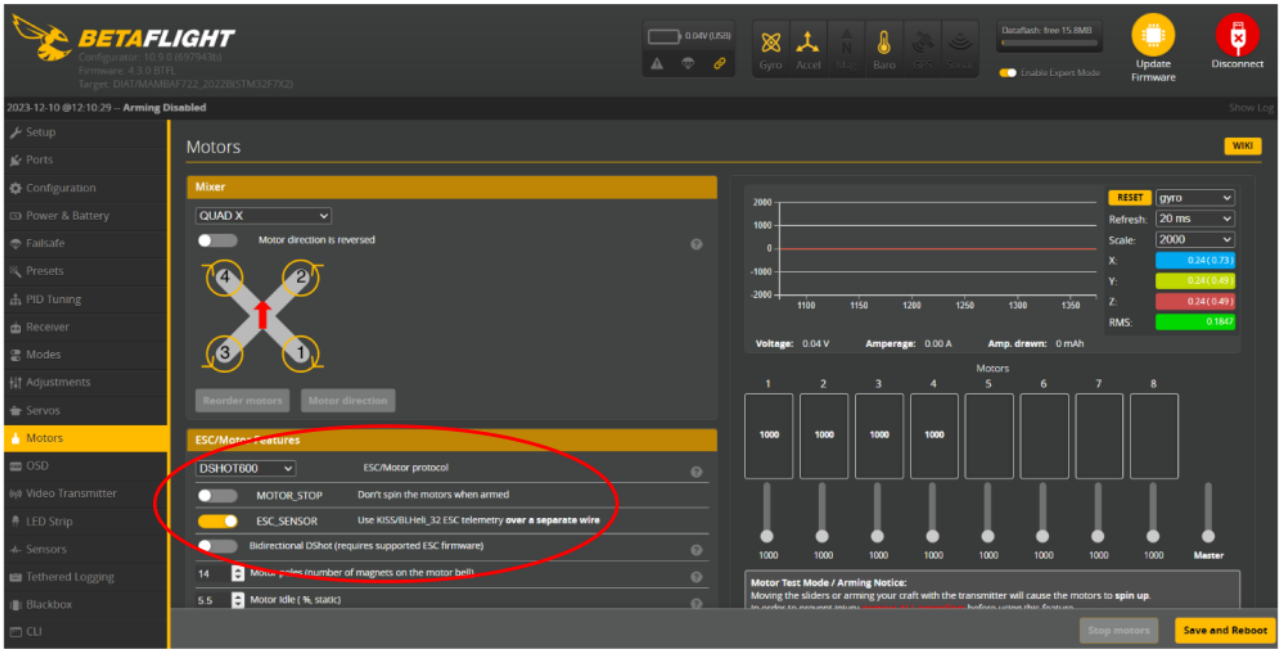


Figure 35 - Configuration Step 7

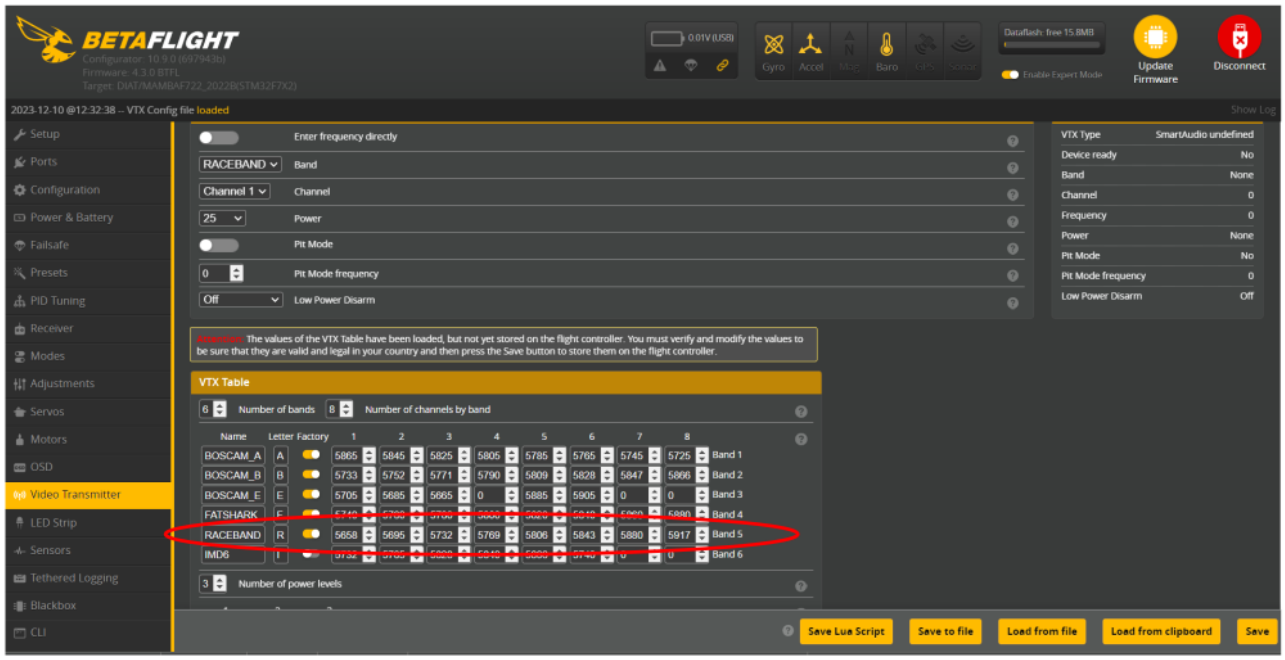


Figure 36 - Configuration Step 8

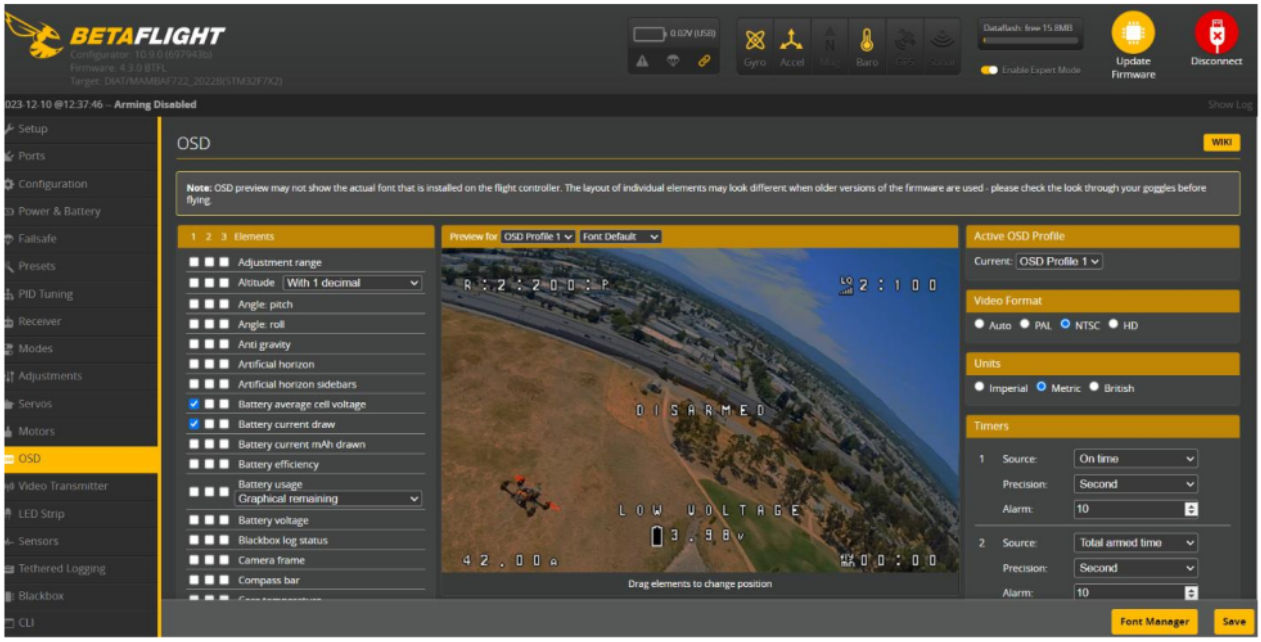


Figure 37 - Configuration Step 9

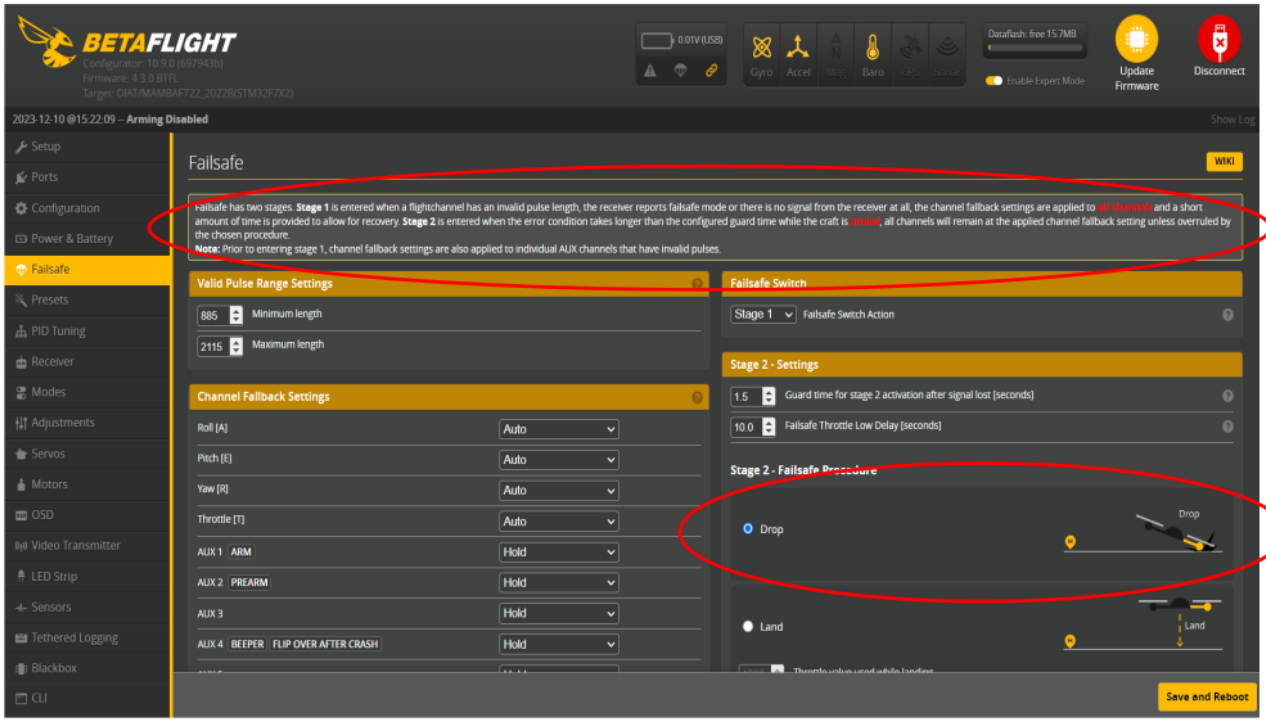


Figure 38 – Configuration Step 10

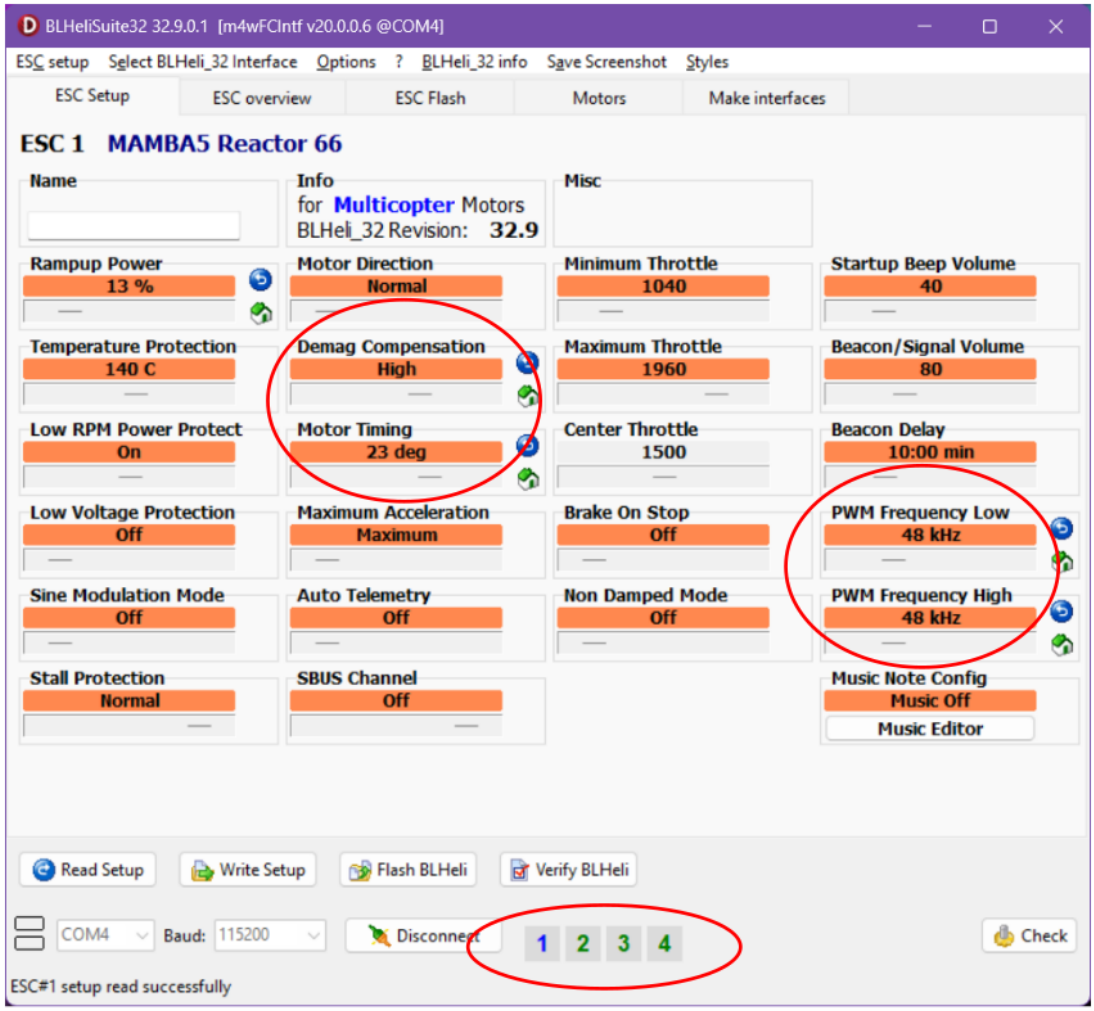


Figure 39 - Configuration Step 11

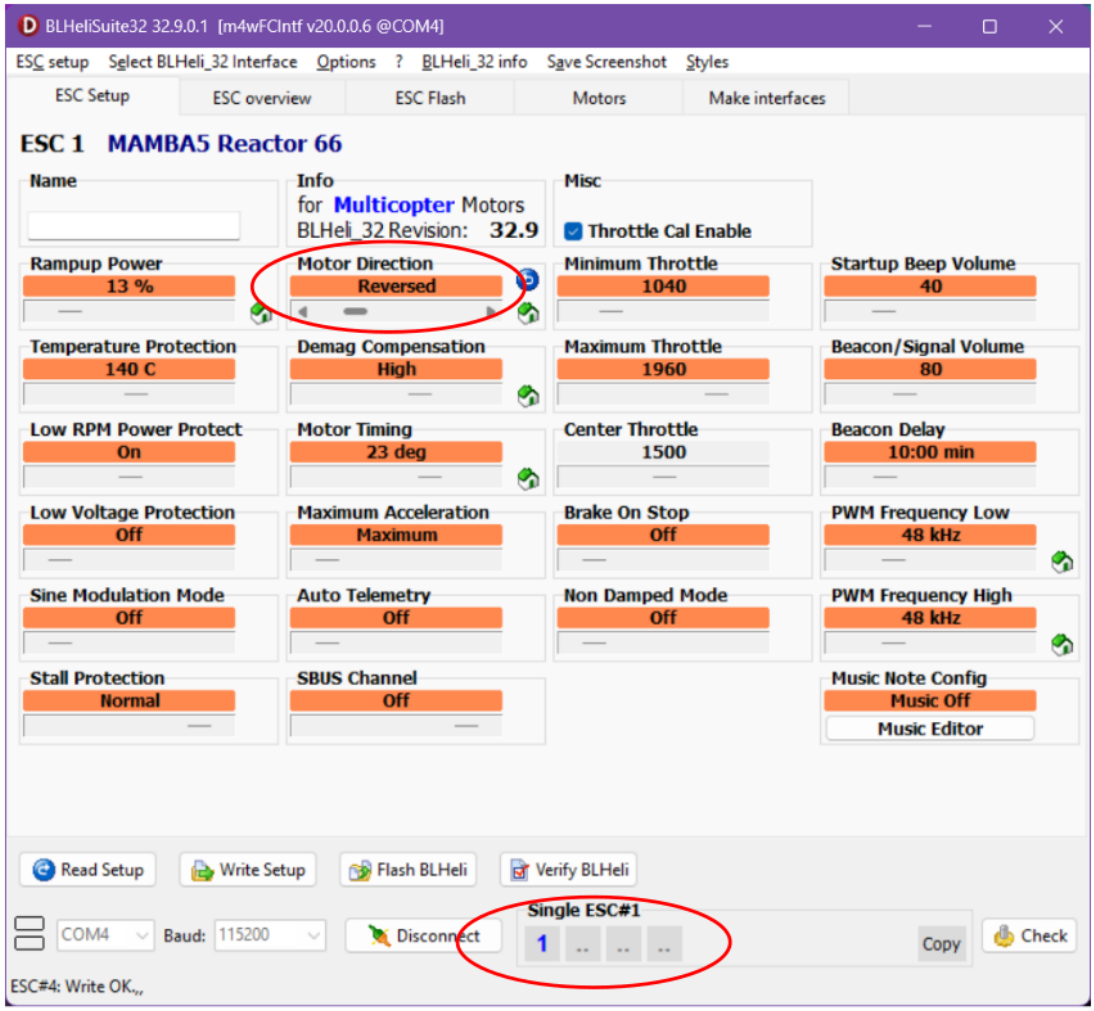


Figure 40 - Configuration Step 12 ESC 1

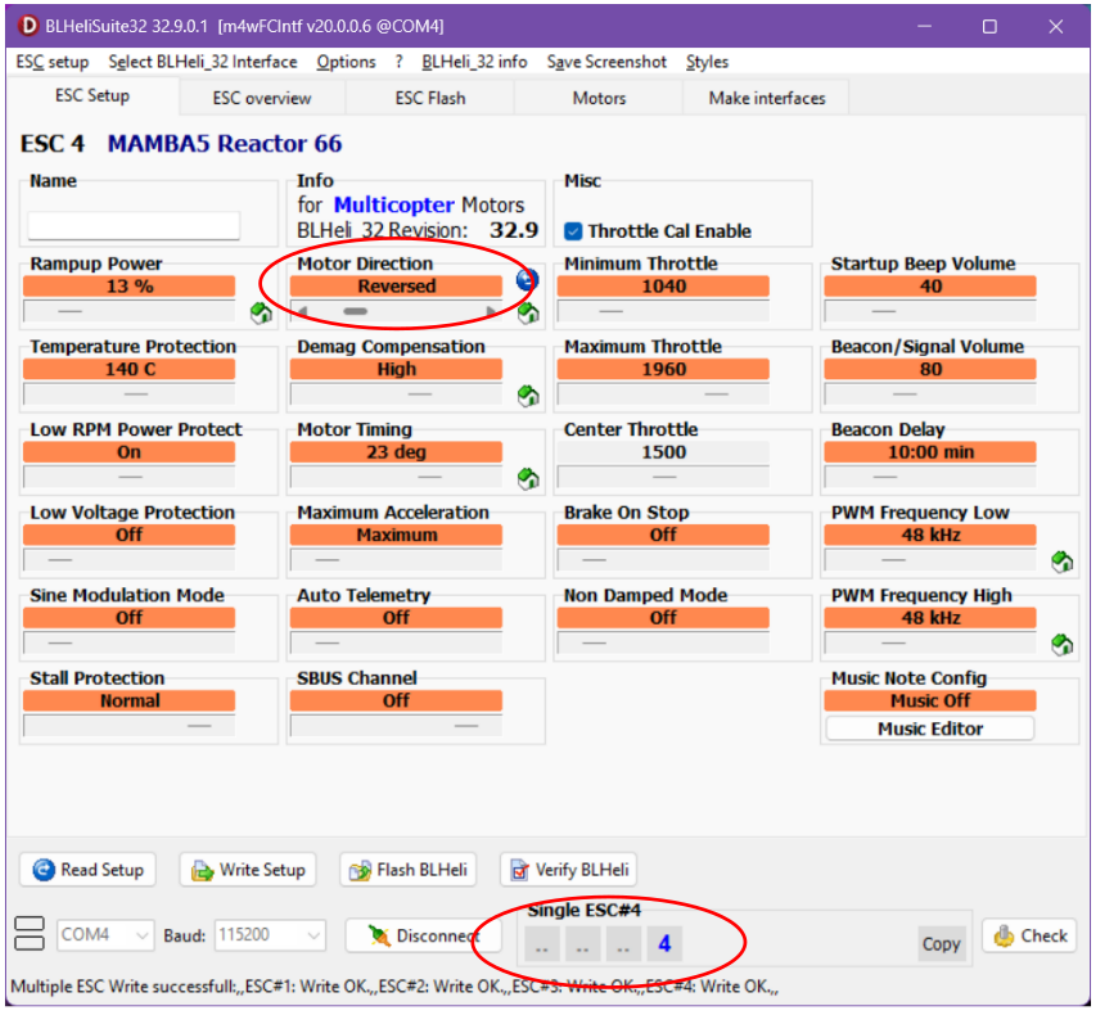


Figure 41 - Configuration Step 12 ESC 4



Figure 43 - Configuration Step 13 Unbound



Figure 42 - Configuration Step 13 Bound

Appendix B – Testing and Results

Test 1 – Wiring Check:

