UNIVERSITY OF AGDER

3DOF Quadcopter Platform

For Educational Purposes

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This Bachelor's Thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

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Abstract

This thesis consists of the development and building of a three degree of freedom platform for student programming in laboratory exercises. The thesis presents the different theories regarding components needed in creating both a fully function platform and quadcopter. It will also present the development process itself as well as the final product containing a detailed view of all the selected components. A discussion of how the platform turned out, and what improvements can be made will be presented at the end of the thesis.

Abbreviations

ABS	Acrylonitrile Butadiene Styrene
AC	Alternating Current
ADC	Analog to Digital Converter
BEC	Battery Eliminator Circuit
CW	Clockwise
CCW	Counter clockwise
DC	Direct Current
DoF	Degrees of Freedom
ESC	Electronic Speed Controller
FC	Flight Controller
GPS	Global Positioning System
I^2C	Inter-integrated Circuit
IEC	International Electrotechnical Commission
IMU	Inertial Measurement Unit
KgF	Kilogram Force
LED	Light-Emitting Diode
LiPo	Lithium-ion Polymer
LPF	Low-Pass Filter
MEMS	Microelectromechanical Systems
ODR	Output Data Rates
PCM	Pulse Code Modulation
PDB	Powerful Distribution Board
PPM	Pulse Position Modulation
PWM	Pulse Width Modulation
RAM	Random Access Memory
RC	Radio Controlled
RPM	Rounds Per Minute
RSSI	Received Signal Strength Indication
RX	Receiver
SMPS	Switch-Mode Power Supplier
SPI	Serial Peripheral Interface bus
TVS	Transient-Voltage-Suppression
TX	Transmitter
UAV	Unmanned Air/Aerial Vehicle

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Introduction

The unmanned aerial vehicle, or drone, has been and still is an aspect of modern technology. Drones have especially played a major part in video and photographic surveillance both in military and recreational contexts. They also come in a variety of types, where some are small enough to fit in a person's hands and some are as big as fighter jet planes. Absent a pilot, it is essential for drones to have some sort of stability and locational software programmed into them as to allow for more smooth flights. This thesis sets out to develop a robust, cost-efficient and user-friendly quadcopter platform for use in educational exercises. It consists of two parts, the platform and a quadcopter. The platform must allow for the quadcopter to rotate in 3 DOF and be supplied with power when connected to the station. It is desired to have the quadcopter functioning for flight independently without the platform, if possible.

The thesis will account for the several theories about the key components of the station itself as well as the drone. It also contains a detailed description of how the design came to be and how the creation of the prototype was conducted. There will also be a discussion about how the docking station turned out and what could have been done differently to perhaps provide improvements. Although the prototype did not turn out as we hoped for regarding materials, we are satisfied with the product and hope that the thesis makes for an interesting read.

Theory

Quadcopters

Drones, which also go by the name of UAV (Unmanned aerial vehicle), were in its early stages mainly used by the military. When looking at how an unmanned drone conducts its flight there are two variants; drones that fly autonomously by the help of several sensors and GPS, and drones that can be flown remotely by a pilot. (1)

The first military UAV was allegedly developed during and after World War I by the Americans and was named the Hewitt-Sperry Automatic Airplane. During World War II more attempts at specifying the UAVs tasks, such as target aircraft, was done by increasing the advanced technology. Especially the U.S Air Force in Iraq and Afghanistan, and the CIA in Yemen and Pakistan, started using drones equipped with weapons after it was launched in 2001. Unlike manned flights, drones avoid the risk of losing or injuring pilots and are more cost-efficient. The Norwegian Armed Forces acquired their first drone, an Aladin, in 2009 to conduct observations in lower airspace altitudes. In the United Kingdom, drones are also being used as a tool for the police, firefighters and security companies which makes their job a lot easier.

Over the years drones have entered the civilian market as well and can now be bought at hobby stores or electronic stores. They are being used as a mean of monitoring weather, traffic, security and are helpful in search- and rescue operations. They can also be used to deliver postal packages and are even sold as recreational toys. Drones are produced in a wide variety of shapes and sizes, ranging from small personal drones to grand scale airplanes with wingspans up to 40 meters long. (1)

Drones with 4, 6 or 8 arms equipped with motors are called multi-rotors. The 4-armed one, which we are building, is the most common drone and is named a quad-copter. There are some advantages in choosing a quad-copter as well as at least one rather major disadvantage. The positives are that a quad-copter can land and take off from almost anywhere due to their rotors having much smaller diameters compared to their helicopter and airplane counterparts. Multi-rotors also have the unique ability to hover, making it ideal for performing tasks in mid-air. The drawback hover is that several motors become severely power hungry, and do have their flight time reduced. New technology has researched the idea of using solar panels, hydro power, combustion power and tethering instead of the standard battery fuel cells. The results look promising as they can increase the flight times from a few minutes up to 2 – 80 hours or more (2) (3).

As mentioned, a quadcopter contains four motors, each producing both torque and lift force. Figure 1 displays how these four motors, or rotors, are placed in accordance to another. A prerequisite is that the drone is designed to be symmetric regarding the x- and y-axis, which means the centre of gravity is in the drone's centre. Therefore, 4 rods with an equal length l are placed from the centre with 90 degrees apart from each other. At the end of every bar is a mounting point where each of the motors are placed. (4)

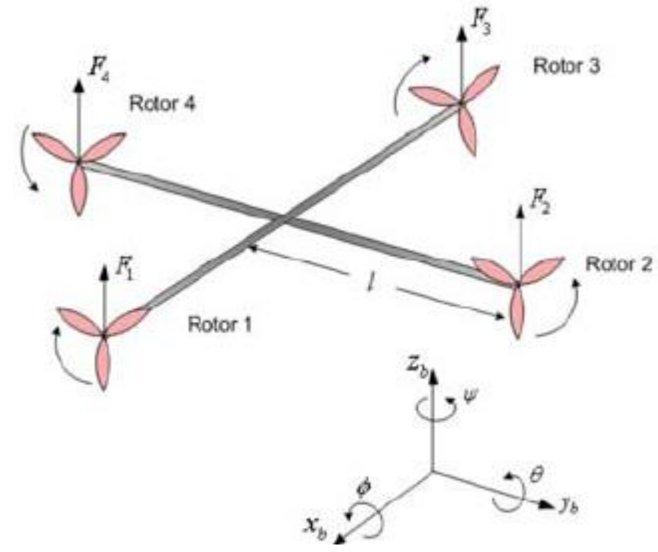

Figure 1: Displaying how motor 1,2,3 and 4 are placed in accordance to each other. Each motor produces a moment and a lift force (F1, F2, F3, F4). The coordinate system shows that rotation around the x-axis makes a roll angle (φ), rotation around the y-axis makes (4)

Motor 1 and 3 makes a pair that both rotates clockwise (CW) while the second pair, motor 2 and 4, rotates counter clockwise (CCW). They do so to eliminate the torque created by the other pair, making it possible to move in a roll, pitch or yaw (figure 1). By maintaining the combined thrust constant and at the same time decreasing motor 4's speed and increasing the speed on motor 2, the drone can perform a roll angle (φ) motion along the body frame's x-axis. In the same way a pitch angle (θ) motion along the body frame's y-axis can be achieved by keeping the combined thrust constant, but now motor 3 increases its speed while motor 1 decreases its. To perform a yaw angle (ψ) motion along the z-axis of the frame body both motor 1 and 3 increases their speed while motor 2 and 4 decreases theirs, while keeping the total thrust constant.

Each rotor produces a lift force (F1, F1, F3, F4). These forces are at a 90-degree angle to the xy-plane, straight up the z-axis. The forces, the moments of inertia (J1, J2, J3, J4), each with respect to their axis, and the force-to-moment scaling factor (ρ) can be represented in equations describing how the quadcopter moves. The equations neglect air drags for simplification. (4)

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \frac{1}{m}\left(\sum_{i=1}^{4} F_i\right)R\overrightarrow{e_3} + (g_r(z) - g)\overrightarrow{e_3}, \quad [1]$$

[2]

$$\ddot{\phi} = l(F_2 - F_4)/J_1, \quad [3]$$

$$\ddot{\theta} = l(-F_1 + F_3)/J_2, \quad [4]$$

$$\ddot{\psi} = \rho(F_1 - F_2 + F_3 - F_4)/J_3.$$

Where,

x, y, z: represents the drone's coordinates in the inertial frame
Φ, θ, ψ: altitude variables in the body frame, representing the roll, pitch and yaw angles

$\overline{e_3} = [0,0,1]^T$
R: the coordinate transformation matrix from body frame to inertial frame

The R transformation matrix describes translation about x, y and z axis, combining Rx, Ry and Rx.

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \quad [5]$$

$$R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \quad [6]$$

$$R_z(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}. \quad [7]$$

Equation 5: translation about x-axis
Equation 6: translation about y-axis
Equation 7: translation about z-axis
Equation 5, 6 and 7 gives us R:

$$R = \begin{bmatrix} c\theta c\psi & s\phi s\theta c\psi - c\phi s\psi & c\phi s\theta c\psi + s\phi s\psi \\ c\theta s\psi & s\phi s\theta s\psi + c\phi c\psi & c\phi s\theta s\psi - s\phi c\psi \\ -s\theta & s\phi c\theta & c\phi c\theta \end{bmatrix} \quad [8]$$

Where,

s = sinus
c = cosine

By simplifications equations 1-4 leads to equations 9-12:

$$u_1 = (F_1 + F_2 + F_3 + F_4)/m$$
$$u_2 = (F_2 - F_4)/J_1$$
$$u_3 = (-F_1 + F_3)/J_2$$
$$u_4 = \rho(F_1 - F_2 + F_3 - F_4)/J_3$$

[9]
[10]
[11]
[12]

Where,

u1 = normalized total lift force
u2 = control inputs of roll
u3 = control inputs of pitch
u4 = control inputs of yaw

(4)

When building a drone there are many components that need to be compatible with each other; FC (Flight Controller), motors, propellers, ESC (Electronic Speed Controller), PDB (Power Distribution Board), battery, Rx (receiver) and Tx (transmitter). A custom-made flight controller is often used and there are even stack towers available on the market containing both FC, PDB and ESC. These are very user friendly, lightweight and compact to attach onto a drone. The “problem” is that they are already at least partly pre-programmed and since our drones are to be used as LAB-equipment, meant for learning how to program drones, it is better to have a flight controller that is completely clean. Therefore, a microcontroller with a suitable IMU (Inertial Measuring Unit) is a requirement in solving the task given.

Flight controller:

A drone has many different components and they all have different unique tasks that they must perform. The flight controller (FC) is the main processing unit. All the programming needed for flight is uploaded and ran by the FC. It also registers and processes motion data as well as it sends and receives information from the other components onboard the drone. A gyroscope and an accelerometer are standard inertial measuring units (IMU) on FCs, and together they minimize the number of sensors needed to detect movement and orientation. Barometer, magnetometer and GPS are extra sensors that are often included to make positioning of the drone more correctly. (5) If the sensors indicate that the drone is tilting too much to one side, the FC sends a signal to the motors on that side telling them to speed up to regain stability. The FC is connected to the receiver, which in turn gets commands from the transmitter about how to move the drone. So, if a person on the ground moves the stick on the transmitter to the forward position, a signal is sent to the receiver which passes it along to the FC. The FC then tells the rear motors to speed up and the drone will move forward (6).