Table 9 - Continuity Check

Description	Terminal Continuity	Expected Result (Ω)	Actual Result (Ω)	Pass/Fail (P/F)
Ensure the correct components have continuity and ensure there aren't any short circuits where there shouldn't be.	Battery + to -	O/C	O/C	P
	FC 9V to GND	O/C	O/C	P
	VTX 5V to GND	O/C	O/C	P
	Camera 5V to GND	O/C	O/C	P

Good use of table for check list



Figure 44 - Battery Terminals (+&-) Continuity Check

Table 10 - Ground Check

Description	Ground Terminals	Expected Result (Ω)	Actual Result (Ω)	Pass/Fail (P/F)
Ensure all components tested are correctly grounded.	Battery GND to FC GND	<1	0.3	P
	Battery GND to VTX GND	<1	0.4	P
	Battery GND to VTX UFL	<1	0.5	P
	Battery GND to RX UFL	<1	0.4	P

Good use of table



Figure 45 - Battery (-) to VTX UFL Connector

Table 11 - Motor Balance Test

Description	Motor No.	Expected Result	Actual Result (Ω)			Pass/Fail (P/F)
			$\phi 1\ to\ \phi 2$	$\phi 1\ to\ \phi 3$	$\phi 2\ to\ \phi 3$	
Ensure each motor is balanced to make sure each phase draw the same amount of current.	1	Each coil should have around the same resistance.	0.4	0.4	0.4	P
	2		0.4	0.5	0.5	P
	3		0.5	0.5	0.4	P
	4		0.4	0.4	0.4	P

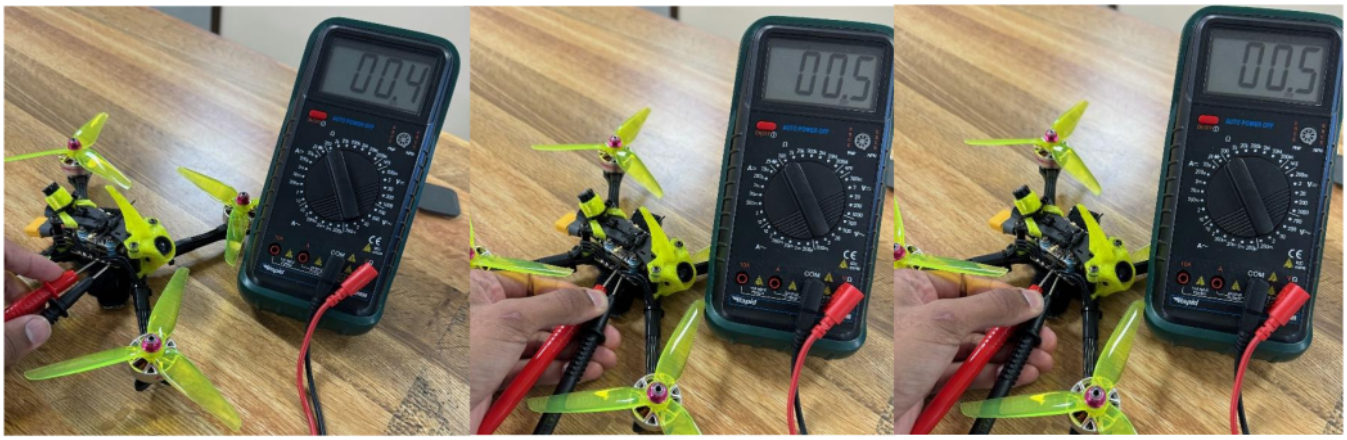


Figure 46 - Motor 2 Phase Balance Test

Good evidence

Table 12 - Motor Ground Check

Description	Motor No.	Expected Result	Actual Result (Ω)			Pass/Fail (P/F)
			$\phi 1\ to\ GND$	$\phi 1\ to\ GND$	$\phi 2\ to\ GND$	
Ensure each motor isn't grounded, which is a potential cause of the motor securing screws touching the windings.	1	There should be no continuity when putting the multimeter probes between any phase and ground.	O/C	O/C	O/C	P
	2		O/C	O/C	O/C	P
	3		O/C	O/C	O/C	P
	4		O/C	O/C	O/C	P

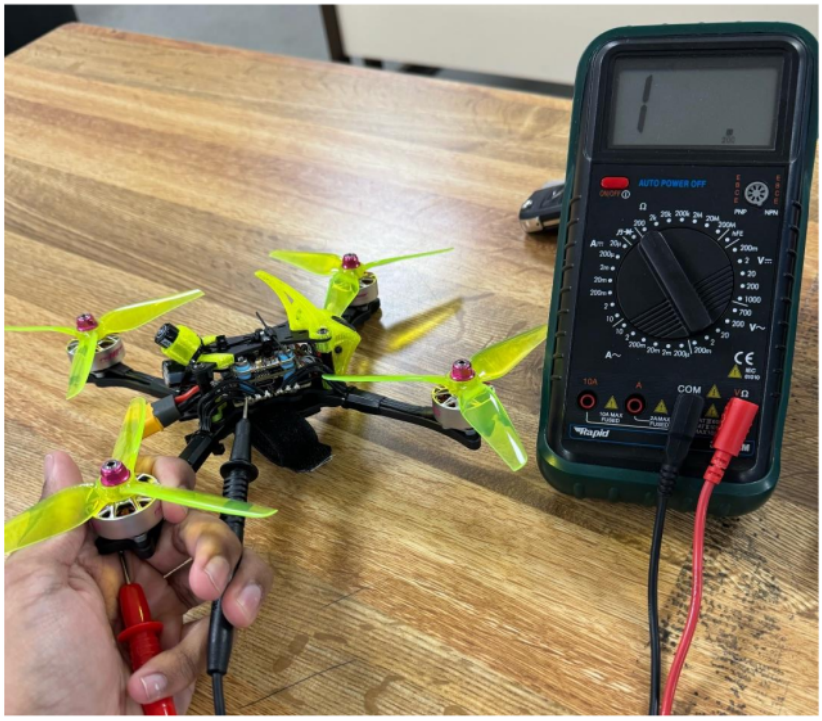


Figure 47 - Motor 1 Ground Check (Phase One to Motor Screw)

Good evidence

Test 2 Part 1 – Input Channel Mapping:



Figure 48 - Gimbal Calibration

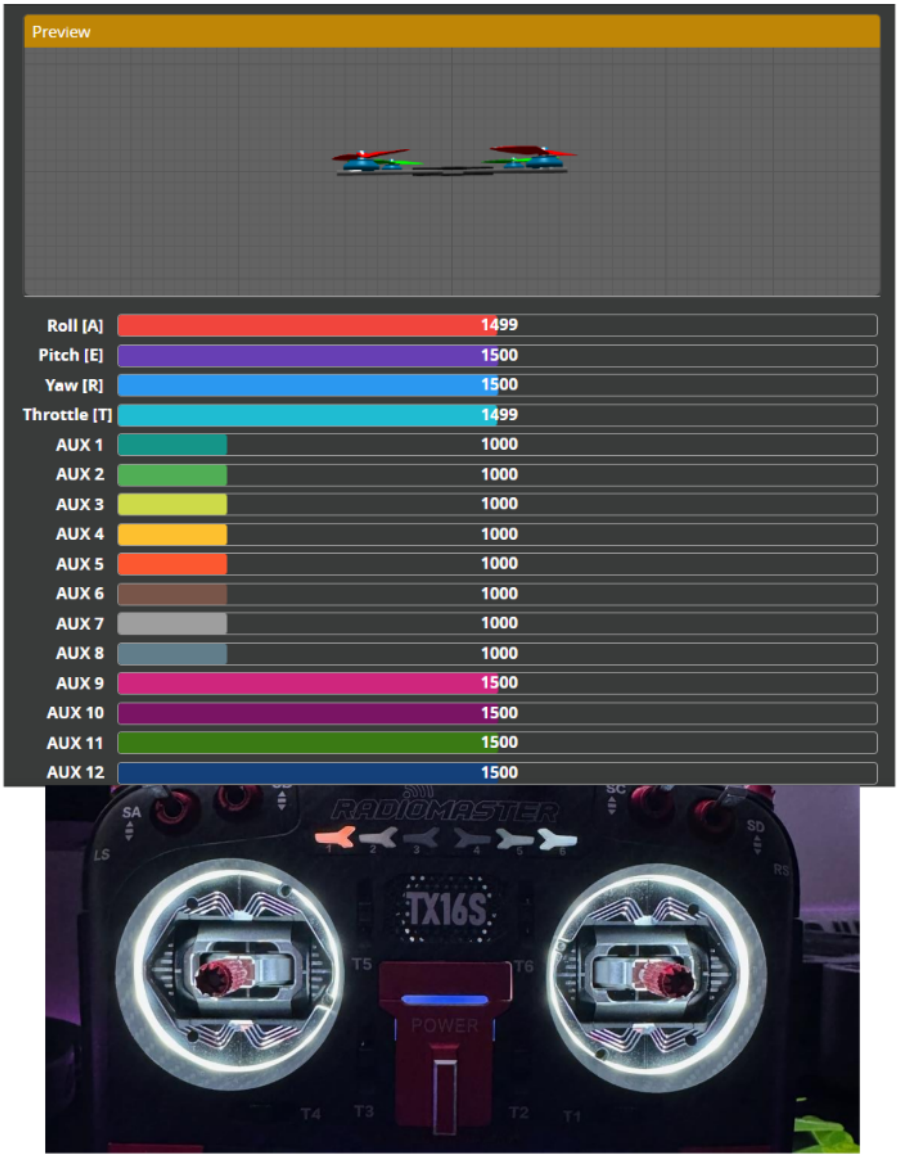


Figure 49 - Gimbals Centred

(See next page for input channel mapping checks)

Table 13 - Input Channel Mapping Checks

Description	Channel No.	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
Each channel being used should correspond to the input being on the receiver tab on betaflight. If they are mismatched, they need changing. This was completed by applying the commands to the radio whilst the drone was plugged into the software. Note that 1000 is the minimum threshold for each channel and 2000 is the maximum threshold.	1 (T)	Input 'T' should show 1000 when channel 1 on the radio is set to its lowest position and show 2000 when at its highest position.	Input 'T' correctly showed a value of 1000 when the radio channel was set to fully low and 2000 when fully high.	P	Figures 50&51
	2 (A)	Input 'A' should show 1000 when channel 2 on the radio is set to its lowest position and show 2000 when at its highest position.	Input 'A' correctly showed a value of 1000 when the radio channel was set to fully low and 2000 when fully high.	P	Figures 52&53
	3 (E)	Input 'E' should show 1000 when channel 3 on the radio is set to its lowest position and show 2000 when at its highest position.	Input 'E' correctly showed a value of 1000 when the radio channel was set to fully low and 2000 when fully high.	P	Figures 54&55
	4 (R)	Input 'R' should show 1000 when channel 4 on the radio is set to its lowest position and show 2000 when at its highest position.	Input 'R' correctly showed a value of 1000 when the radio channel was set to fully low and 2000 when fully high.	P	Figures 56&57

Good use of table

	5 (AUX1)	Input AUX 1 should show 2000 when the arm/disarm switch is made.	AUX 1 showed a value of 2000 when the switch was made.	p	Figure 58
	6 (AUX2)	Input AUX 2 should show 2000 when the pre-arm switch is made.	AUX 2 showed a value of 2000 when the switch was made.	P	Figure 59
	8 (AUX4)	Input AUX 4 should show 1500 when the beeper/flight Mode switch is in the middle position and 2000 at the last position.	AUX 4 showed a value of 1500 when in the middle position and 2000 when the switch was at the last position.	P	Figures 60&61