Brushless Motors:

Brushless DC motors consist two characteristic parts. I the center of the motor there is a permanent magnet rotor and inside the housing there are several pairs of coils mounted to the walls. The coils attached to the housing (stator) create an electromagnet when supplied with a current, and result in the housing rotating about the permanent magnet.
The only real similar characteristic between brushless and brushed motors are their linear relationship between torque and speed. Apart from price and the necessary complex electronics needed to drive it, the brushless motor wins in all aspects. Since there are no brushes moving inside the brushless motor, only bearings, it makes less mechanical noise than the brushed motor. Whereas the brushed motor makes electronical noise when interfacing between brushes and the commutator, the brushless is quiet. Depending on where the motors are operational, one can also point out that the brushed motor can be a hazard in explosive environments due to the sparks that can come from the brushes. More relevant to our use is how the brushless motor is more efficient than the brushed motor. The brushes both cause mechanical friction and add a higher electrical resistance element in the current path, making the motor less efficient. In addition to efficiency the brushless motor can also reach a higher maximum speed; the brushed can reach as much as 10.000 rpm while the brushless can go as fast as 100.000 rpm. Brushless motors are also better at cooling down than brushed motors due to how the coils are positioned in the motor, which leads to the heat being more easily dispersed. This opens to the possibility of making the brushless motor more compact while still maintaining the power output. The continuous torques at lower speeds can also be higher on brushless motors than on brushed motors. (7)
The motors determine how much the drone can weigh and still be able to accelerate enough to translate its position. Some motors have the same specifications regardless of manufacturer due to the market demand and classifications. However, most motors do not, and they have different thrust values. Thrust is measured in grams and it varies depending on the power (wattage) it is supplied. Manufacturers usually test their motors and create specific tables and datasheets. These test results display how much thrust a motor has when equipped with different sets of propellers, while varying the voltage and the electrical current from the power source. It is necessary to maintain a certain thrust to weight ratio. A helpful rule of thumb when selecting the proper motors is for them to have twice as much thrust value than what the drone weighs. This to make sure that the drone is capable of hovering at half of the thrust capacity whilst still having the opportunity and ability to withstand wind and do more aggressive flight-moves if needed. The thrust tables also show the motor's efficiency, thrust divided by power (g/W), which reflects how efficient the motor is and thus how much time the drone will be able to fly. Efficiency over 7g/W is considered good and the higher the value the better. However, it is very essential what type of drone/copter the motors are supposed to drive. For smaller, more acrobatic drones, efficiency is not necessarily the thing to be prioritized. In this case, the ability to quickly change the direction of flight might be more valuable, and thus usually resulting in lower efficiency ratings for motors used on those types of drones. (8)
Motors usually have different KV ratings. The KV rating stands for how many rpm (revolutions per minute) the motor can turn while having 1 volt supplied, without any load and at maximum throttle. So, the equation is: rpm = KV x voltage. A low KV rating will in many cases mean a more effective motor because it uses less power and thereby has an increased flight time. However, a higher KV rating will yield a higher performance for the drone which means it will be more acrobatic, and is generally the type of motors used on smaller drones (9).

Electronic Speed Controller:

The Electronic Speed Controller (ESC) converts PWM (Pulse Width Modulation) signals sent from the flight controller to the motors and make sure the motors get the correct amount of electrical power to perform their task. What to consider when choosing a ESC is how many amps it can supply the motor. (10)

There is one ESC for each motor; one connected to each of the two motors spinning clockwise (CW) and one connected to each counter clockwise (CCW) spinning motor. Figure 2 below shows how the motors are connected to spin CW and CCW. The way to connect the CW motor is straight forward: left cable on the motor connects with left cable on the ESC, middle one with middle one and the right cable with the right cable.
The CCW motor on the other hand is inverted, where the left cable from the motor goes with the ESC's right cable and the motors right cable goes with the ESC's left cable. The middle ESC cable still goes with the motors middle one. This will ensure that the propellers spin in the correct direction. (11)

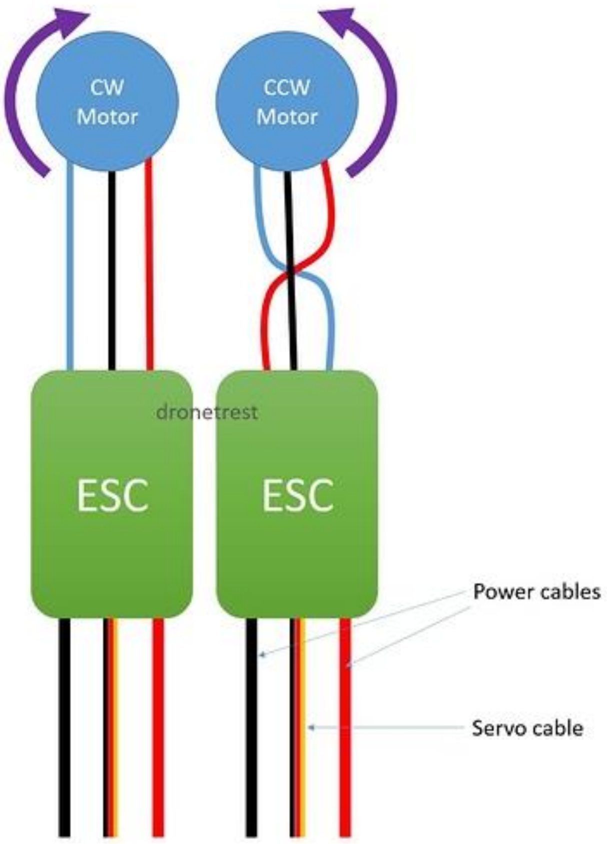

Figure 2: How to connect ESC to motor CW and CWW. (11)

Power Distribution Board:

The power distribution board does, as the name implies, distribute the power from the battery, or other power sources, to the motors. Since microcontrollers cannot handle too much ampere or volt running through them the PDBs are quite handy. It is always safer to choose a PDB that has a higher maximum current rate than the maximum draw rate of the ESCs combined (12). The maximum voltage input must also be higher than the maximum output voltage of the battery/ power supplier.