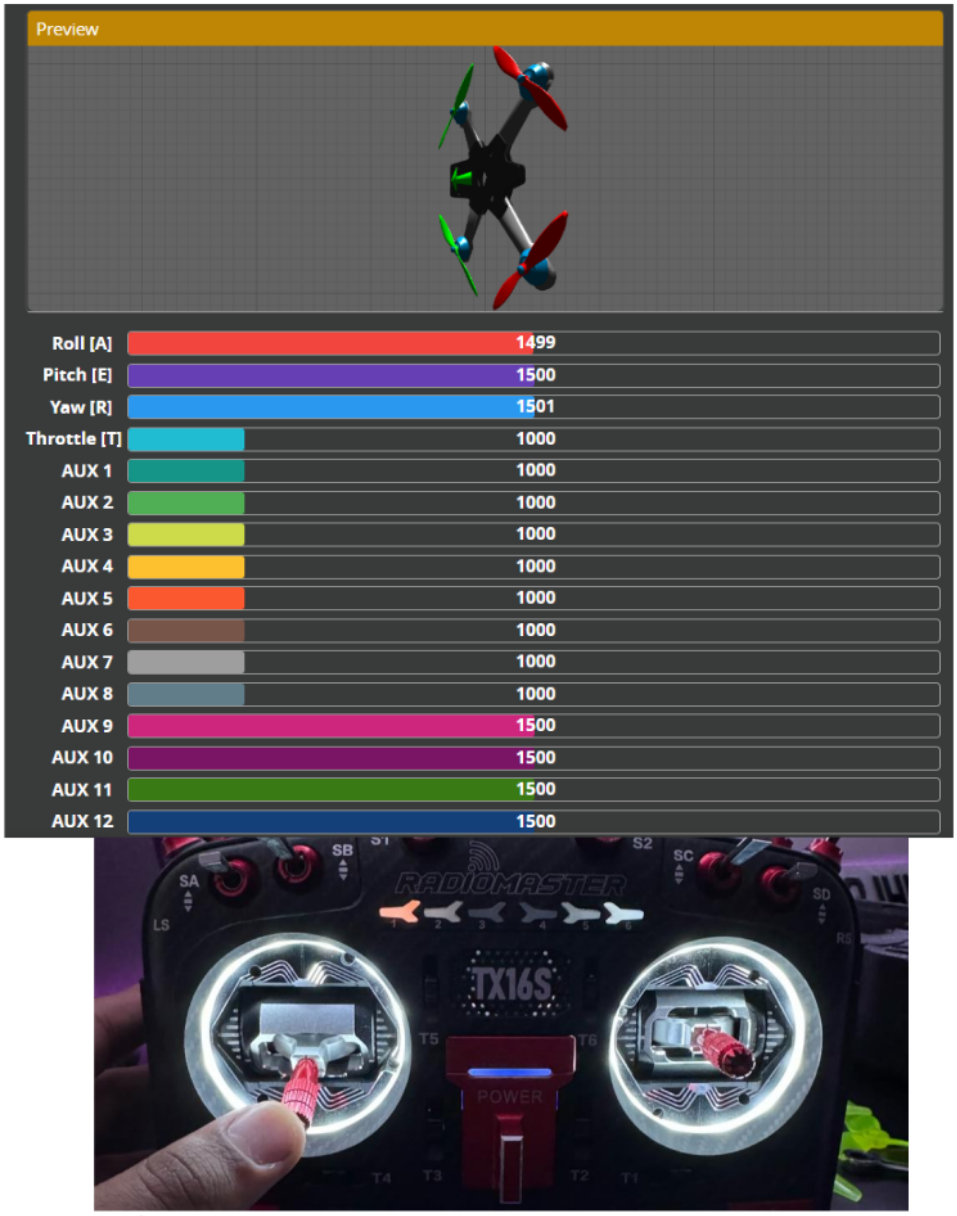


Figure 50 - Channel 1 (Throttle) Minimum Value

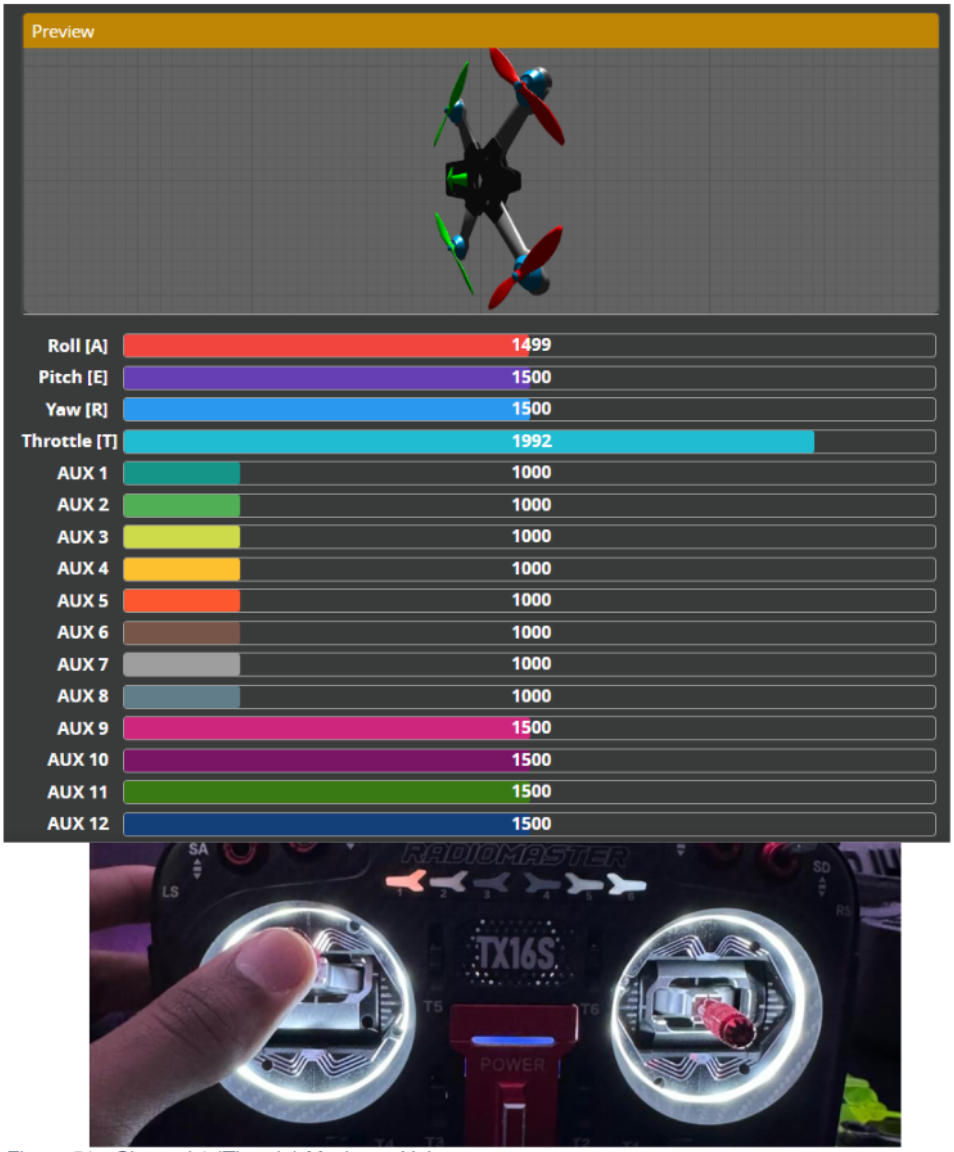


Figure 51 - Channel 1 (Throttle) Maximum Value

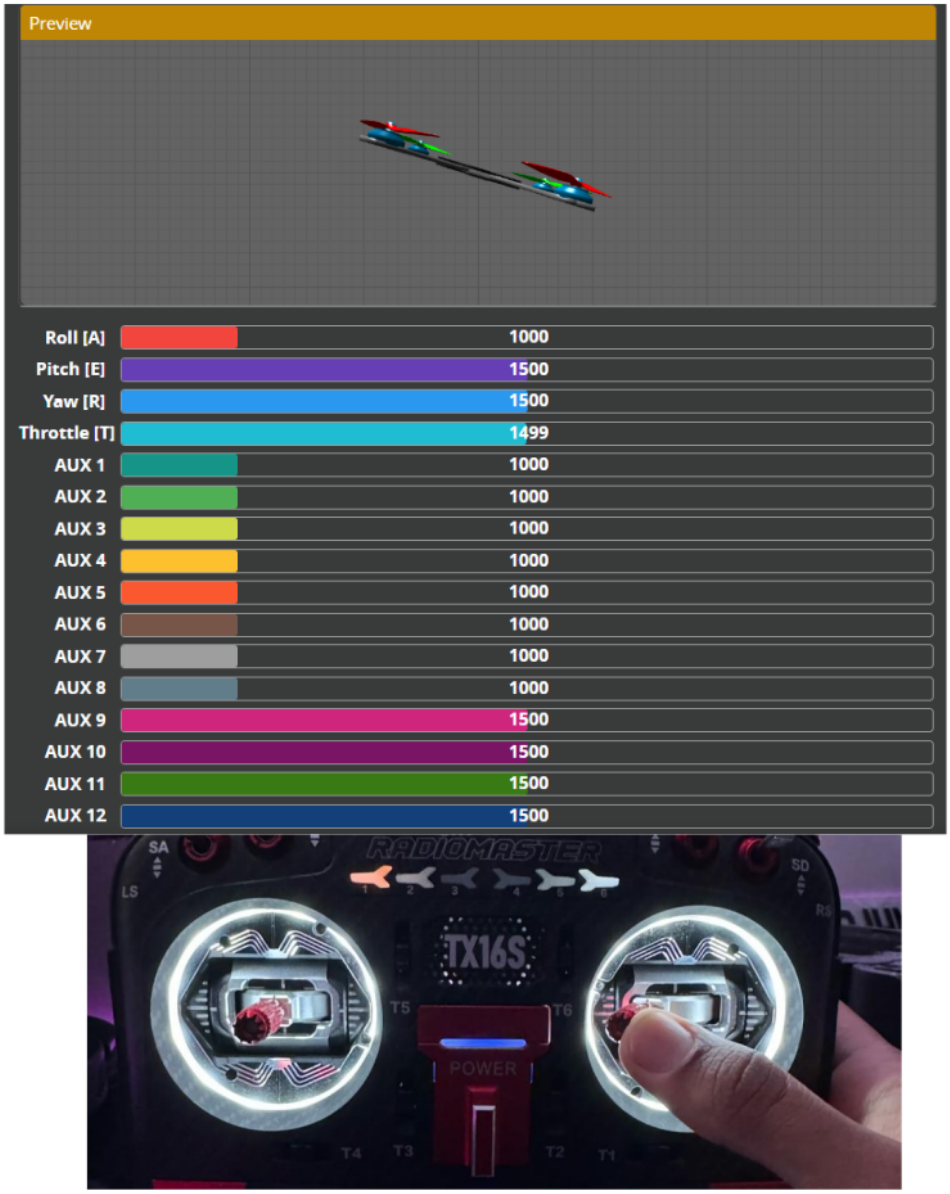


Figure 52 - Channel 2 (Roll) Minimum Value

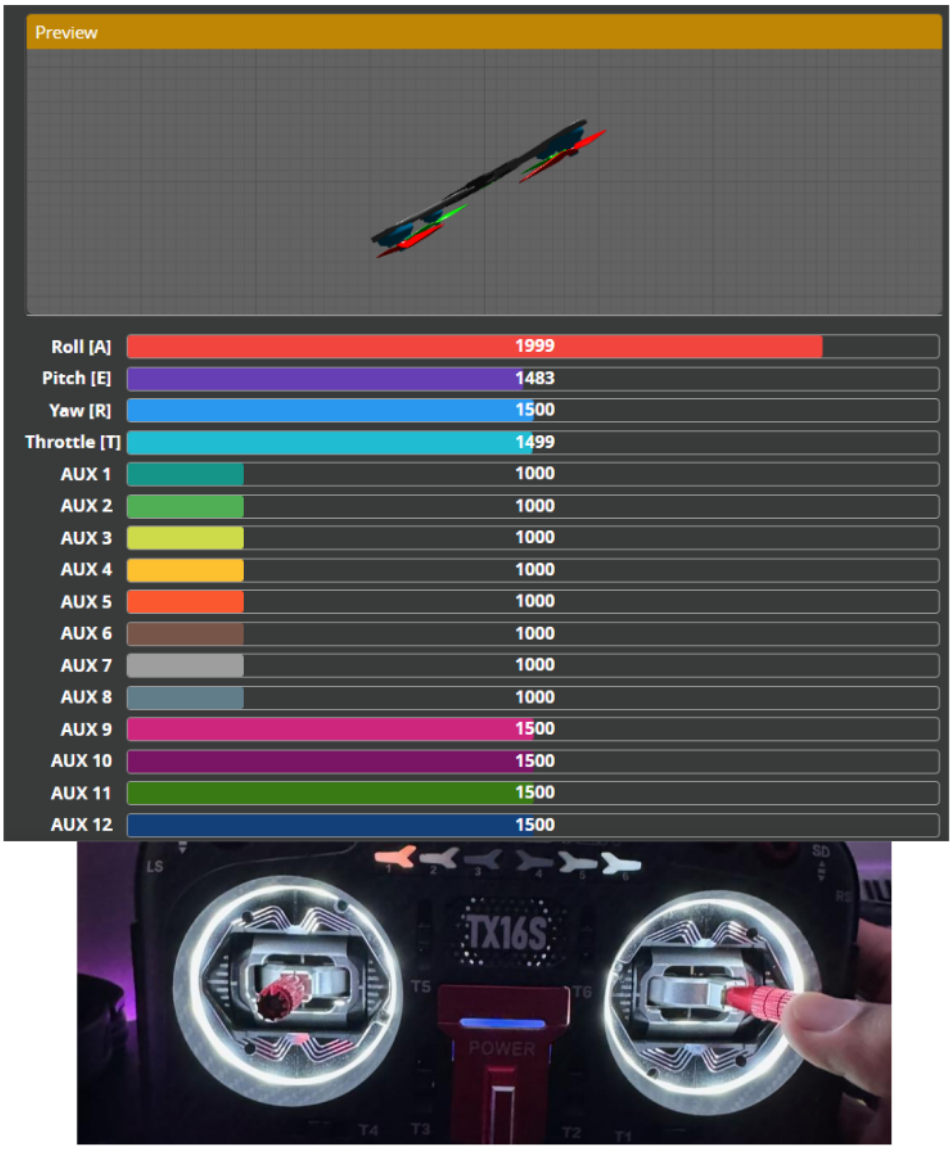


Figure 53 - Channel 2 (Roll) Maximum Value

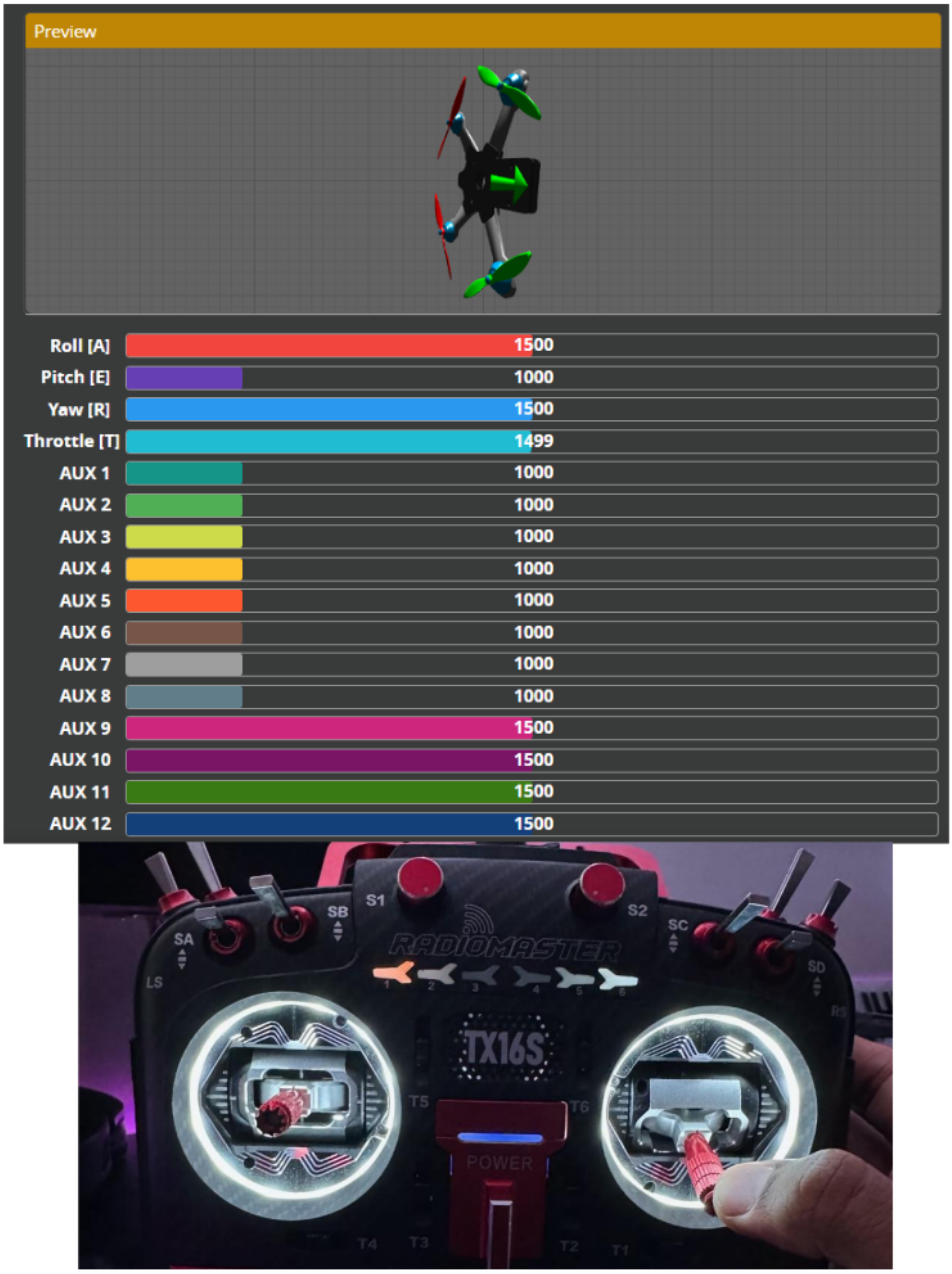


Figure 54 - Channel 3 (Pitch) Minimum Value

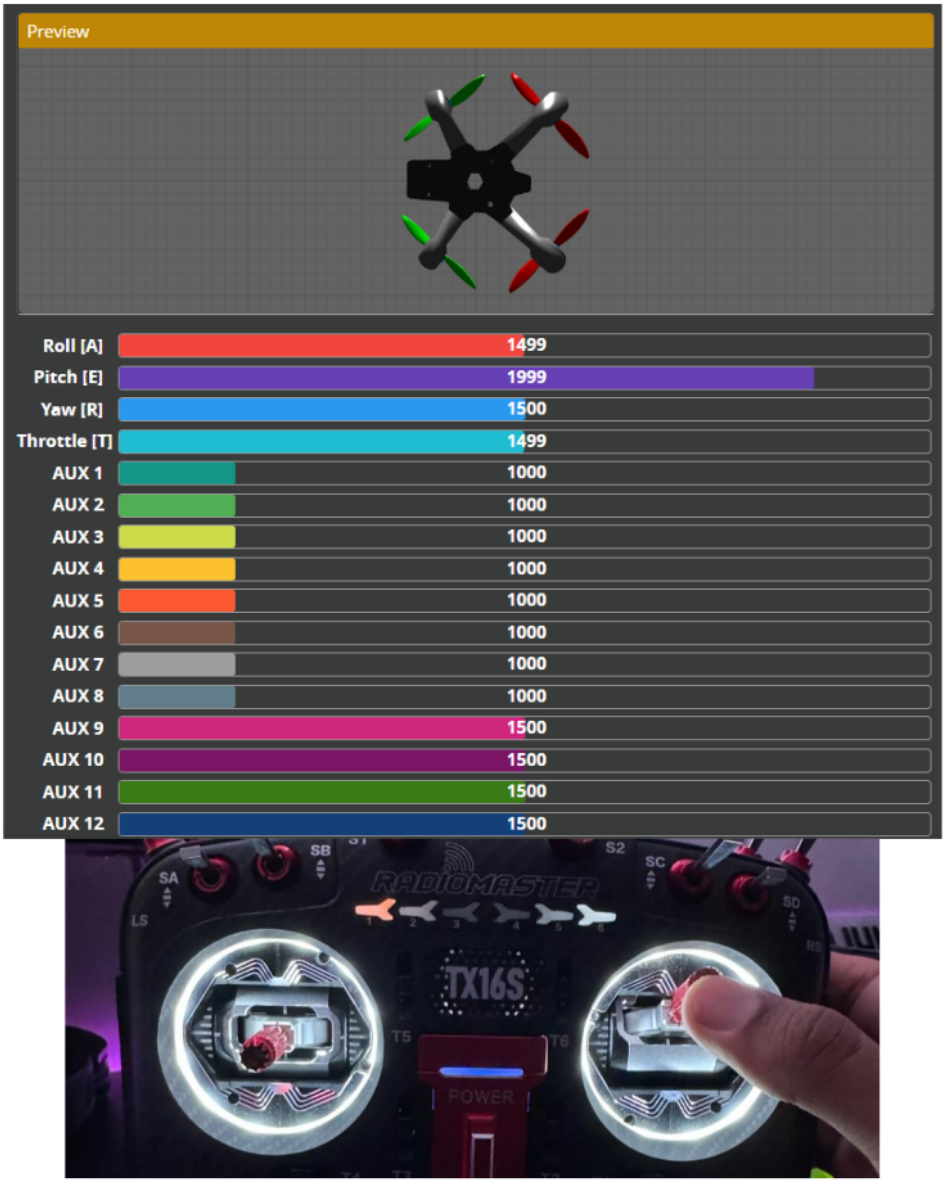


Figure 55 - Channel 3 (Pitch) Maximum Value

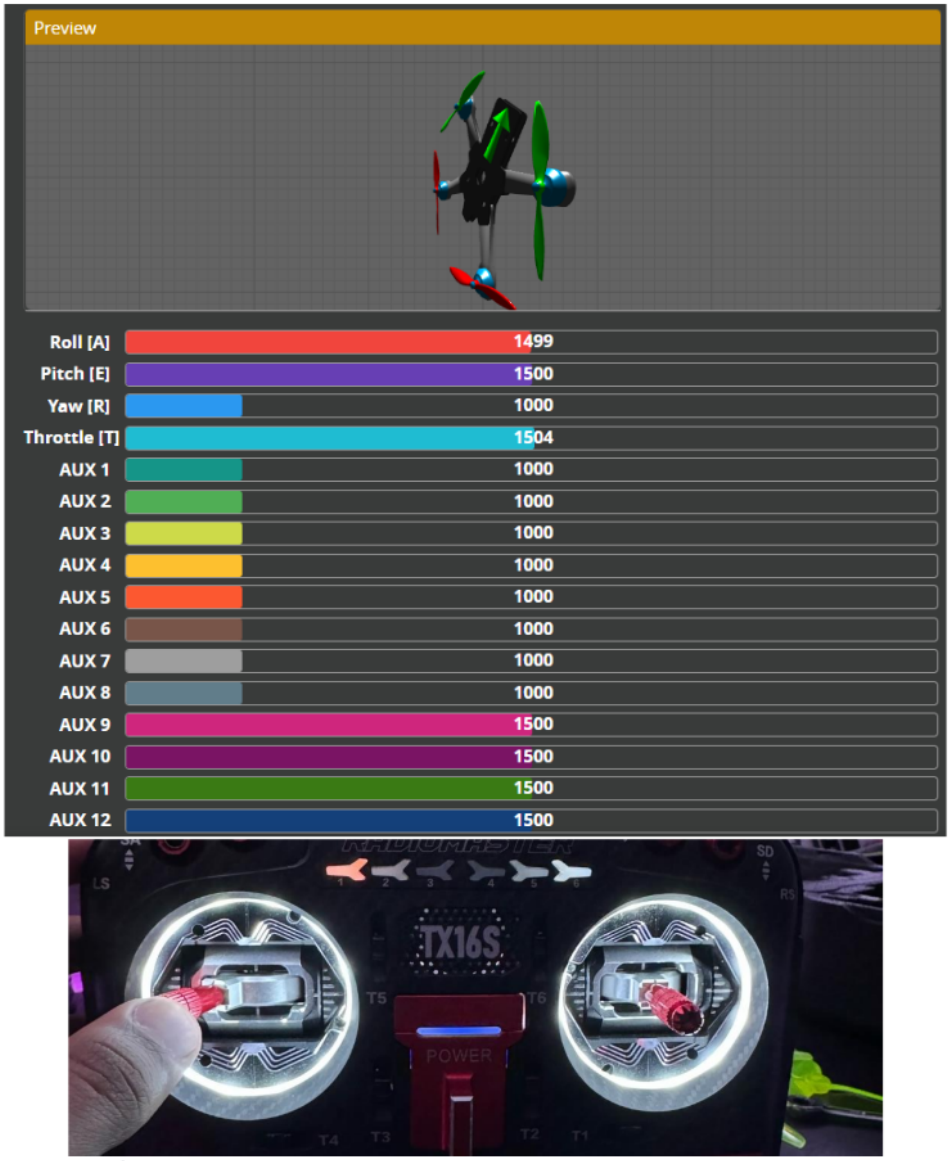


Figure 56 - Channel 4 (Yaw) Minimum Value

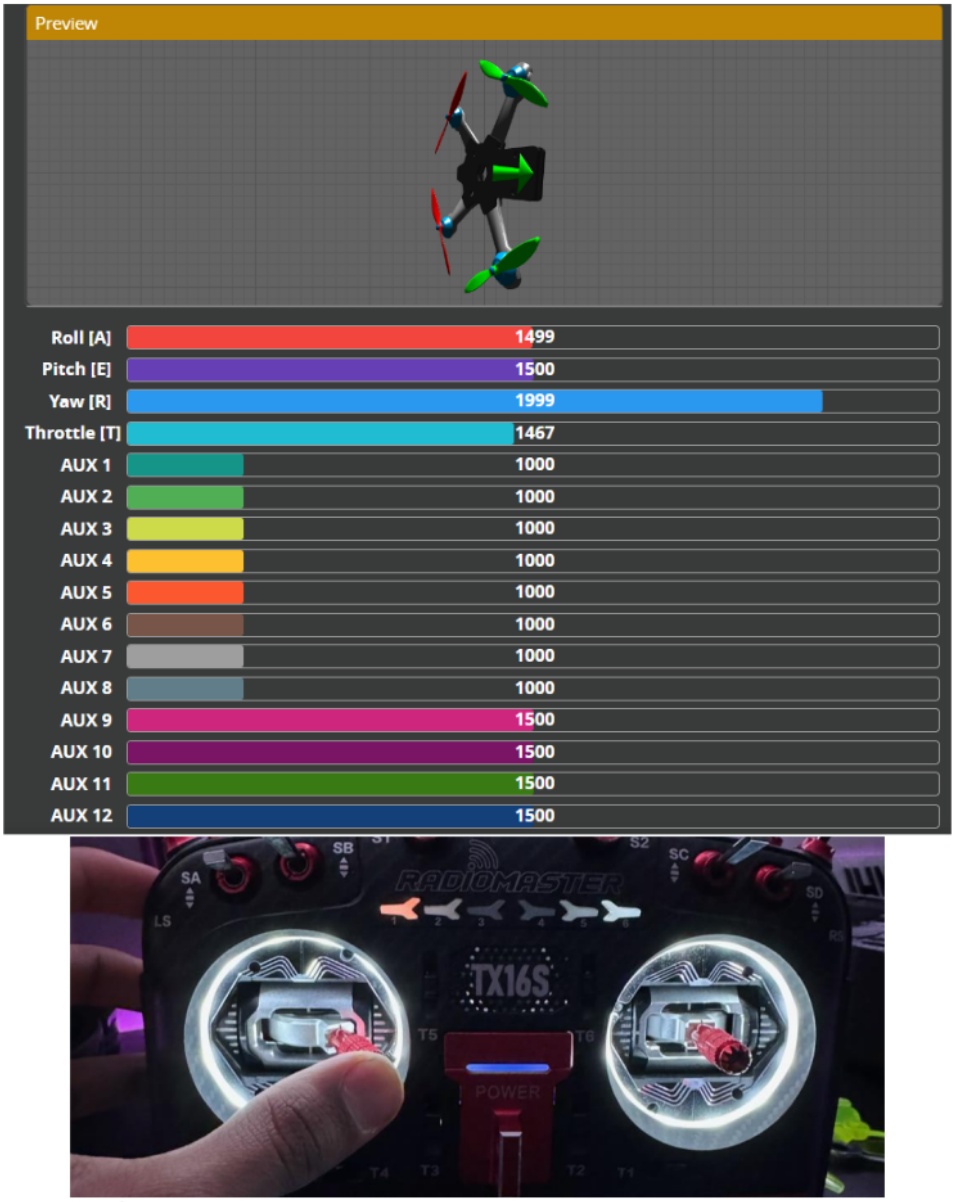


Figure 57 - Channel 4 (Yaw) Maximum Value

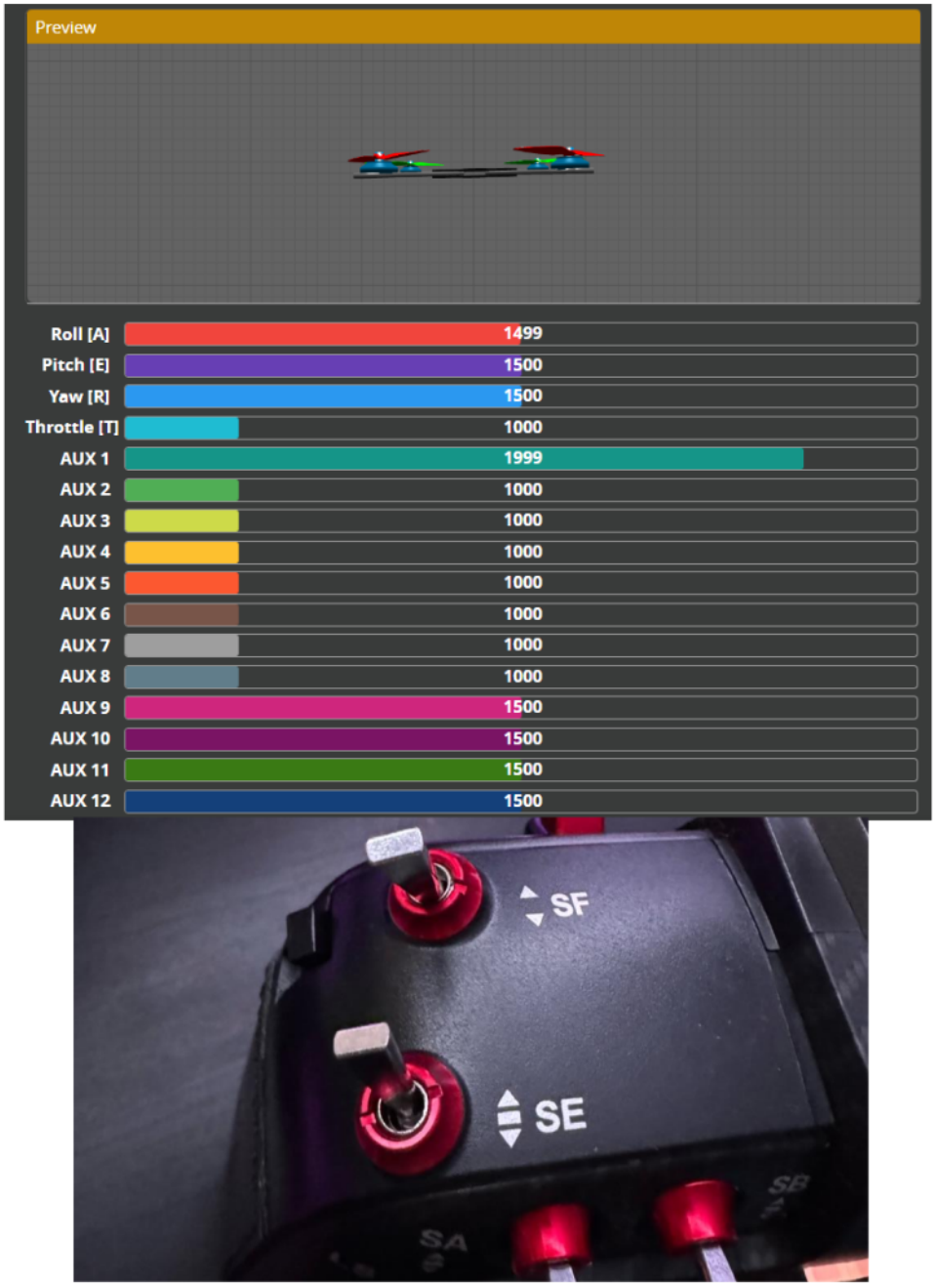


Figure 58 - Channel 5 (AUX1) Switch Made



Figure 59 - Channel 6 (AUX2) Switch Made

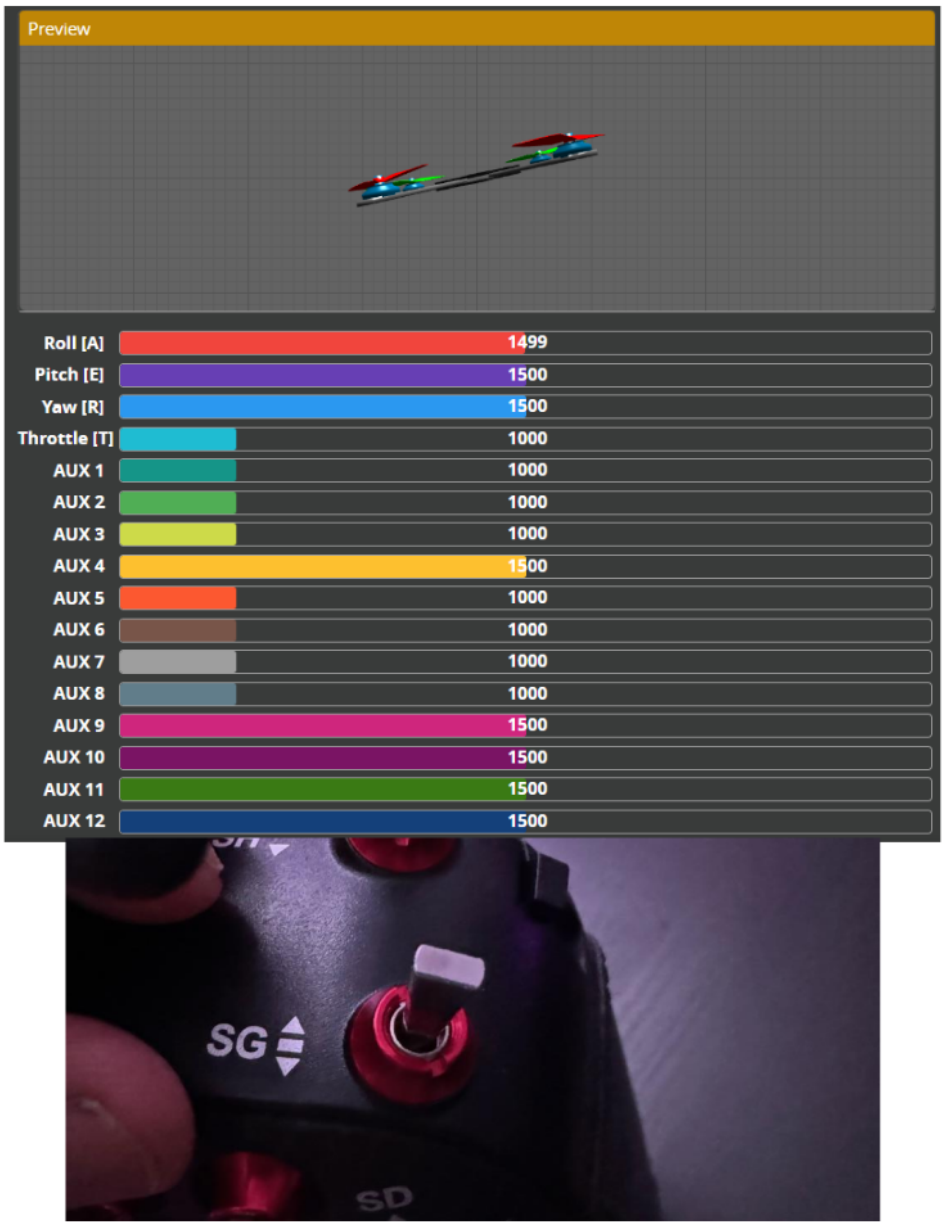


Figure 60 - Channel 8 (AUX4) Switch Middle Position

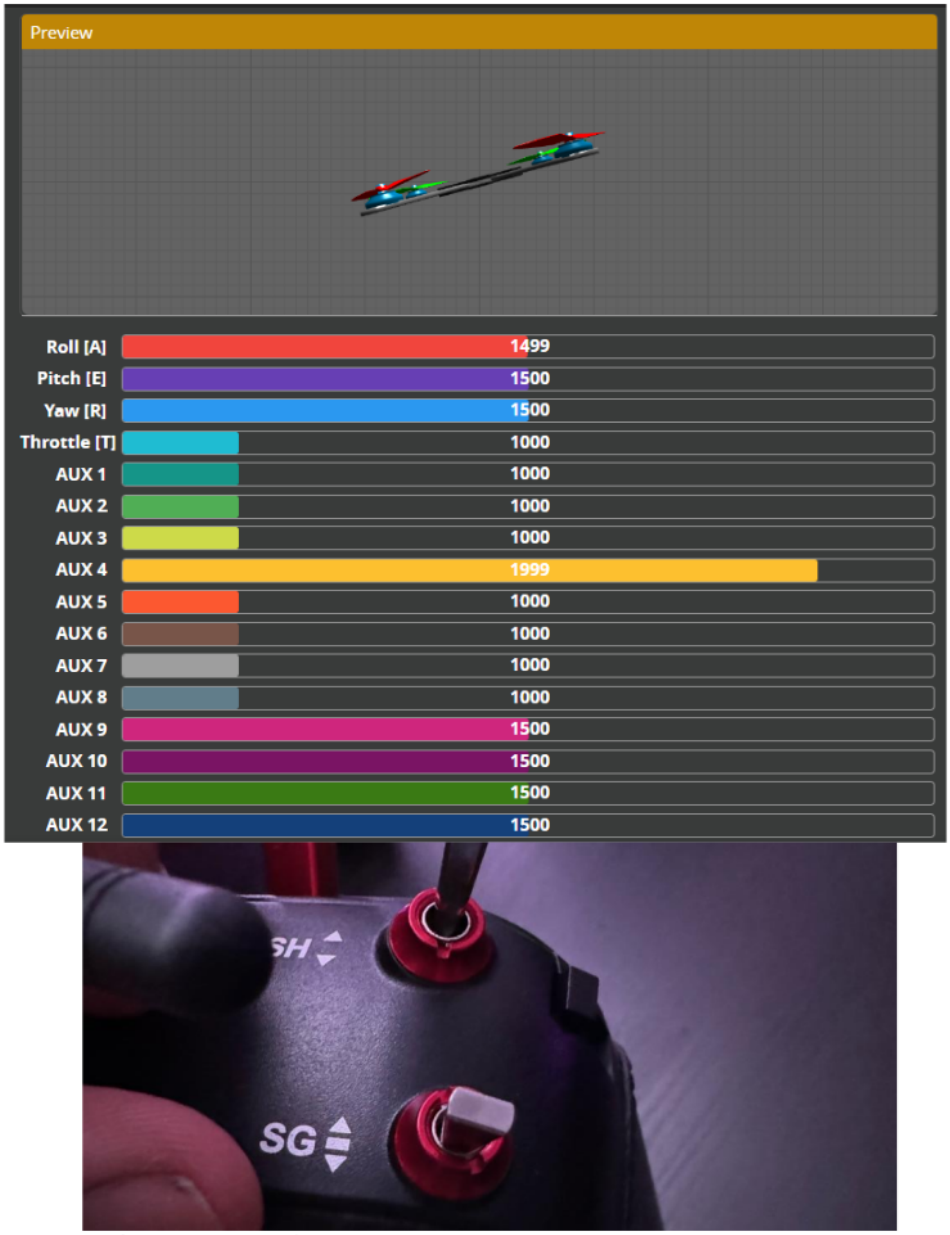


Figure 61 - Channel 8 (AUX4) Switch Last Position

Test 2 Part 2 – Switch Outputs:

Table 14 - Switch Outputs Test

Description	Test	Switch Channel(s)	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
Ensure the assigned switches are operational by testing the drone outputs.	A	AUX1 & AUX2	The motors should only arm and spin at an idle of 5.5% speed if both of the switches are made.	The motors did NOT arm with only AUX1(Arm switch) and did NOT arm with AUX2 (Pre-arm switch). The motors armed with both switches engaged with Pre-Arm first and at 5.5% idle.	P	Figures 62, 63&64