Battery Eliminating Circuit:

BEC (Battery Eliminating Circuit), a voltage regulator, makes it possible to power auxiliary equipment such as the flight controller/microcontroller, cameras, RC-receivers, video transmitters, LEDS etc. without connecting a second battery (13). BECs can be found both on ESCs and on PDBs (10) (12).

Lithium Polymer Battery:

Lithium polymer batteries, also referred to as LiPo-batteries, are popular to use when size is essential. They are so called secondary batteries, meaning that they can be charged, discharged and then recharged multiple times. A standard LiPo battery has a lifecycle of between 500-1000 recharges in them. They have high midpoint cell voltage, 3.7 volt per cell, and can attain a high energy density level. LiPo batteries are likely to be found in consumer electronic devices such as mobile phones and PC's. There are however downsides to LiPo batteries (7). If exposed to low temperatures the battery's capacity is severely reduced (14). LiPo batteries are prone for explosions, which means that one must exercise caution when handling such a battery, as physical harm, short circuiting or overcharging may cause them to blow up. Careful maintenance is also important when dealing with LiPo batteries, as a battery can be damaged if left idle without recharge for a long period of time. However, in modern applications that use these types of batteries, there are security measures that see to that the battery does not discharge fully or overcharge (7). One good example of such a product is the common household laptop computer, which shuts down before the battery reaches 0%.
A battery's capacity is the maximum amount of energy the battery is capable of storing. The measuring unit is commonly amp hours (Ah) or milliamp hours (mAh). As mentioned earlier, it is important to charge the battery in a correct manner. In addition to the capacity batteries also comes with a specification called the C-rate, telling how high a current the battery should be charged at. The C-rate is the ratio between current drawn by the battery and the battery's rated capacity.
C-rate = Current / Rated Capacity. (7)

Receiver and Transmitter:

When choosing a receiver and a transmitter it is best that both are from the same brand, since a TX usually only works with a RX from the same manufacturer. (15) The transmitter, which is the hand-held controller, sends signals using TX protocols to the receiver that is placed on the drone. These signals are then passed along, using RX protocols, from the receiver to the flight controller. (16)

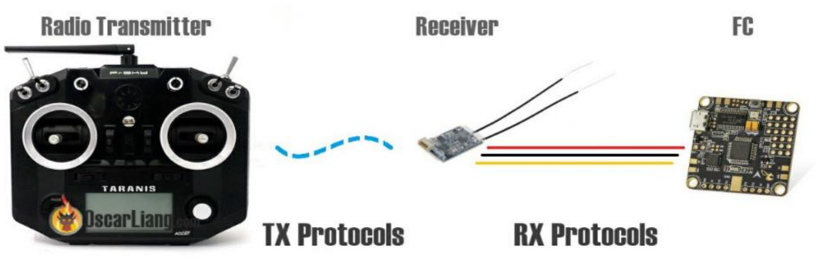

Figure 3: Communication between transmitter and receiver; TX protocols, and between receiver and flight controller; RX protocols. (16)

There are different TX and RX protocols, some are universal for different brands while other solutions are reserved for specific brands. RX protocols that are universal are: PWM, PPM and PCM. The PWM (Pulse Width Modulation) is the most commonly used protocol, but it requires using one signal wire per channel the RX/TX offers, which is at least four. PPM (Pulse Position Modulation) on the other hand only needs one signal wire for typically up to eight channels, making the wiring much easier. The PPM sends the signals as a series of PWM signals, one channel after another sending signal after each other. Serial connections are therefore more accurate and have less jitter. PCM (Pulse Code Modulation) is the digital version of the PPM. Here the issues can be signal error detection or error correction. Spektrum, a RC brand, has designed their own TX protocols: DSM2 and DSMX. The DSM2 has a great ability to block out signals interfering from other devices, such as transmitters, that operates at the same frequency. DSMX is a further developed and more reliable version of the DSM2. (16) The DSMX combines a wideband signal, which has high data capacity and interference resistance, with the ability to switch frequency. This is especially useful in situations where several people use the 2.4 GHz frequency. (17) What frequency the radio controller uses differs, but the most commonly used is 2.4GHz. Lower frequencies, which would allow for longer range, are also available but seldom used in small drones. (15)

Telemetry is an extra feature on some RXs which makes it possible for the receiver to send information such as battery voltage and current draw. It also offers RSSI (received signal strength indication) measurements, which can help avoiding losing radio signal and thereby prevent accidents. (15) (18).

Minimum four channels are required to fly a quadcopter, to be able to perform pitch, roll, throttle and yaw. The recommended number of channels for a quadcopter is at least 5-6. The more channels added the more individual actions can be controlled, such as switching to different flight modes or to activate pre-programmed features. (15)

Accelerometer

While the gyroscope measures the angular velocity, it is necessary to have a device that can measure acceleration which is changes in speed and/or direction. An accelerometer can perform this task, and in addition to detecting acceleration, accelerometers can also sense vibration (19). They can be used for a wide array of applications, such as to navigate and control different kinds of vessels, as a trigger in an airbag, to measure vibrations in buildings etc. and they can be used to measure earthquakes (20).

Acceleration is measured in meters per second squared (m/s^2) in the metric system and feet per second squared (ft/s^2) in the imperial system, or gravity units. Accelerometers are usually calibrated in G-forces (g), whereas 1 G-unit equals the weight of the object (21). The accelerometer can measure acceleration in one of three ways. One way is to connect a body with a certain mass to a spring so that the instrument can measure its movement and thereby calculate its acceleration. The second method would be to measure the time a pendulum takes to swing, time = *y*, and then solve the equation: $y=kx$ where *k* is a constant and *x* is the acceleration. So, the acceleration would then be: $y=(ky)^2$. And lastly, the accelerometer could measure by using the precession rate of a hanging gyroscope. (22)

Acceleration can be measured on 1-, 2- or 3-axis, but since the price on the 3-axis accelerometer has sunk they have become more popular to use. The accelerometers used in drones are electromechanical instruments, detecting static forces of acceleration like gravity, or dynamic ones likes movement and vibrations.

As mentioned, accelerometers can detect and measure acceleration with the help of springs and an attached object. These objects can be capacitive plates which, as they move relative to the springs when applied acceleration forces, varies in capacitance. By monitoring these swings in capacity, the acceleration can be decided. Piezoelectric materials can also be used in accelerometers (19). When put under pressure or mechanical stress, such as acceleration, the crystals become electrically polarized, sending out electrical charges. Once the pressure or stress is removed the charges change polarity (19)(23).

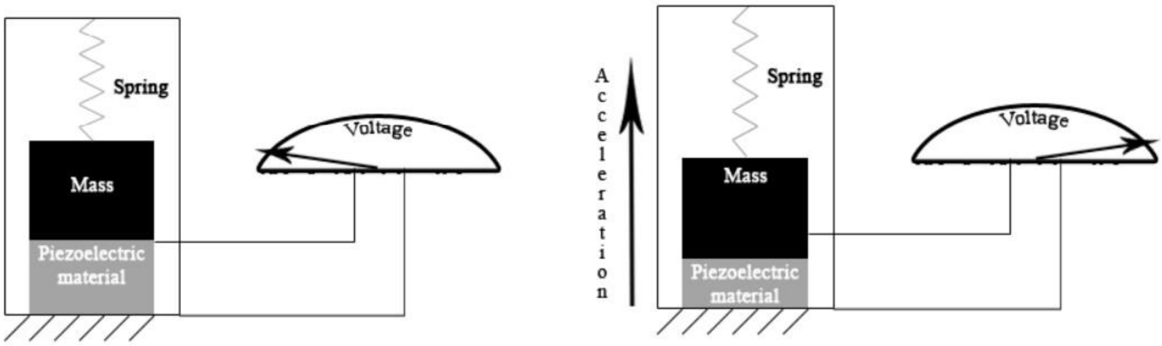

Figure 4: How the inside of a Piezoelectric accelerometer could look like. (19)

To communicate with an accelerometer, one can choose between PWM, analog or digital signals. The PWM sends its signal in squared waves with a given period, but depending on acceleration the duty cycle changes. Analog accelerometers are usually cheaper than digital ones, but for the added cost of purchasing a digital one, it often has more features and is less exposed to noise compared to the analog variety. When using an analog accelerometer the acceleration is determined by reading the changes in volt, most commonly between ground and Vin, and read by an ADC on the microcontroller. The digital accelerometers send their signals using either a SPI or I2C. (19)

Magnetometer

Earth has a strong magnetic field between its poles that can be used as a tool to help us navigate around the globe. People have used instruments to navigate by the magnetic field for many years and a modern version of such navigational instruments is the magnetometer. This instrument can measure the magnetic field's strength and direction and plot it to a digital interface. (24) By installing a magnetometer on a small aircraft like a drone it can serve as a compass that helps the drone navigate without the use of a GPS. This ability is especially useful for drones that are not necessarily meant for outdoor use.

Precision altimeter

Altimeters are instruments designed to measure altitude. Air pressure decreases as altitude increases and this fact is what traditional altimeters are built upon. (25) Sensors within an airtight metal box senses the changes in pressure and then passes this information along. (26) If the changes in pressure are below a certain point the pressure sensors will not be able to give reliable data. This is known as the sensors resolution. Altimeters are often used in devices such as smartphones, navigation systems, weather stations etc. (27)

Gyroscope

The name gyroscope comes from Greek and combines the two words gyro and scope. Gyro, or "guros" which is the correct Greek word, means rotating and directly translated guros=round. Scope, "skopeo", is an instrument used to watch and observe something and directly translates to "I aim" (28). In present day the gyroscope is commonly used for stabilization of direction, as well as directional control and indication. There are different variations of gyroscopes; free gyroscopes and single-axis gyroscopes. As the names indicates, in free gyroscopes the rotor-axis can move freely in all directions while in the single-axis gyroscope the rotor-axis is limited to movement along only one axis (29).

Gyroscope technology is divided into three main versions: optical, vibratory and spinning mass. The optical gyroscopes assume that light has a given constant velocity when it stands still within a given frame. So, by measuring the velocity of light the gyroscope will be able to tell if there is angular movement; if the gyroscopes move in the direction of where the light comes from the distance the light will have to move is shortened and the lights speed will be recorded as higher. The opposite will happen if the gyroscope is tilted the other way, the light's path will be longer, and the speed will therefore be registered as lower. Rotations will thus increase or decrease, depending on direction, the light patch length and this is referred to as the "Sagnac effect". (30)

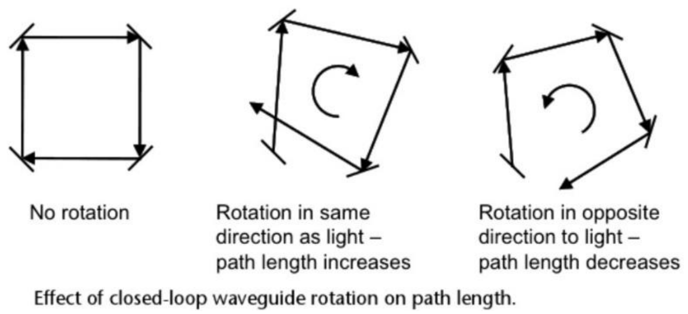

Figure 5: The mindset behind optical gyroscope, the Sagnac effect, illustration (30)

What makes the gyroscope particularly useful is its rigidity in space and its precession. The rigidity in space makes sure that the gyroscope retains its axis of rotation at all times and independently from the aircraft's current tilt. Precession is a rotating axis' ability to rotate about a second axis, which allows for the gyroscope to respond to a force applied to a point located 90 degrees from its current rotational position. (31)

Modern gyroscopes can be quite small. MEMS (microelectromechanical system) gyros, like the one on the picture below looks nothing like the older versions. They are tiny but using sensors they can measure angular velocity, speed of rotation, in either degrees per seconds (°/s) or revolutions per seconds (RPS) (32).