	B	AUX4	The drone should start beeping on the middle selection switch and switch to 'flip after crash mode' in the third position.	The drone started beeping when the middle selection was engaged and the 'flip after crash mode' showed enabled on the OSD in the goggles.	P	Figure 65

Good table of checks



Figure 62 Test A- AUX1 Arm Switch Made (Motors Not Armed)



Figure 63 Test A - AUX2 Pre-Arm Switch Made (Motors Not Armed)



Figure 64 Test A - AUX1 (Arm) & AUX2 (Pre-Arm) Switches Made (Motors Armed at 10% idle)



Figure 65 Test B - AUX4 3 Position Switch Made to 3rd Position and 'Flip After Crash Mode' Selected in OSD

Test 3 Part 1 - Motor Mapping and Direction Check:

Table 15 - Motor Mapping and Direction Check

Description	Motor No.	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
Ensure the motors are correctly mapped when each one is selected and are spinning in the correct directions shown in the software.	1	Motor 1 should spin clockwise when motor 1 is selected on betaflight.	Motor 1 spun clockwise when motor 1 was selected.	P	Figure 66
	2	Motor 2 should spin anti-clockwise when motor 2 is selected on betaflight.	Motor 2 spun anti-clockwise when motor 2 was selected.	P	Figure 67
	3	Motor 3 should spin anti-clockwise when motor 3 is selected on betaflight.	Motor 3 spun anti-clockwise when motor 3 was selected.	P	Figure 68
	4	Motor 4 should spin clockwise when motor 4 is selected on betaflight.	Motor 4 spun clockwise when motor 4 was selected.	P	Figure 69

Good table with ref to evidence

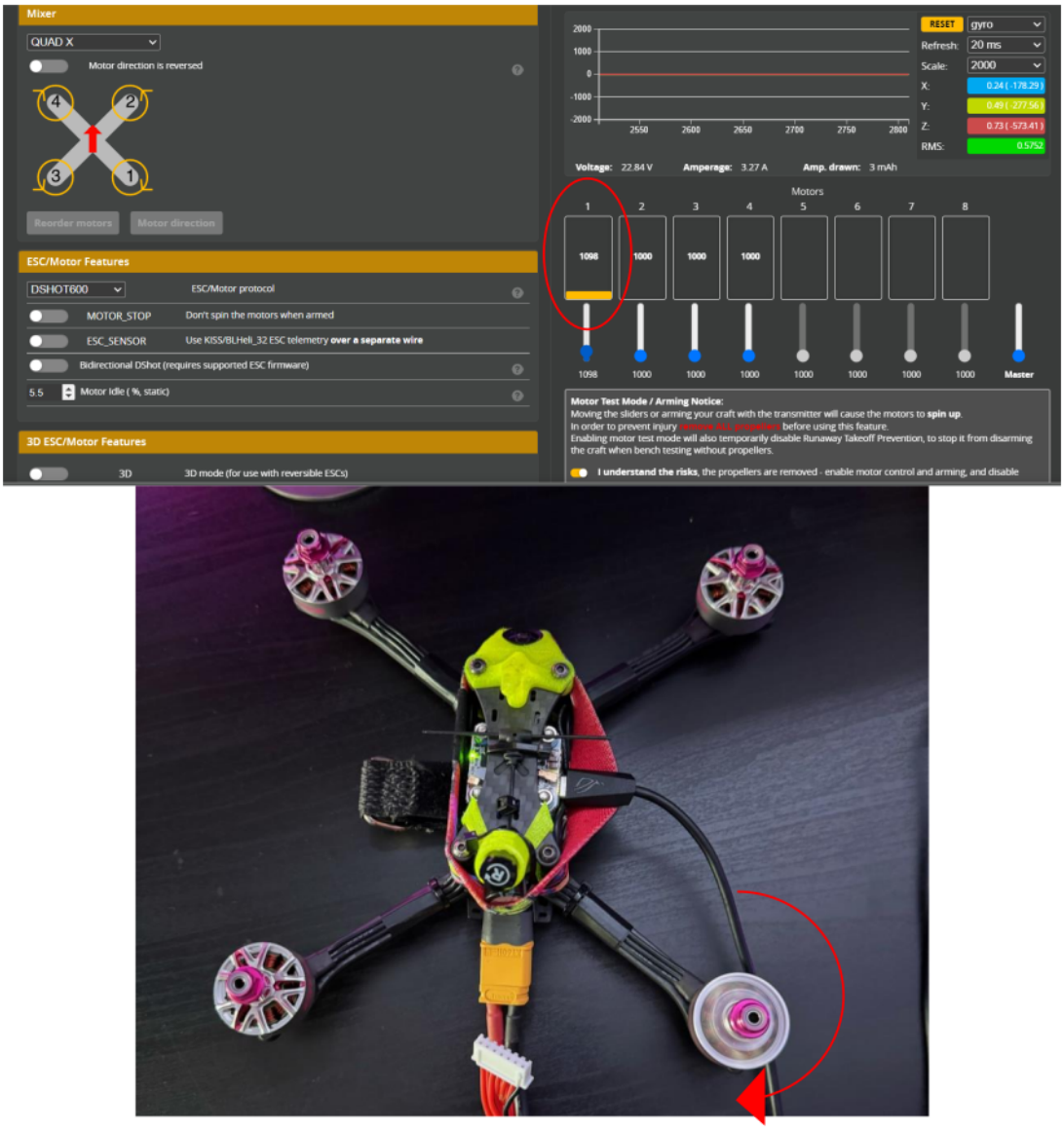


Figure 66 - Motor 1 Selected

This is a very interesting test wherby individual motors can be selected and tested