Figure 6: LPY503 gyroscope on a breakout board placed on top of a quarter dollar, an example of how small modern gyroscopes can be (33).

Gyroscopes can, as mentioned earlier, measure rotation around 1, 2 or 3 axes. The 3-axis gyroscope can detect and measure rotation around the x-, y- and z-axis, and due to affordable prices and the tiny sizes they have become more and more preferred. If the gyroscope is moved forward or backwards, straight up or down, that will not be registered by the gyroscope since it only measures angular velocity (pitch, yaw and roll) and not acceleration or linear velocity.

The communication interface can be digital or analog. By using the SPI (Serial Peripheral Interface) or I²C (Inter-Integrated Circuit) the gyroscope can get a digital communication interface. The communication between gyroscope and microcontroller will then work great and some digital gyroscopes can have a low power standby mode featured, a good thing if the power source is meant to be a battery. The downside is the maximum sample rate, which is lower on digital versus analog; I²C = maximum 400 Hz while SPI can be higher depending on the gyroscope. By using an ADC (Analog to Digital Converter) on a microcontroller an analog gyroscope can send signals in the form of varying voltage, most common between ground and supply, to inform about rotational velocity. The cons to analog interface gyroscopes are price and, if the analog signals are read correctly, they can be more precise. (32)

Gyroscopes will differ from each other regarding features and specifications, such as measurement/full-scale range, sensitivity and bias drift/instability. The range determines the maximum and minimum angular velocity rate the gyroscope can detect. Here it all depends on what kind of object is monitored; some objects have higher speed of rotation and therefore needs a higher measurement range compared to others that might not move much/fast at all.

The sensitivity is the ratio between voltage change and measured angular velocity, and has the unit mV per degree per second (mV/°/s). For instance, a gyroscope with 20mV/°/s which sends a 100mV change in output rotates with a velocity of 5°/s. A rule of thumb: high range gives low sensitivity, and the other way around.

Even though the gyroscope is kept completely still, the measurements might not be zero. This is due to so called bias or error. Temperature plays a big part in how much bias a sensor has. So, to minimize the error many gyros have a temperature sensor embedded. This will give a clue as to how much error is to be expected due to the given temperature. (32)

Power supply unit

Switch-mode power supplies (SMPS) have the advantages of high power capacity, at a low price in a small size and with a low weight. This overcomes the disadvantage of high electrical noise, at least in some cases such as PCs etc. (7)

To compensate for the electrical noise, unwanted variations in current and voltage, a line filter is added as the first block in the block diagram shown in figure 7. The line filter makes sure that electrical noise will not be feed back into the AC supply. If this had not been included other devices drawing power from the same AC supply could have been affected by the electrical noise. Secondly, to convert AC to DC, a rectifier is included. Next a filter capacitor then filters out the lowest frequencies. Finally, a voltage regulator switches the voltage to values much lower than inputted.

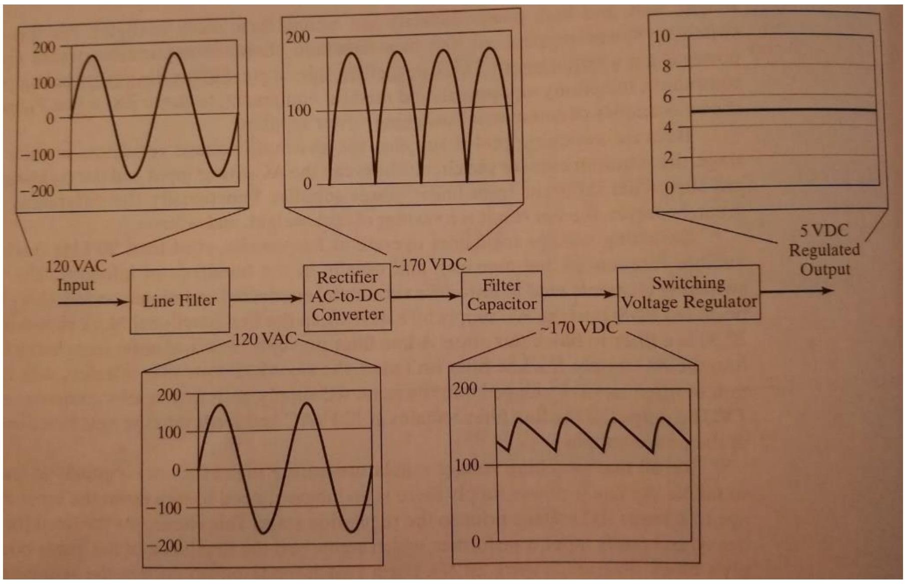

Figure 7: A block diagram for a switch-mode power supplier, showing how input voltage pases trough filters and alternates before outputted. (7)

The values in figure 7 is based upon the American line voltage, so the values do not exactly represent our European values. But, how the switch-mode power supplier works and is described in the block diagram is still valid.