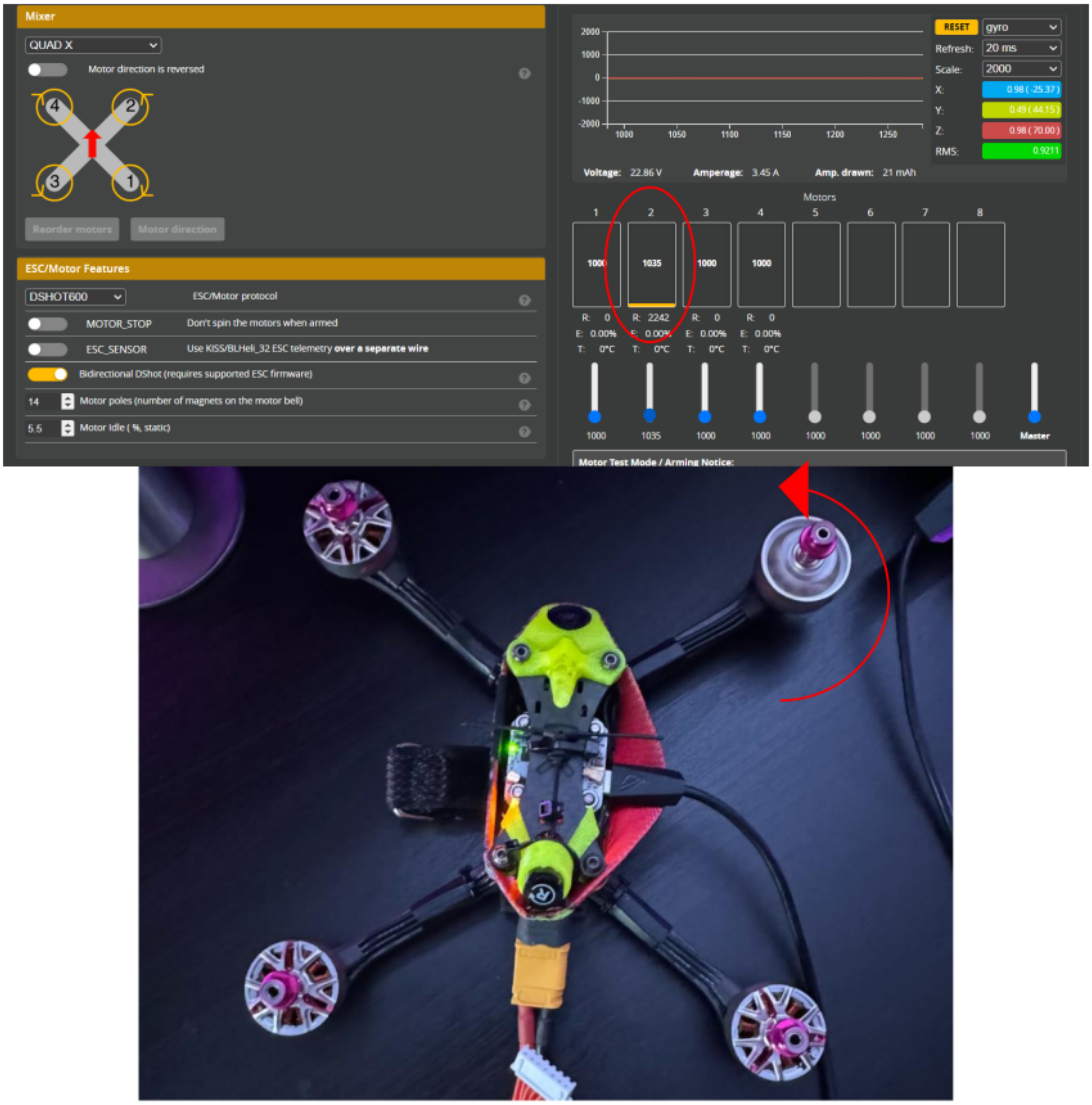


Figure 67 - Motor 2 Selected

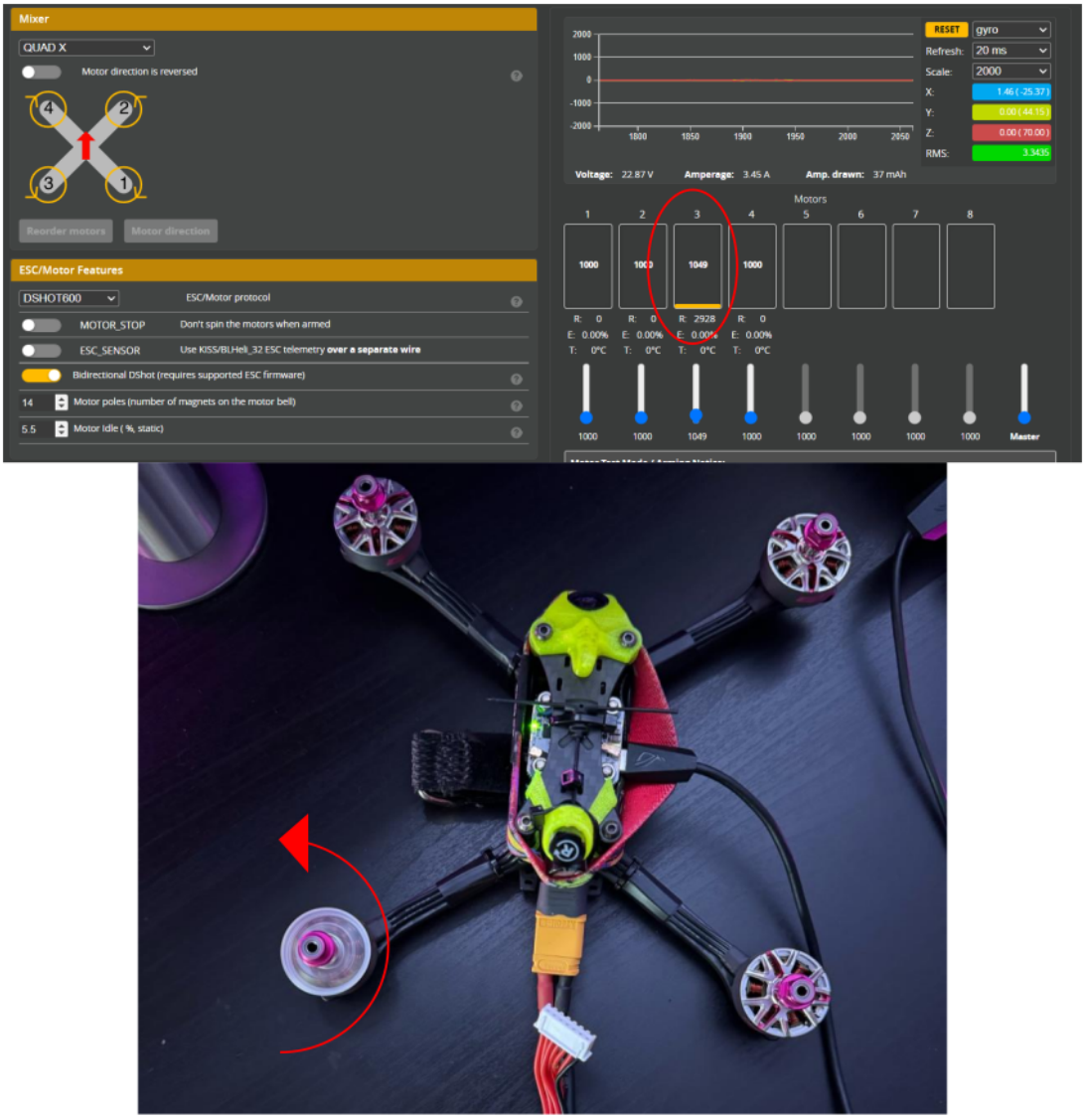


Figure 68 - Motor 3 Selected

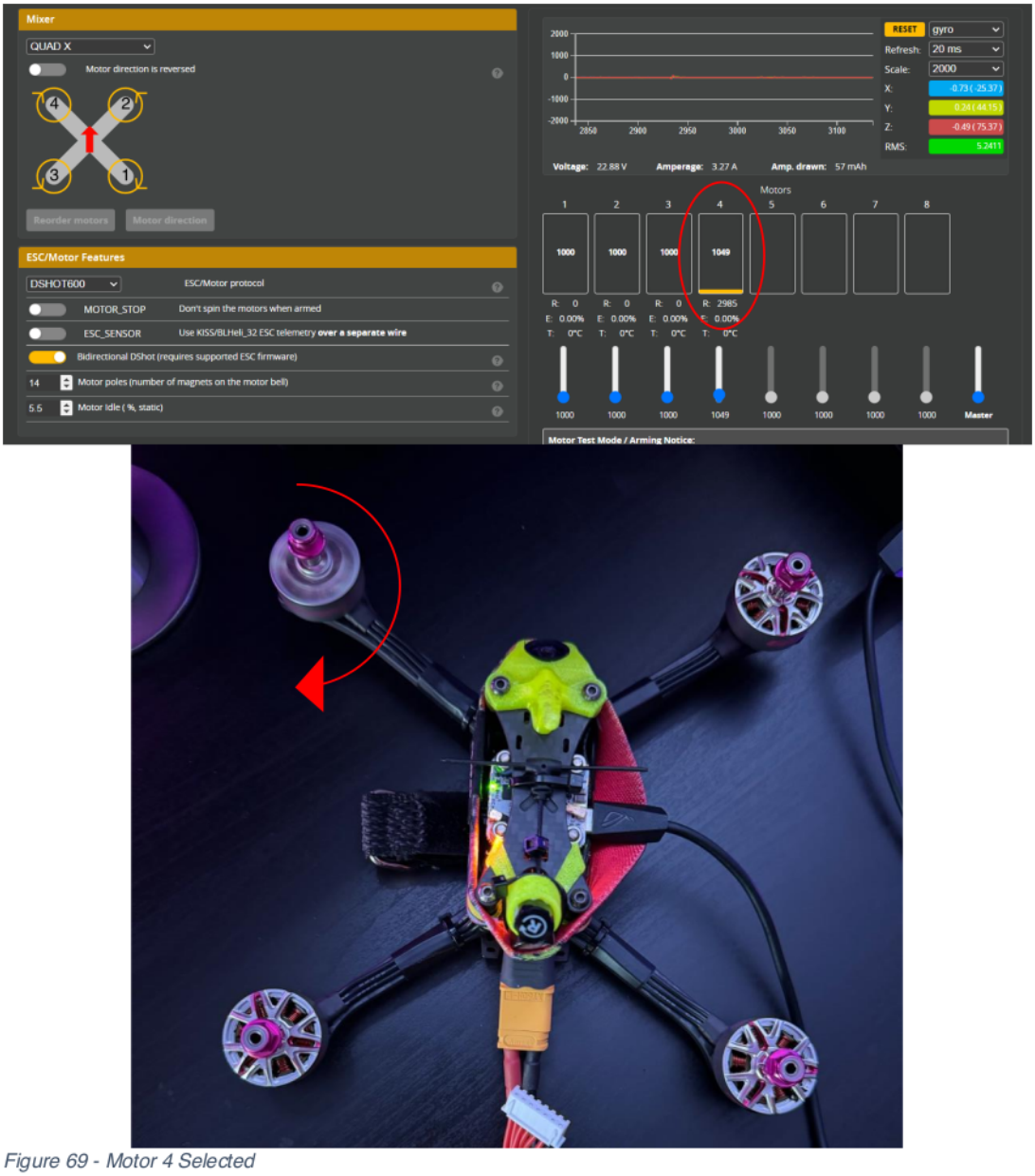


Figure 69 - Motor 4 Selected

Test 3 Part 2 – Failsafe Check:

Table 16 - Failsafe Check

Description	Procedure	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
Ensure all of the motors disarm when connection to the radio transmitter is lost.	With both the transmitter and drone powered up, arm the motors and turn the radio off.	When the transmitter is turned off, the radio signal is lost, and the drone should enter failsafe mode by disarming all of the motors.	The motors disarmed straight after the radio was turned off. The light on the receiver also turned from green to red to show its lost connection.	P	Figures 70&71



Figure 70 - Motors Armed

Good table with ref to evidence



Figure 71 - Motors Disarmed After Radio Turned Off

Test 4 Part 1 – VTX Output Power Check:



Figure 72 - VTX Transmitting at 25mW Output Power

Test 4 Part 2 – VTX Channel Accuracy:

Table 17 - VTX Channel Accuracy

Description	VTX Channel Number (Using Raceband)	Result	Pass/Fail (P/F)	Evidence
Ensure the drone is transmitting on the correct channel when selected on the transmitter. The channel should show its being received on the spectrum analyser on the goggles without any significant frequency interference on the adjacent channels.	1	Frequency received on race channel 1 with very little interference on other channels.	P	Figure 74
	2	Frequency received on race channel 2 with very little interference on other channels.	P	Figure 75
	3	Frequency received on race channel 3 with little interference on channel 8.	P	Figure 76
	4	Frequency received on race channel 4.	P	Figure 77
	5	Frequency received on race channel 5.	P	Figure 78
	6	Frequency received on race channel 6.	P	Figure 79
	7	Frequency received on race channel 7.	P	Figure 80
	8	Frequency received on race channel 8.	P	Figure 81

Good test for signals with ref to evidence



Figure 73 - Channel Selection Menu

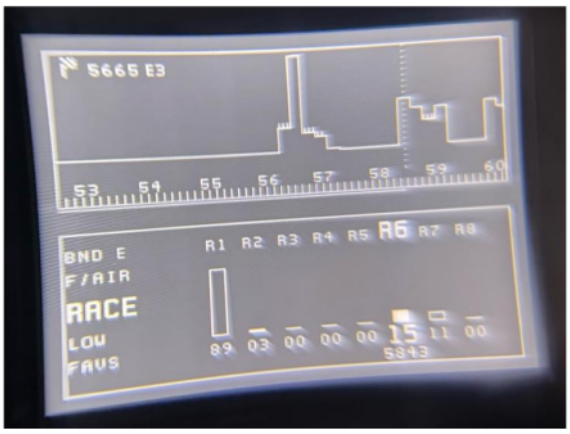


Figure 74 - Race Channel 1

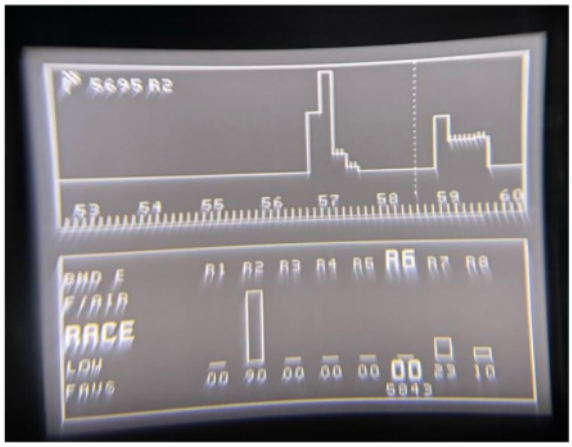


Figure 75 - Race Channel 2

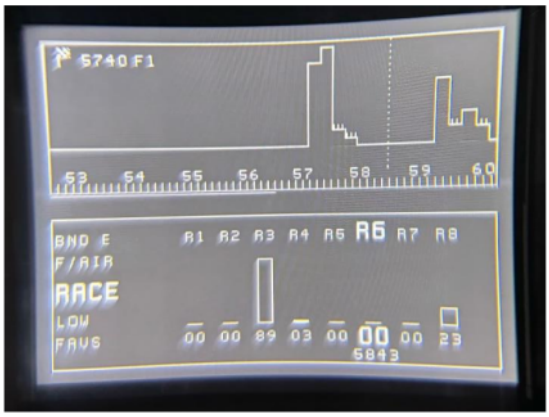


Figure 76 - Race Channel 3



Figure 77 - Race Channel 4

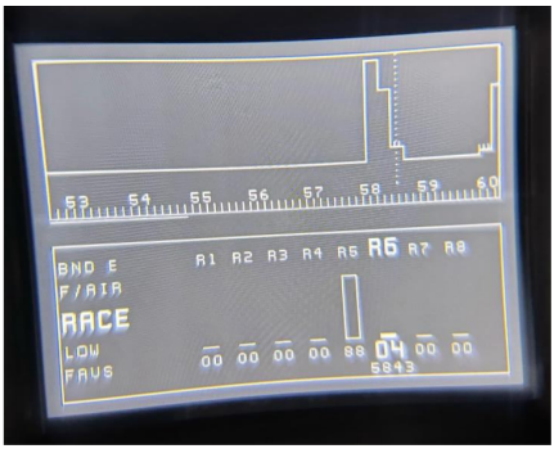


Figure 78 - Race Channel 5

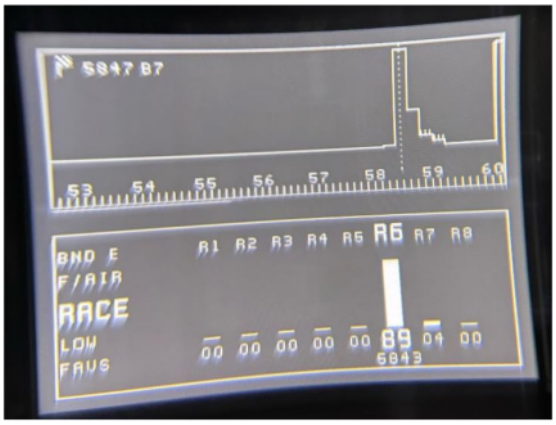


Figure 79 - Race Channel 6

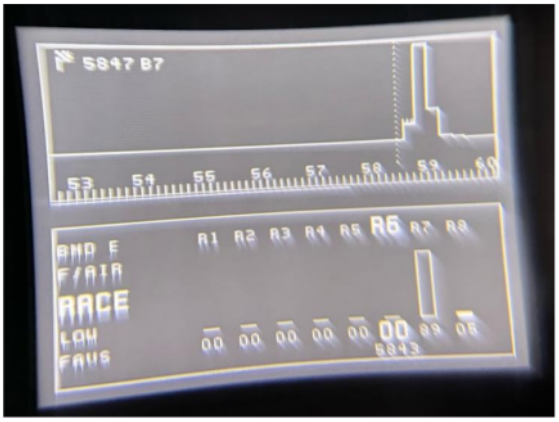


Figure 80 - Race Channel 7

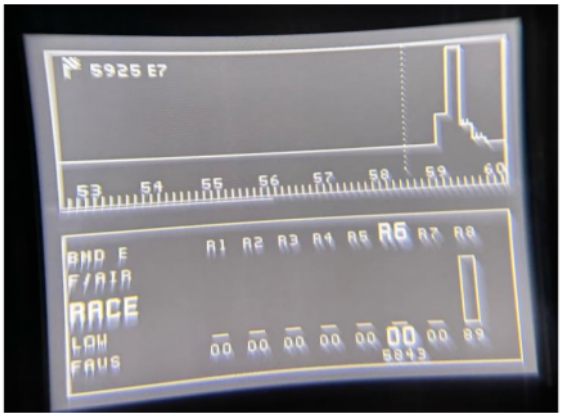


Figure 81 - Race Channel 8

Test 5 Part 1 – Initial PID and Flight Characteristics:

Table 18 - Initial PID and Flight Characteristics

Description	Axis	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
On the initial flight, ensure there are no extreme oscillations on each axis of rotation. Noise should also be monitored to see if the gyro angle fluctuates when it shouldn't. Ensure the drone is flyable without fast manoeuvres causing it to go unstable. Resultant actions must be considered, which includes what filters to enable and what parameters to tune.	Roll	On the blackbox log, the gyro [roll] feedback should follow the setpoint. Mild fluctuations due to noise can be expected.	The gyro angle feedback followed the setpoint on most of the flight duration, however the motor outputs became slightly unstable on some occurrences with mild setpoint change.	F	Figure 82
	Pitch	On the blackbox log, the gyro [pitch] feedback should follow the setpoint. Mild fluctuations due to noise can be expected.	The gyro followed the setpoint for most of the flight duration. It was noticed that there were oscillations during some occurrences when the setpoint dropped from high to low, but not significant.	P	Figure 83
	Yaw	On the blackbox log, the gyro [yaw] feedback should follow the setpoint. Mild oscillations due to noise can be expected.	This axis only uses PI control as yaw isn't used as much, but still performed well without significant oscillations.	P	Figure 84

God table for PID tests and ref to evidence

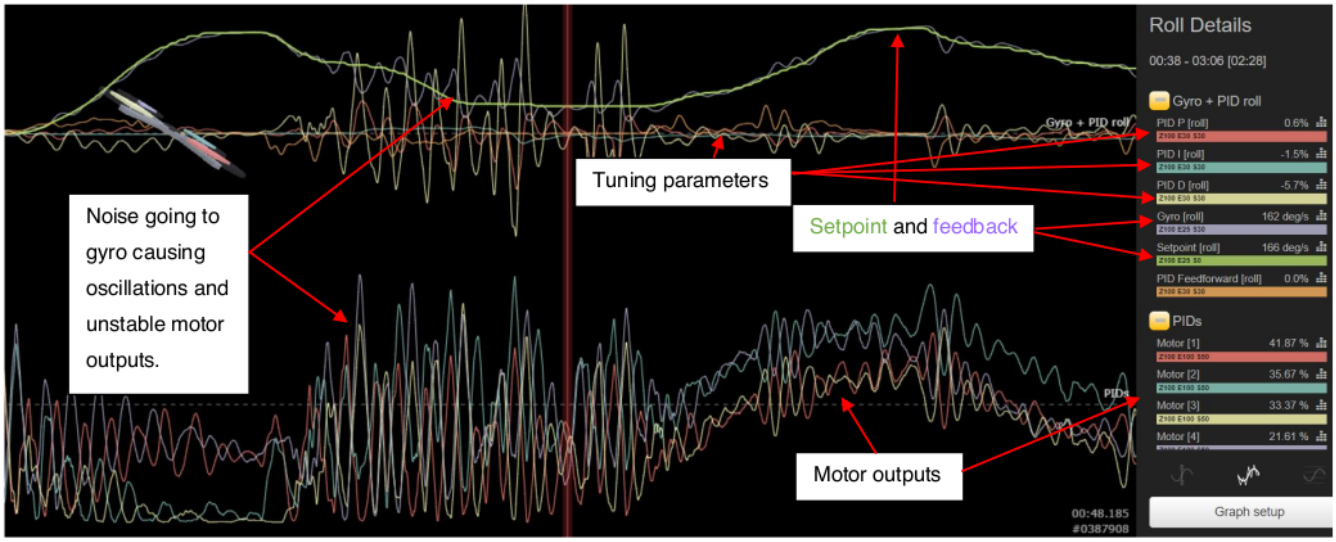


Figure 82 - Roll Axis Initial PID Performance

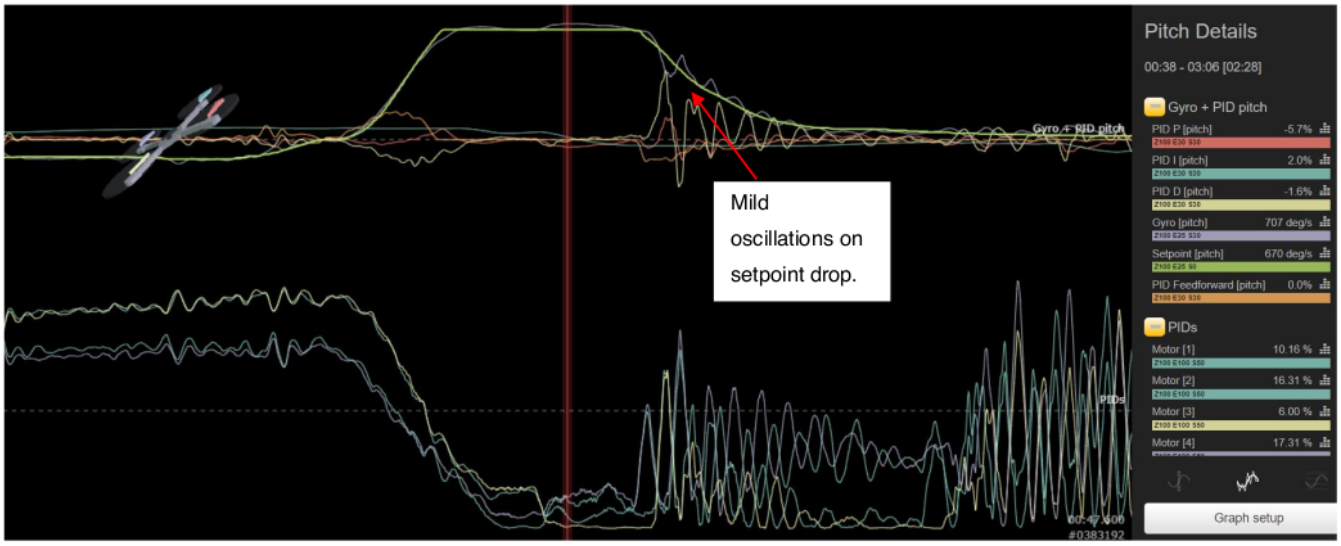


Figure 83 - Pitch Axis Initial PID Performance

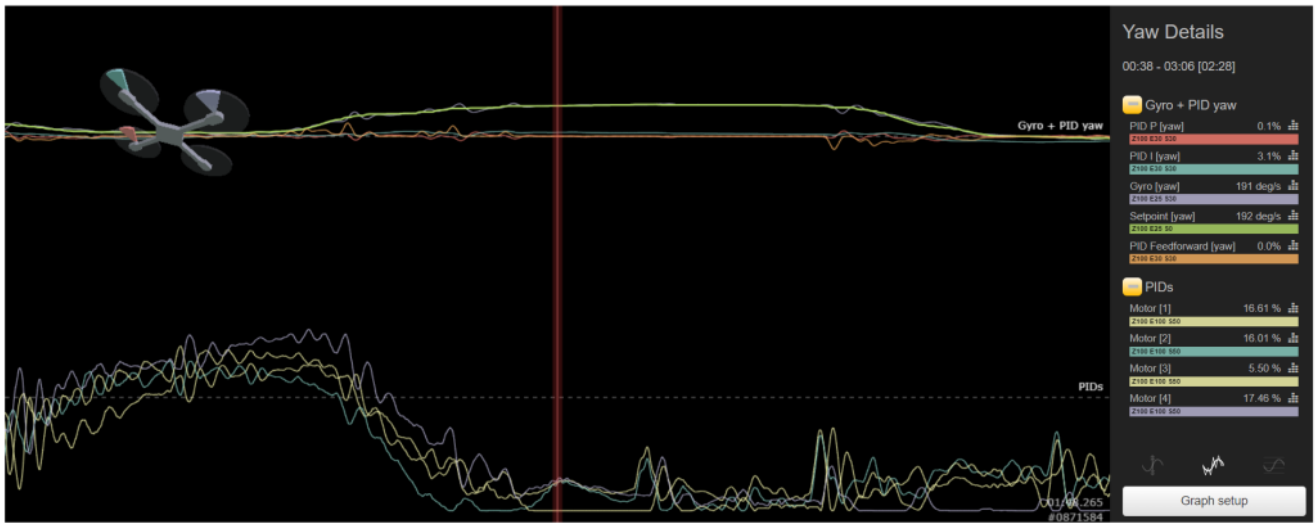


Figure 84 - Yaw Axis Initial PID Performance

Very good test evidence to support test table

Test 5 Part 2 – Current Draw:



Figure 85 - Current Draw Approx. 30A Average

Test 6 – Harmonic Analysis:

Table 19 - Harmonic Analysis

Description	Axis	Spectrograph Analysis		Evidence
		Frequency Spectrum	Frequency vs Throttle Spectrum	
Observe the noise and harmonics produced by the motors and determine which filters to apply for each case.	Roll	Max motor noise is seen at around 500Hz. A spike is also seen around 400Hz and in the low region at 40Hz. Low amplitude high frequencies can also be seen.	An exponential curve is seen from 150-400Hz and another one from 400-1000Hz. A notch is also present at 500Hz. This is most likely frame resonance.	Figures 86&87
	Pitch	Max motor noise is seen at around 500Hz. A low spike is also seen around 40Hz. Low amplitude high frequencies can also be seen.	An exponential curve is seen from 150-400Hz and another one from 300-1000Hz. Overall, not as noisy as the roll spectrum. A notch is also present at 500Hz which is likely to be frame resonance.	Figures 88&89
	Yaw	Max motor noise is seen at around 300Hz. Low amplitude high frequencies can also be seen.	An exponential curve is seen from 150-400Hz and another one from 300-1000Hz. Overall, not as noisy as the roll spectrum. The first harmonic appears to be noisier.	Figures 90&91