Universal joints

Universal joints allow for a more seamless motion in systems where it is necessary to have two parts rotating in misalignment. Single universal joints normally consist of two yokes and a center block with two separate pins locking the three in place. It can also consist of two yokes and a center block with pins welded on. There is however a limit to how fast a single universal joint can rotate with misalignment, and speeds over 10 rpm usually only allow for an angle up to 30 degrees. (34)

Slip ring

Apart from wireless power transfer using applications like modern spools, it is problematic to transfer electric currents and signals across a rotating surface. The most commonly used solution to this problem is the slip ring. The concept of a slip ring is to have two circular objects rotating about the same axis whereas one object has a metal ring pressing against a metal brush attached to the second object. Some slip rings can have several of such rings and brushes which in turn yields more electric current and data transfer potential. To avoid having dust and moisture interfere with the transfer, the entire slip ring is covered by a housing with connector wires leading out of both objects. Usually one of the two objects of the housing will be fixed and the other will be rotating. To provide a stable and rigid rotation it is also necessary to incorporate bearings in addition to the rings and brushes. There also are various versions of slip rings. Some have through bores which allow for the use of an axle or mounting components directly onto the slip ring which will be rotating independently of one another (Figure 9). They can also be designed as a more solid piece where they will be explicitly used for signal or electrical current transfer to or from a rotating object (Figure 8). (35)

Figure 9: Senring USB slip ring (36)

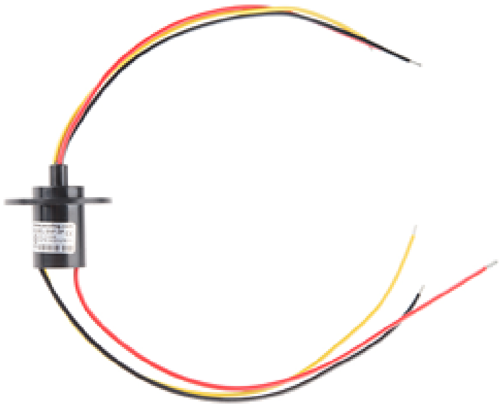

Figure 8: Senring slip ring(37)

Aerospace laws

Several laws apply to aircrafts travelling in the Norwegian airspace, including the unmanned ones such as a drone. There are mainly two characteristics that separate drones into categories; weight and line of sight of the drone. Furthermore, weight and the purpose of the unmanned aircraft determines its classification as RO1, RO2 or RO3, where each classification sets different demands to both licenses and flying. Regarding line of sight there is two types of drones, those that are within visual line of sight (VLOS) and those that are beyond line of sight (BLOS). To avoid that the drone poses a risk to both other aircrafts and the public there exists restrictions to altitude and where one can fly the drone. The maximum altitude allowed is 120 meters above ground and sea level and it is not allowed to fly any closer than 150 meters from public masses with more than 100 people. Furthermore, it is not allowed to fly the drone any closer than 50 meters from a person, building or vehicles unless said persons or owners explicitly have approved of such flight. However, if a person flies a drone that weighs less than 250 grams they can disregard said rules if the drone’s altitude does not exceed 50 meters above sea level. As drones under 250 grams are also excluded from the RO categories, the operator of such a drone does not need any license to fly either. (38)

Metals

Aluminium

Aluminium is a commonly used material in modern industry due to its qualities of being stable, light weight and that it comes in several different alloys with varied ductility and strength. Aluminium is also low priced, so it helps bring down production costs as well as weight in different appliances and products. The method of producing aluminium is done in two separate processes. First it is turned into aluminium oxide from bauxite, which is then turned into aluminium through a process called the Hall-Hérould process. (39) The process involves electrolysing the aluminium oxide into aluminium and CO_2. (40)

Aluminium is used in a wide array of applications, ranging from common household appliances to construction materials, vehicles, containers and more. (39)

Steel

Steel is a yet another material that is commonly used in the modern industry. Steel comes in a wide variety of classifications and types; all depending on an industry's different requirements for strength and endurance.

There are three methods that are considered the primary methods in steel production. The first method is called BF-BOF method, and involves the use of recycled steel and iron. In short; Iron ore is reduced to iron in a furnace, which is then smelted to steel by combining the iron with coal and recycled steel. The second method that is used is the EAF method. Here steel is produced by using electricity to smelt recycled steel. The third, and last method to produce steel is the "Open Hearth Furnace" method, or in short; OHF. This is a method which requires great amounts of energy and is not a method commonly used by steel producers. The BF-BOF method is the most commonly used method in the world with its production percentage of 70%, followed by the EAF which holds 29% of the production, and lastly the OHF with 1%. (41) The reason for this is that, while it would be ideal to rely on EAF for all of the steel production, given it only uses recycled steel, there simply is not enough recycled steel to make it sustainable. Thanks to the abundance of raw iron all around the world, the compromise of using some recycled steel in combination with iron, compared to only using recycled steel, is acceptable. The BF-BOF serves as a sustainable method which meets the world's large demand of steel materials. (41) While producing steel, several by-products are also created; such as slag, gases, sludge and dust. Most of these by-products are fortunately useful in both the steel-industry and other industries. Slag is formed because of adding substances to remove impurities in the iron and steel, while in the furnace. Thankfully the slag has many uses in other industries such as; asphalt and concrete. (42) Another by-product is gases. It is unavoidable that some of the gases disappear into the atmosphere, but some of the gases can efficiently be used to help power the factory and furnace. According to World Steel association (2014) the reuse of the gases formed by the steel production can supply with up to 40% of the required energy needed to power the furnace. The last two by-products, sludge and dust, usually contains a lot of iron and can have a further use in the steel production and other industries. Steel products usually have a long lifetime, especially the products that get treated properly with anti-rust coatings and are followed up with good maintenance. When it eventually is time to dispose of the steel it can, as mentioned earlier, be recycled in the production of new steel materials. According to World Steel Association (2014) up to 100% of steel can be recycled without any loss of quality, if the product ends up back at the furnaces. (41)

Welding of steel and aluminium

There are several methods and techniques for welding metals and other materials together. Most relevant for this thesis is the method called TIG welding. TIG stands for “Tungsten Inert Gas”. As the name implies, it involves the use of two materials, namely tungsten and argon gas. This is a very difficult method of welding, but is a very clean and precise way of welding materials together. It has been common knowledge that aluminium and steel does not bond well together in welding. This is due to how molten aluminium reacts with other materials, as it forms intermetallic compounds that are prone to breaking. Although, new and modern techniques have made it possible to weld the two metals together. To do this the welder can either use bimetallic transition inserts or weld after coating the steel. The first method involves in inserting parts that consist of 50%/50% bonded aluminium and steel. The second method involves in coating the steel with aluminium before welding. (43)