Good use of table

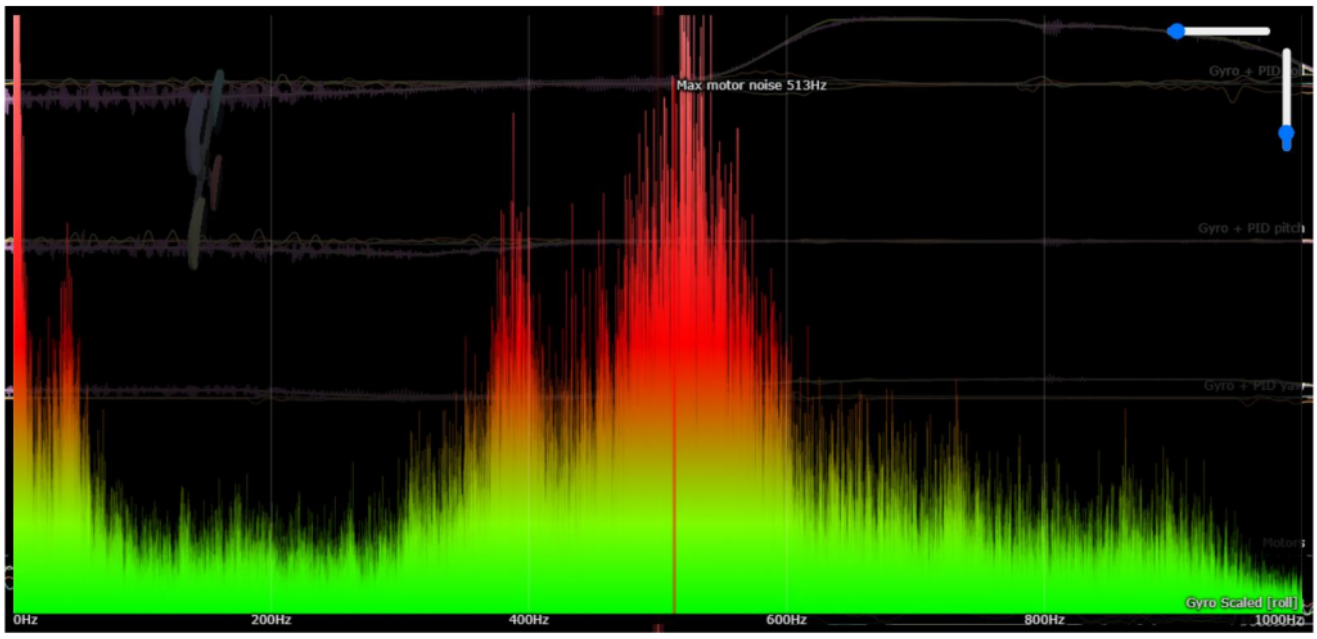


Figure 86 - Gyro [Roll] Frequency Spectrum

Spectrum shows harmonic interference

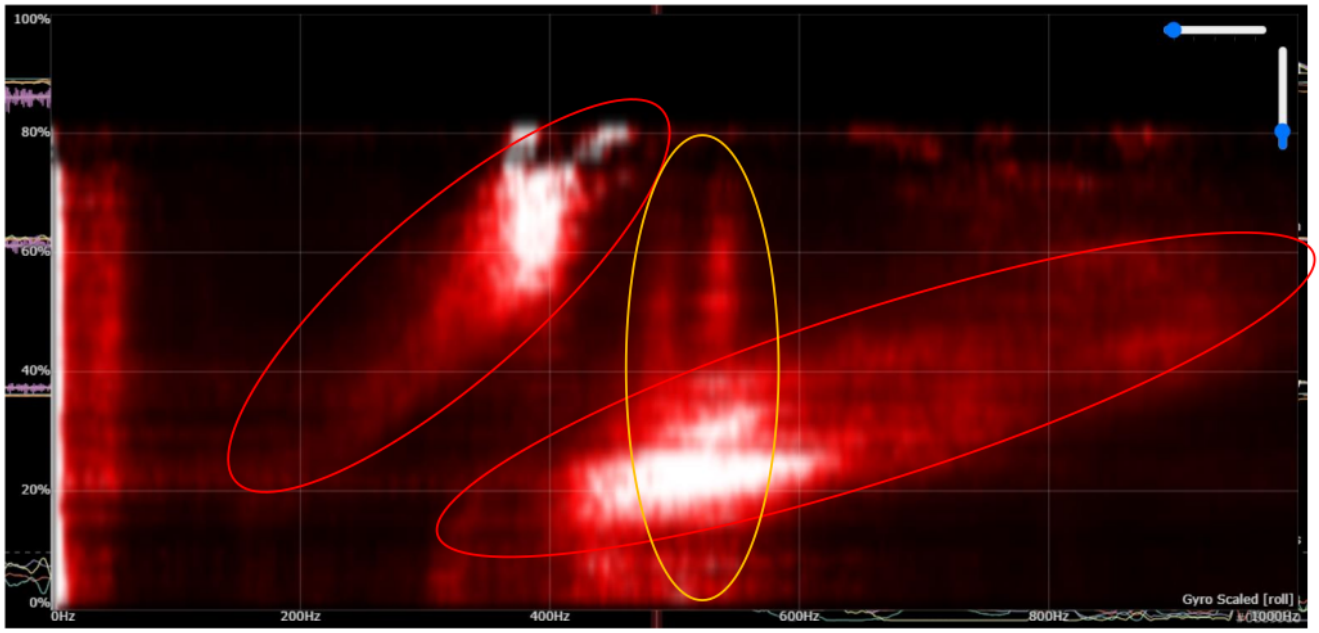


Figure 87 - Gyro [Roll] Frequency vs Throttle Spectrum

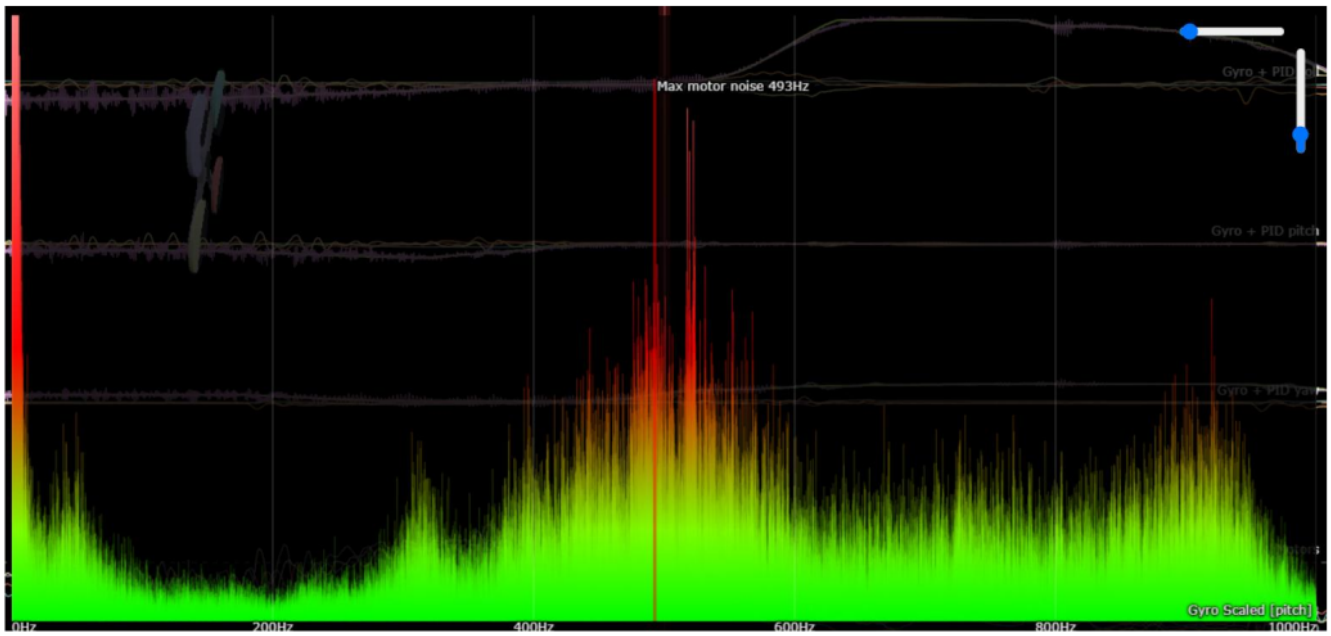


Figure 88 - Gyro [Pitch] Frequency Spectrum

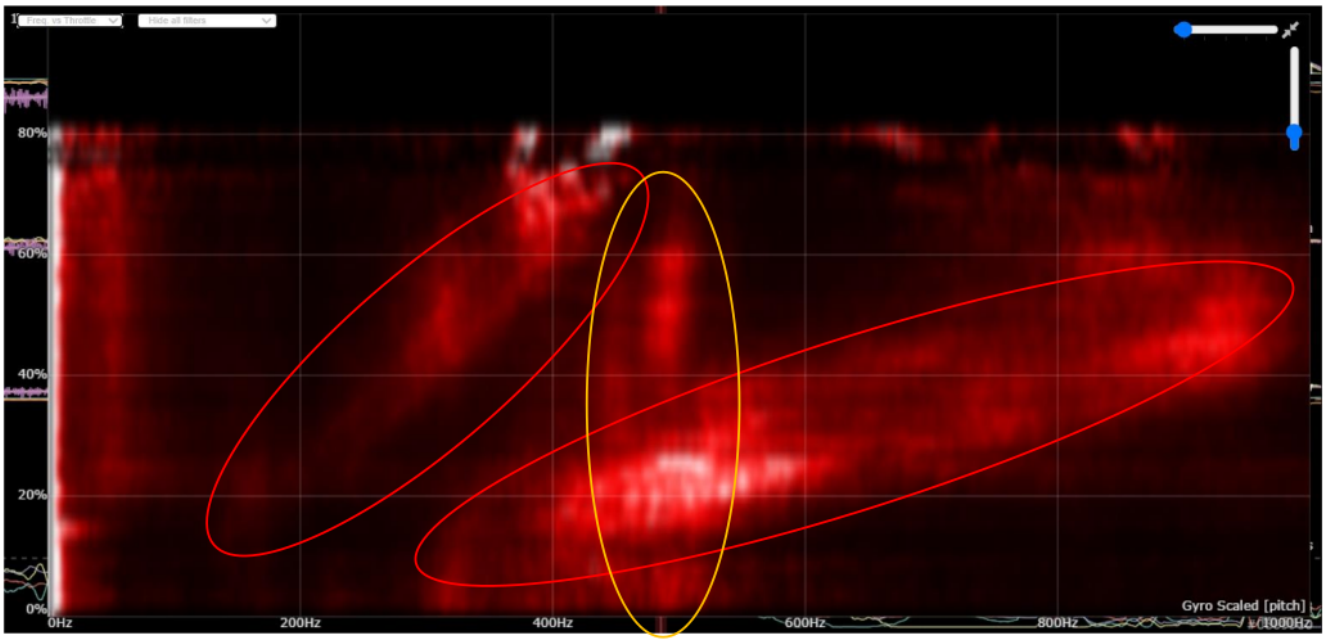


Figure 89 - Gyro [Pitch] Frequency vs Throttle Spectrum

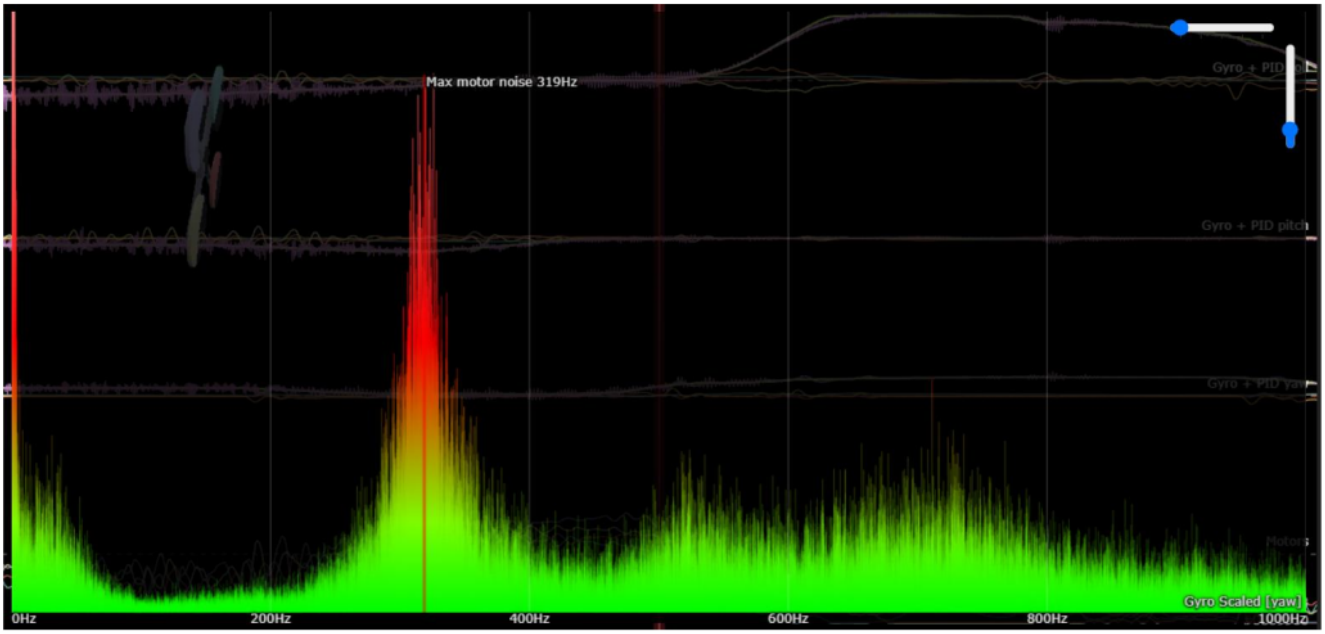


Figure 90 - Gyro [Yaw] Frequency Spectrum

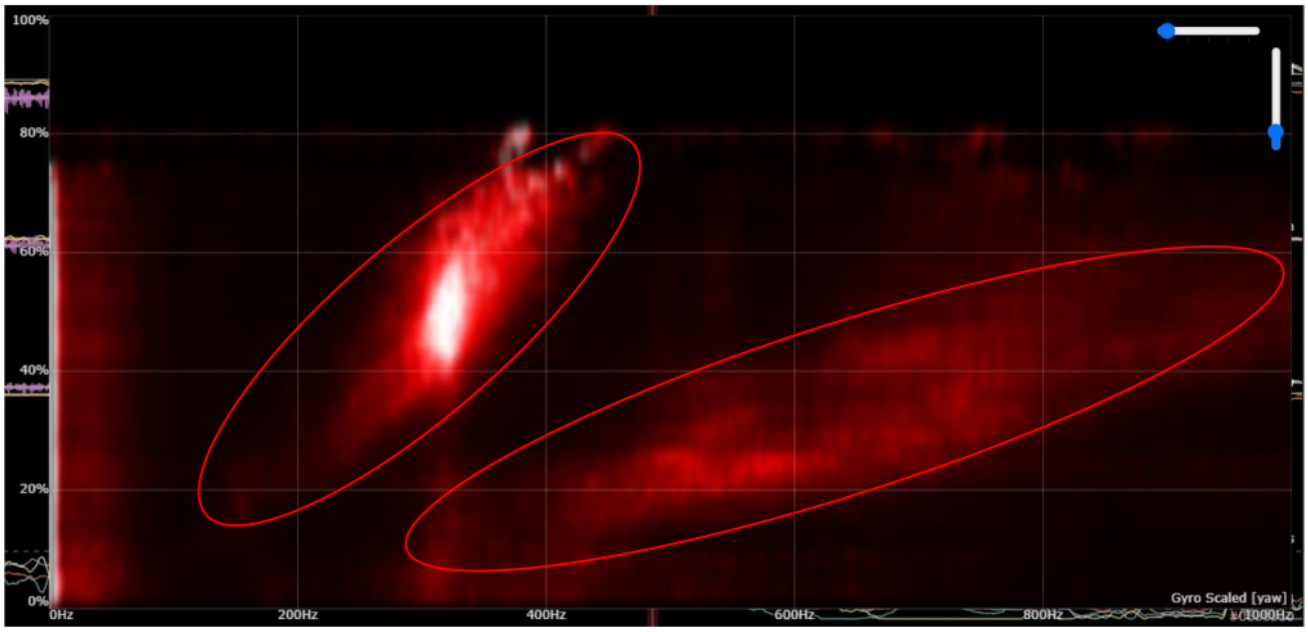


Figure 91 - Gyro [Yaw] Frequency vs Throttle Spectrum

Test 7 - Final PID Test and Flight Characteristics After Tuning and Applying Filters:

	Proportional	Integral	D Max	Derivative
Basic/Acro				
ROLL	45	80	40	30
PITCH	47	84	46	34
YAW	45	80	0	0

Figure 93 - Stock PID Tune

	Proportional	Integral	D Max	Derivative
Basic/Acro				
ROLL	45	85	42	34
PITCH	47	88	48	37
YAW	42	84	0	0

Figure 92 - Optimal PID Tune

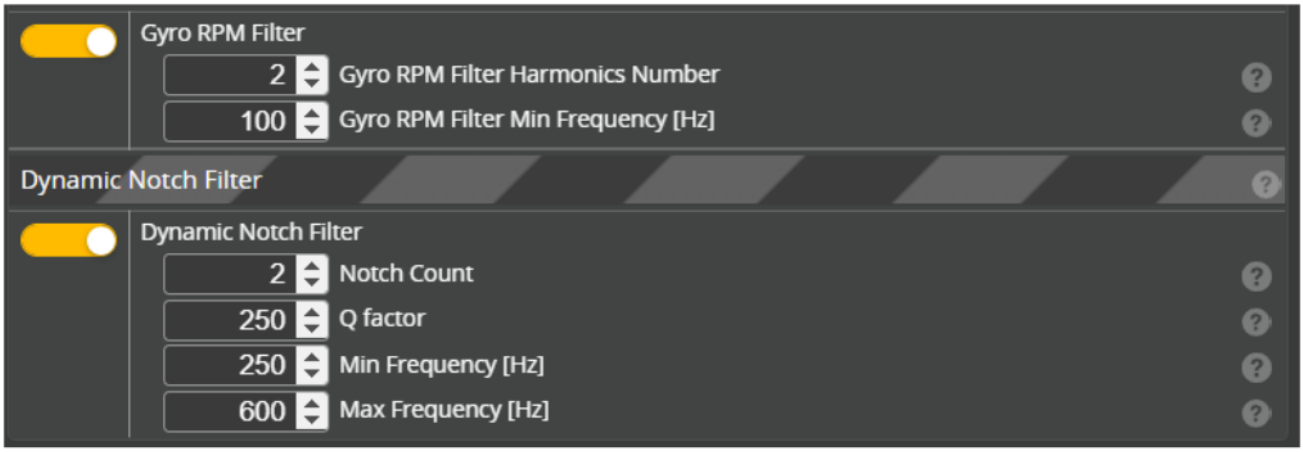


Figure 94 - Applied RPM and Dynamic Notch Filter

Test 7 Part 1 – Final PID Test:

Table 20 - Final PID Test

Description	Axis	Expected Result	Actual Result	Pass/Fail (P/F)	Evidence
Ensure there are minimal oscillations on each axis of rotation. The drone should respond to exactly what is being inputted and respond quickly to fast movements.	Roll	On the blackbox log, the gyro [roll] feedback should follow the setpoint with little to no phase delay and no oscillations.	The gyro roll axis managed to follow the setpoint well throughout the flight without any oscillations occurring and very little phase delay.	P	Figure 95
	Pitch	On the blackbox log, the gyro [pitch] feedback should follow the setpoint with little to no phase delay and no oscillations.	The gyro pitch axis managed to follow the setpoint well throughout the flight without any oscillations. There was little overshoot but overall didn't affect performance.	P	Figure 96
	Yaw	On the blackbox log, the gyro [yaw] feedback should follow the setpoint, but oscillations can still be expected.	This axis only uses PI control as yaw isn't used as much, but still performed well without noticable oscillations.	P	Figure 97

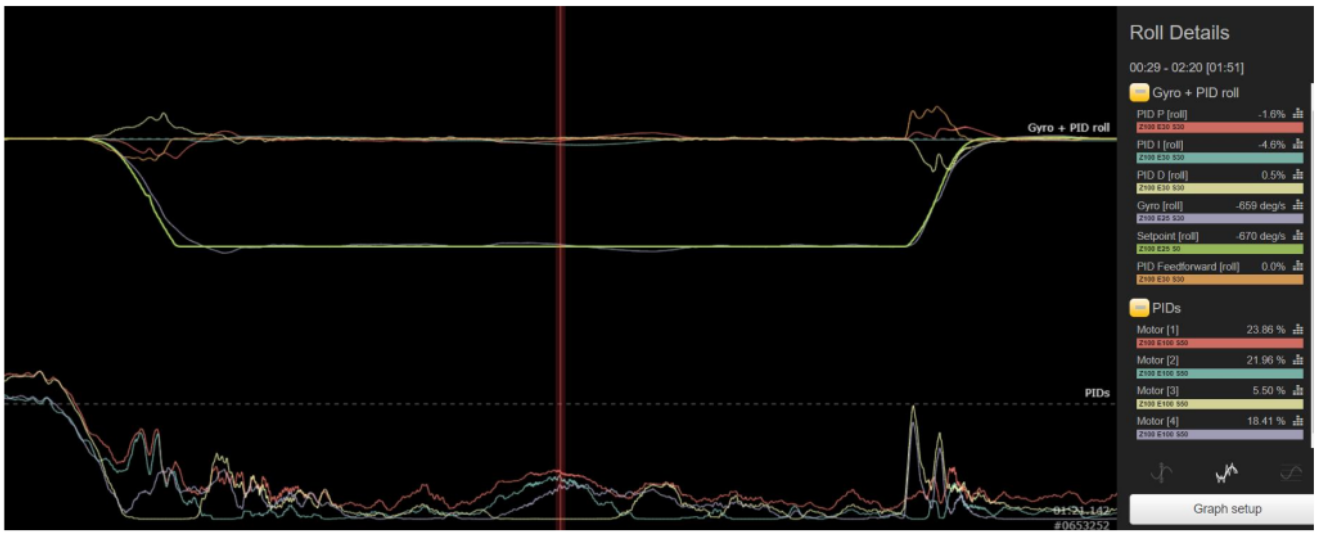


Figure 95 - Gyro [roll] Final PID Tune

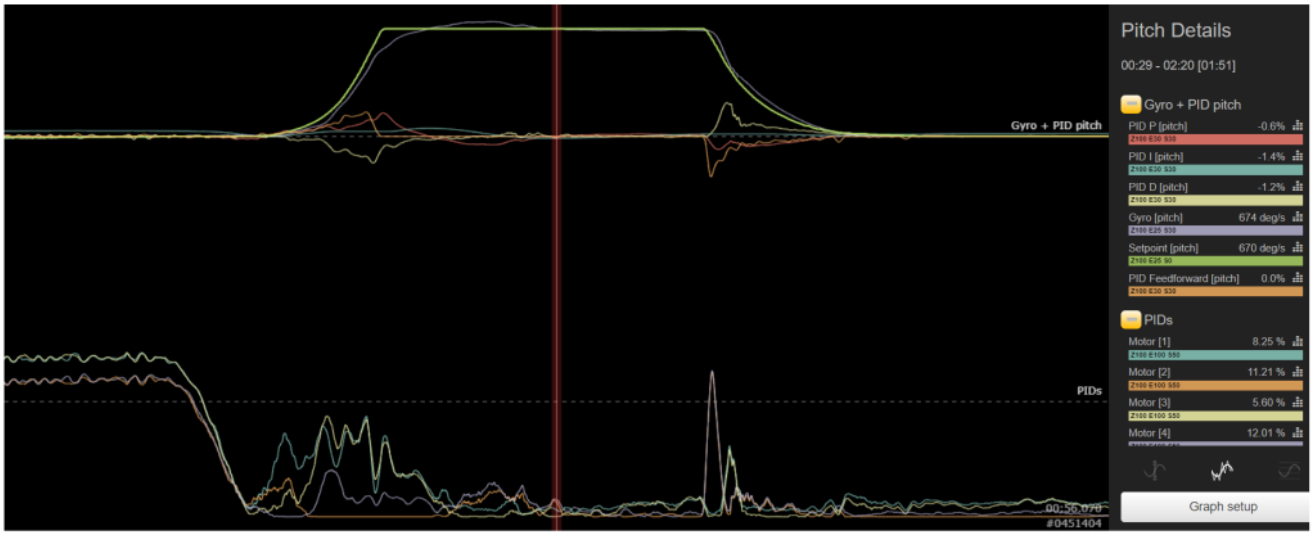


Figure 96 - Gyro [pitch] Final PID Tune

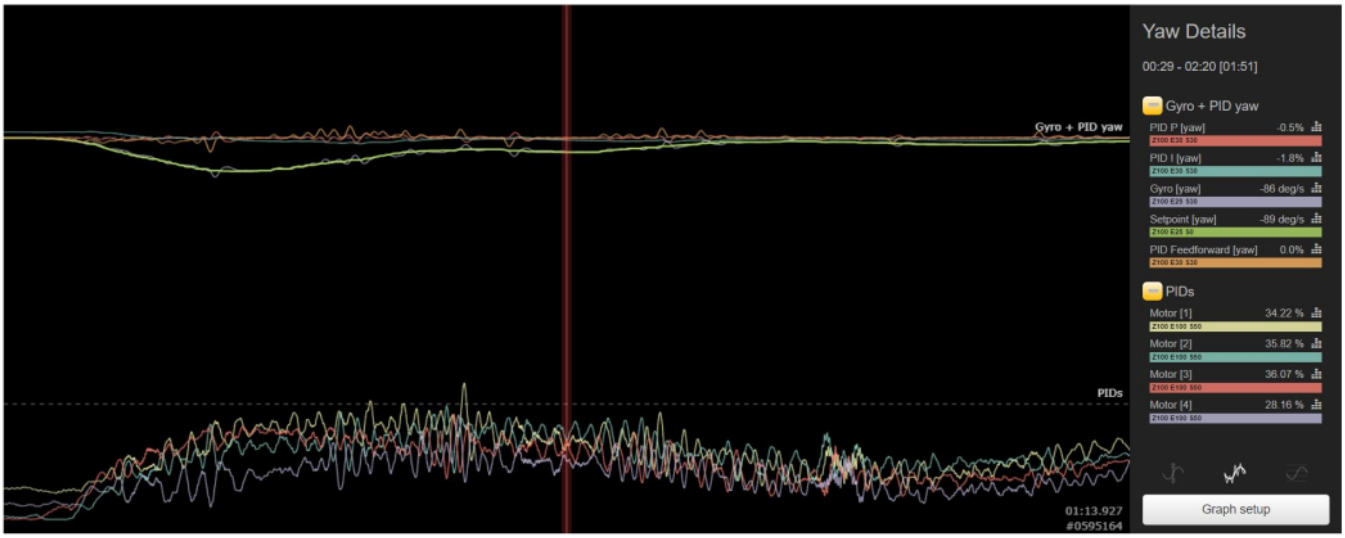


Figure 97 - Gyro [yaw] Final PID Tune

Test 7 Part 2 – Final Harmonic Analysis:

Table 21 - Final Harmonic Analysis

Description	Axis	Spectrographs Analysis		Pass/Fail (P/F)	Evidence
		Frequency Spectrum	Frequency vs Throttle Spectrum		
Observe the harmonic spectrographs to see if the filters have filtered out the harmonics generated.	Roll	The noise spikes have been filtered out by the dynamic notch filter and very little noise can be seen.	The RPM filter has filtered out the two harmonics as seen from the initial harmonic analysis.	P	Figures 98&99
	Pitch	The noise spikes have been filtered out by the dynamic notch filter. A small spike in the 60Hz region is present but did not affect performance.	The RPM filter has filtered out the two harmonics as seen from the initial harmonic analysis.	P	Figures 100&101
	Yaw	The noise spikes have been filtered out by the dynamic notch filter and very little noise is present.	The RPM filter has filtered out the two harmonics as seen from the initial harmonic analysis.	P	Figures 102&103

Very good test showing effects of filtering where the spectrum shows the eliminated harmonics

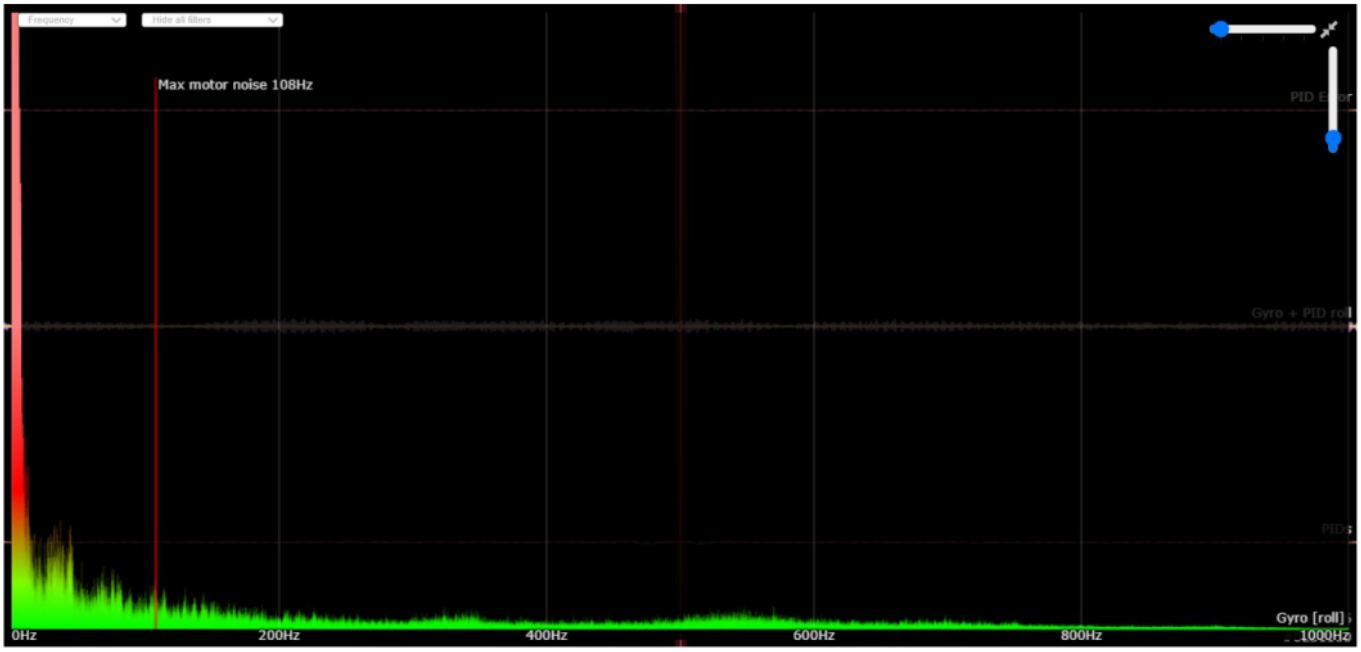


Figure 98 - Gyro [roll] Frequency Spectrum After Filtering

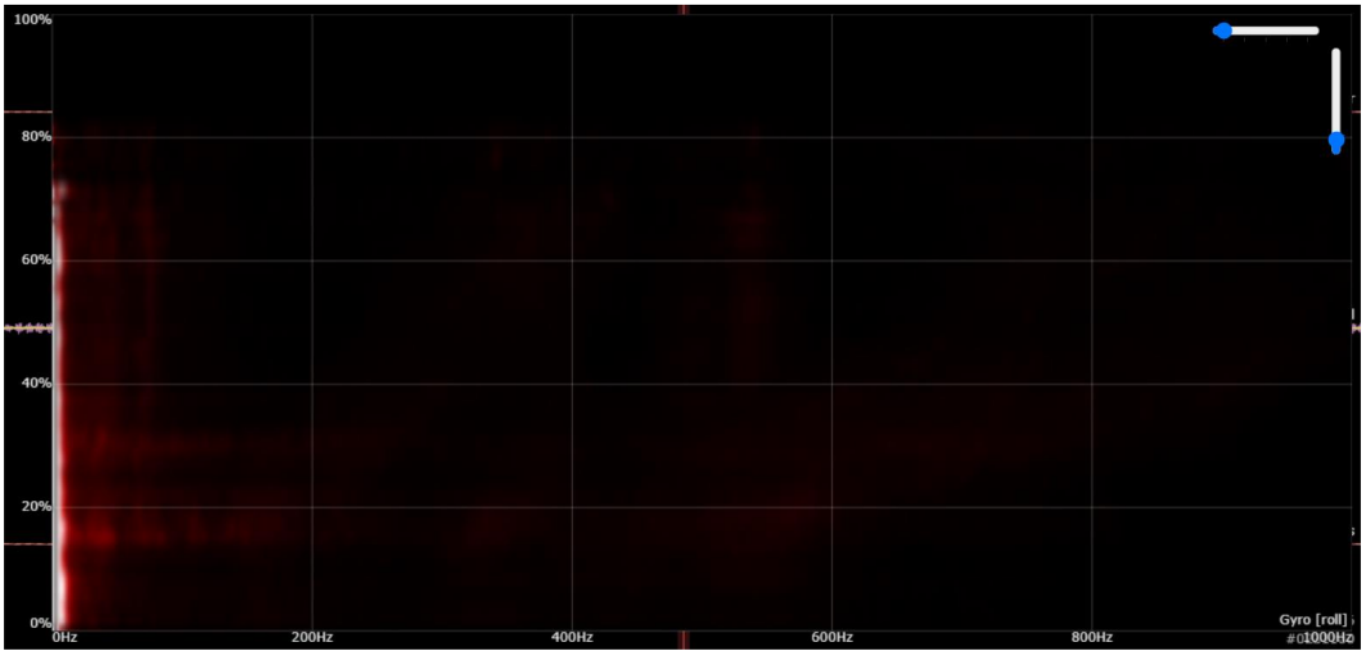


Figure 99 - Gyro [roll] Frequency vs Throttle Spectrum After Filtering

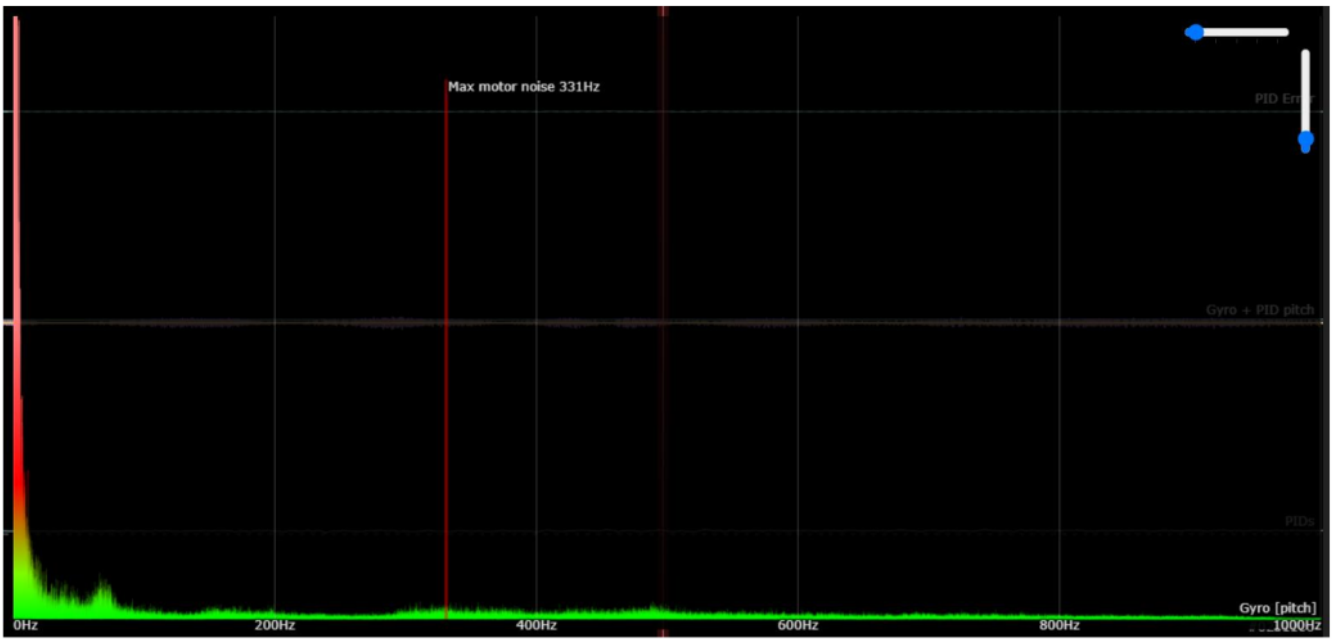


Figure 100 - Gyro [pitch] Frequency Spectrum After Filtering

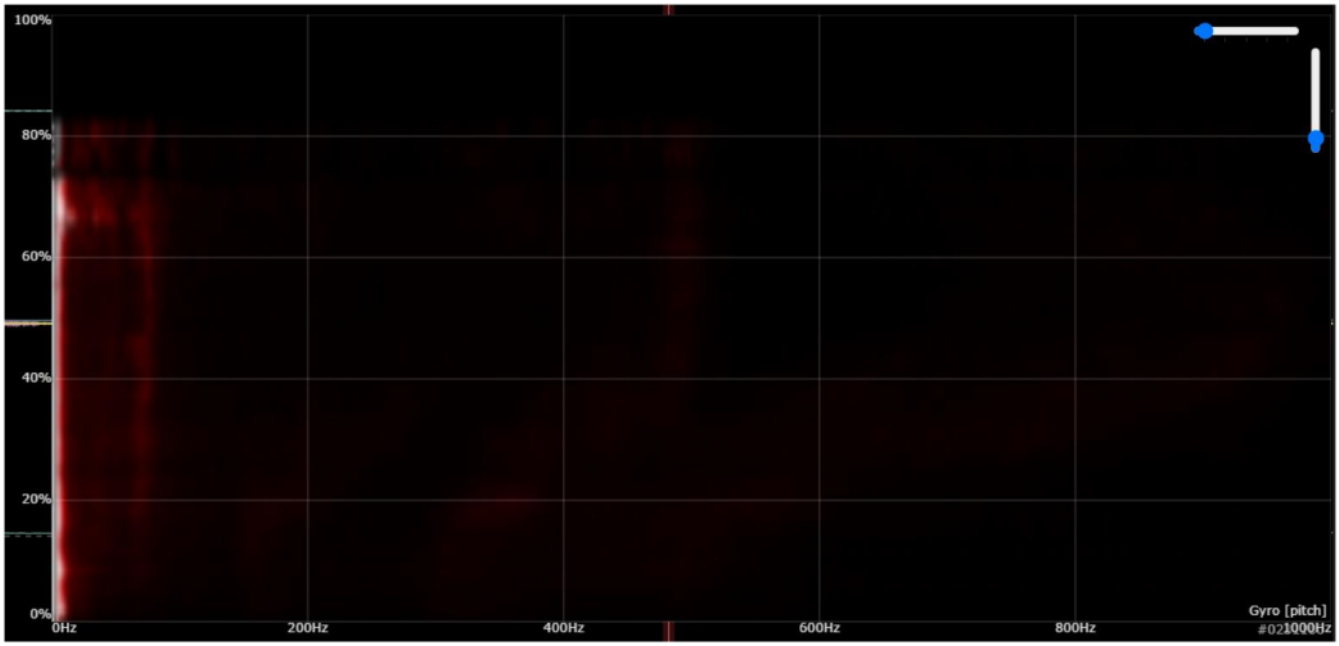


Figure 101 - Gyro [pitch] Frequency vs Throttle Spectrum After Filtering

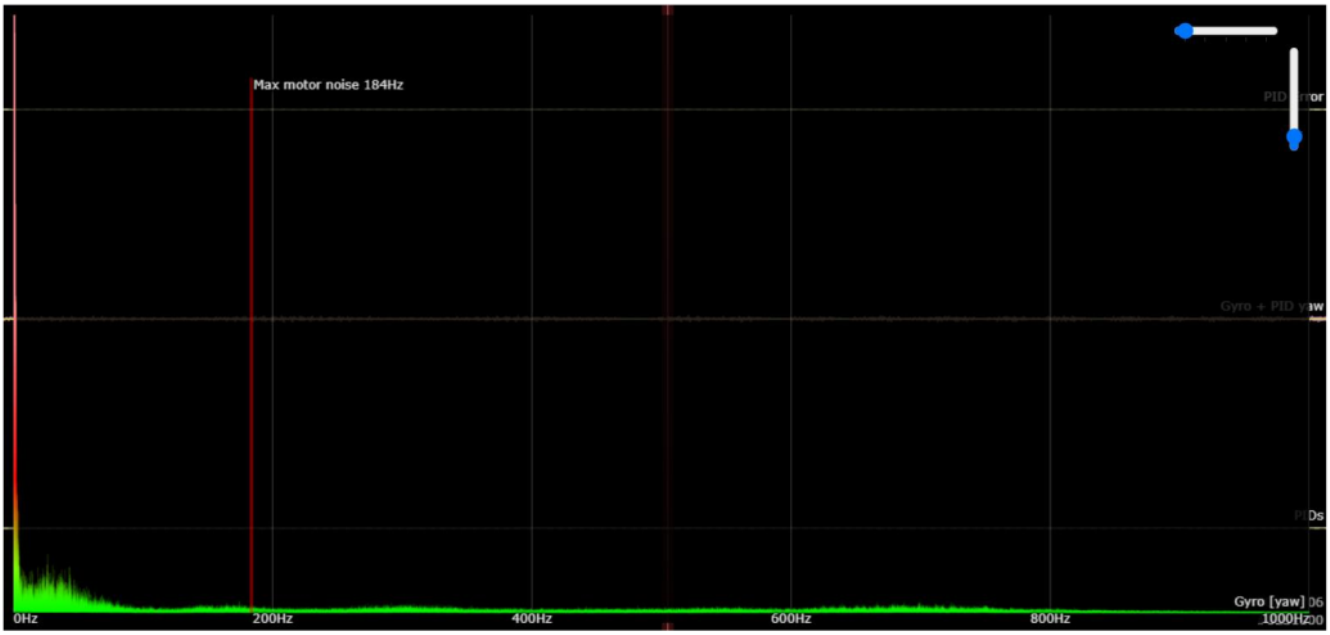


Figure 102 - Gyro [yaw] Frequency Spectrum After Filtering

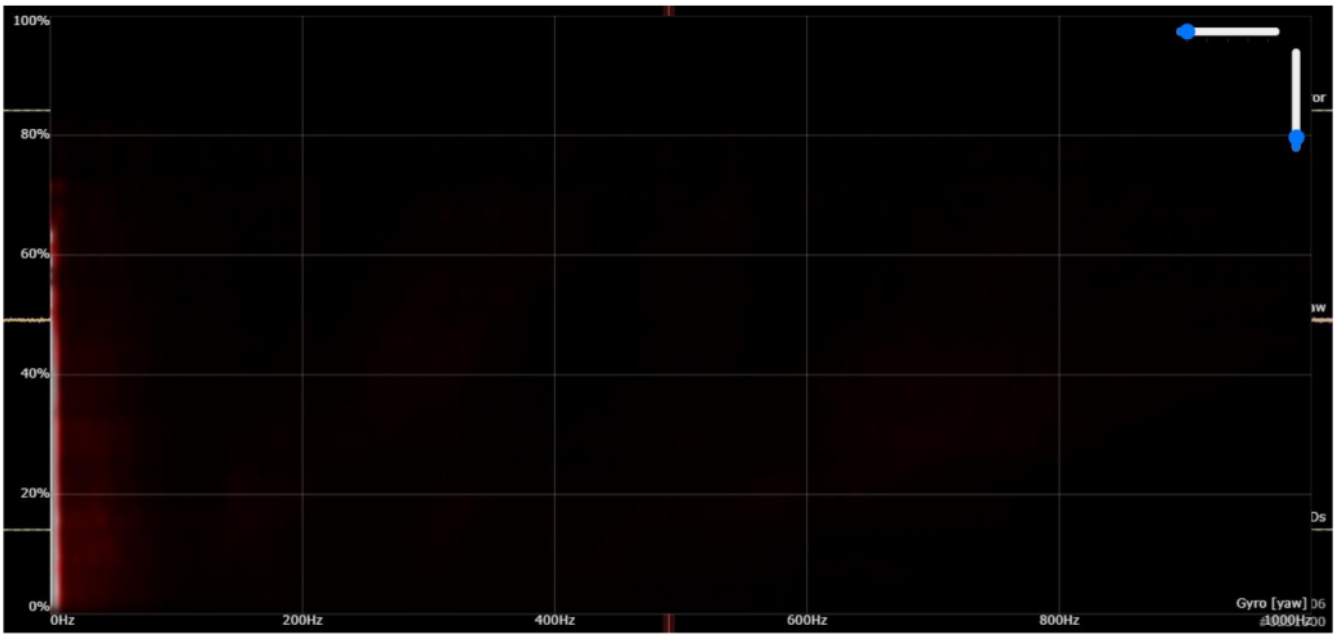


Figure 103 - Gyro [yaw] Frequency vs Throttle Spectrum After Filtering

A very interesting test result that shows a very effective method of filtering

2224559

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

85 /100

PAGE 1

PAGE 2

PAGE 3

Text Comment. Good detailed table of contents

PAGE 4

PAGE 5

PAGE 6

PAGE 7

Text Comment. Good extensive list of figures

Text Comment. Good use of tables

PAGE 8

Text Comment. Correct citation

Text Comment. Correct citation

Text Comment. Good background

PAGE 9

PAGE 10

Text Comment. Good explanation with corect citation

PAGE 11

Text Comment. Good explanation with good technical content

PAGE 12

Text Comment. Good explanation

Text Comment. Good supporting image

PAGE 13

PAGE 14

PAGE 15

Text Comment. Good work

PAGE 16

Text Comment. Good use of table to identify outcomes

PAGE 17

Text Comment. Good detailed Gantt chart

PAGE 18

Text Comment. Good informative test plan

PAGE 19

Text Comment. Good explanation and supporting image

PAGE 20

Text Comment. Good explanation and supporting image

PAGE 21

Text Comment. Good table of comparison to evaluate the options

Text Comment. Good argument made for final solution

PAGE 22

Text Comment. A vert detailed spec

PAGE 23

Text Comment. This is a good method to identify functionality of separate systems

PAGE 24

Text Comment. Good evidence of inventory

PAGE 25

Text Comment. Good use of tables

PAGE 26

PAGE 27

Text Comment. Assembly method is identified

PAGE 28

PAGE 29

Text Comment. Good detailed explanation

PAGE 30

PAGE 31

PAGE 32

Text Comment. A good structured test method

PAGE 33

Text Comment. THre are significant points that affect the progress explained here

Text Comment. Excellent work with the Gantt chart comparison

PAGE 34

Text Comment. Good explanation

PAGE 35

PAGE 36

Text Comment. Good number of sources

PAGE 37

Text Comment. This is an informative diagram

PAGE 38

PAGE 39

Text Comment. Good evidence

PAGE 40

PAGE 41

Text Comment. Good evidence

PAGE 42

Text Comment. Good evidence showing components fitted

PAGE 43

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PAGE 44

PAGE 45

PAGE 46

PAGE 47

PAGE 48

Text Comment. Good evidence of software setup

PAGE 49

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PAGE 50

PAGE 51

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PAGE 52

PAGE 53

PAGE 54

PAGE 55

PAGE 56

PAGE 57

PAGE 58

PAGE 59

Text Comment. Good use of table for check list

PAGE 60

Text Comment. Good use of table

PAGE 61

Text Comment. Good evidence

PAGE 62

Text Comment. Good evidence

PAGE 63

PAGE 64

PAGE 65

Text Comment. Good use of table

PAGE 66

PAGE 67

PAGE 68

PAGE 69

PAGE 70

PAGE 71

PAGE 72

PAGE 73

PAGE 74

PAGE 75

PAGE 76

PAGE 77

PAGE 78

PAGE 79

Text Comment. Good table of checks

PAGE 80

PAGE 81

PAGE 82

PAGE 83

PAGE 84

Text Comment. Good table with ref to evidence

PAGE 85

Text Comment. This is a very interesting test wherby individual motors can be selected and tested

PAGE 86

PAGE 87

PAGE 88

PAGE 89

Text Comment. Good table with ref to evidence

PAGE 90

PAGE 91

PAGE 92

Text Comment. Good test for signals with ref to evidence

PAGE 93

PAGE 94

PAGE 95

PAGE 96

PAGE 97

PAGE 98

Text Comment. God table for PID tests and ref to evidence

PAGE 99

PAGE 100

Text Comment. Very good test evidence to support test table

PAGE 101

Text Comment. Good use of table

PAGE 102

Text Comment. Spectrum shows harmonic interference

PAGE 103

PAGE 104

PAGE 105

PAGE 106

PAGE 107

PAGE 108

PAGE 109

Text Comment. Very good test showing effects of filtering where the spectrum shows the eliminated harmonics

PAGE 110

PAGE 111

PAGE 112

Text Comment. A very interesting test result that shows a very effective method of filtering

GRADING FORM: CSG-RUBIC

MOHAMMED IBRAHIM	**0**

RESEARCH-INFORMED LITERATURE

Level of research is exceptional here with many sources investigated. **17/20**

KNOWLEDGE AND UNDERSTANDING

Good detailed spec with outcomes evaluated. Two solutions cosidered in detial with comaprison table. The two solutions have been explained with **17/20**

a good level of technical information from research. The solutions components have also been evaluated.

ANALYSIS

An exceptional amount of tetsing has been carried out. Excellent PID tests with evidence from live graphs.
Very good testing of individual motors.
Excelent test results for effective filtering of harmonics.
Very good conclusion with good researched recommendation

18/20

PRACTICAL APPLICATION AND DEP.

Gantt chart and project test plan have been prsented very efficiently with time line comparison on the Gantt chart.
The two solutions considered have been investigated at a very good technical level. The argument for final solution is explained and justified.
Impelementation section here is extensive due to the many parts of the software that need to be used to configgure the drone for most efficient performance. This has been explained in excellent detail with tables used to simplfy results.
Many tuning tasks have been carried out with good detailed explanations and ref to evidence.

21/25

SKILLS FOR PROFESSIONAL PRAC.

A very good structured report with good quality content.

12/15