Existing applications

Stewart Platforms

One of the existing simulation platforms. These platforms typically consist of 6 DOF motions, which includes pitch, roll, yaw and translations along the x, y and z-axes. When first introduced, it was solely intended to be used as a flight simulator, but today it is used for other applications and testing. Although it still is being widely used for flight simulation, some other areas of application include heave compensating for cranes and winches at sea, aerospace technology and the automotive industry. The platforms main purpose is applying position control. It consists of two platforms, one lower, one upper and six hydraulic legs connecting them together by universal joints in parallel. It’s ability for motion and positioning is very precise and the structure is very strong. However, relative to a drone, this type of platform is meant for simulation, and not programming for independent flight. (44)

Quanser 3DOF Hover platform

Perhaps the most fulfilling 3DOF platform currently on the market. The application is designed as a small tower like structure consisting of a base with an axle connected to an encoder that measures its yaw angle. On the axle is a slip ring, making it possible to have power fed to the top of the platform without twisting the electrical power and signal cables. There are also encoders at the top of the platform that measures pitch and roll. To actuate the roll and pitch, there are motors mounted with equal spacing and angles on a circular transparent disc with holes for airflow. Lastly there are propellers on the motors providing thrust and they are protected with extensive propeller shields for added security. The platform was designed to further the understanding on how flight dynamics and control of flying vehicles work. The disc cannot however, be dismounted and flown on its own. (45) (46)

Method

Development

Design methodology is a method that will help show others how and why the product is designed the way it is. It will make it easier for others to get into the mindset and possibly take on and further develop unfinished work. There are several phases within product development and they can be divided into these four main ones (47):

1. Demand and market analysis: Identifying the needs and what the market is looking for.
In our case there is a desire to have a construction that can be used in lab exercises at the University of Agder.

2. Concept phase: Features and solutions, what should the product do, and which solutions are out there?
Here it is important to analyse and identify critical functions and technologies. It is and advantage to start with the "bottleneck", meaning the aspects most difficult to apply, and then solve the related problems in accordance with the solution to the bottleneck.
Our bottleneck is how to supply power and signal to a rotating object. Another main issue is how to achieve three degrees of freedom.

3. Design phase: Determine which parts and solutions that are to be included in the construction. Parameters here is for instance location, amount, form geometry and form dimensions.

4. Detailed phase: Dimensioning, selecting suitable materials and making estimates.

By using the ideas and following the progression list from the product development method, our plan on how to solve the project is:

1. Understand the construction task
    - Create specifications
2. Establish functional structures
    - Dividing into sub functions
3. Establish a concept
    - Develop partial solutions
    - Develop concepts
    - Evaluate and choose a main concept
4. Constructional Drawings
    - Dimensions and materials
5. Build
    - Detailed Drawing

(47)

Point 1-3 is will be part of the method, while 4-5 will be included in the results of the thesis.

1. Understanding the constructional task at hand

Product specification:

	Function	Must	Should
1	Functional properties 1.1 Product 1.1.1 Power Supply 1.1.2 programming a stabilization program for a drone 1.1.3 Degrees of Freedom 1.1.4 Mounting 1.1.5 Interface 1.2 Ergonomics 1.3 Operating	1.1 1.1.1 Must supply the drone with power, either through a battery, a power outlet or both. 1.1.2 Must be able to program a drone via a computer. 1.1.3 The drone must have 3 degrees of freedom with full rotational possibility around yaw. 1.1.4 Must be able to attach the drone to the platform, as detach it from the platform. 1.1.5 The platform must have a user interface containing a on/off switch/button and a way to connect the pc to the drone for programming. 1.2 Must have a certain weight, but should not be too heavy. One should easily be able to move it to the workplace. 1.3	1.1 1.1.1 Preferably without the use of a battery when connected to the platform. 1.1.2 1.1.3 The drone should have as large a pivoting angle in roll and pitch as possible. 1.1.4 Chosen mounting solution should not add much extra weight or be too difficult/time consuming to use. 1.1.5 Should have lights to signal if it is on and if it is connected for programming. 1.2 1.3 Should be user friendly for students that are not necessarily accustomed to the construction.

2	Surroundings (boundary conditions)	The platform must weigh enough to not elevate/tilt when the drone is flying. To avoid regulations the drone must not weigh over 250-500 grams. Due to the airflow from the rotors the drone must not be positioned too close to the surface/table top, and the platform itself must also be designed in regard to the airflow. Since the platform is going to be used in labs there is no demand for it to withstand outdoor weather.	It will be kept in a closet, so not too big and easy to store Withstand normal wear and tear.
3	Aesthetics		Should be relatively nice to look at.
4	Project plan	The whole project, including the manufactured construction and the report, must be finished within December 1st.	
5	Costs	Limit: 5000-6000NOK	
6	Production/mounting	Will have to be able to reproduce 10-15 equal platforms. Ours is the prototype.	Should consist of as few and “simple” parts as possible for easy production. Should be able to produce/ assemble a lot of it in the lab at school.
7	Standards		
8	Safety	Since there is electricity involved this has to be done according to regulations and students’ safety when using the platform is important.	
9	Environment		It should not be too polluting to produce in terms of material

			selection and the production process itself. Should not be too high energy consuming to drive the system. Should be recyclable.

Table 1: product specifications. (47)

2. Establish function structures

Sub functions:

1. Power the drone.
2. Contain a computer to drone programming possibility.
3. 3 Degrees of freedom.
4. Attaching and detaching the drone from the platform.
5. Interface

3. Establishing concepts

Solutions to the functions:

1. Supply the drone with power without any wires getting in the way (should ideally be without the use of battery, but that is a backup solution). Needs 30-40 amps.

Solutions:
1.1 Use a slip ring.
1.2 Battery.
1.3 Wireless charging.

2. Being able to program a stabilization program for drones.
Solutions:

2.1 Programming the flight controller on the drone via a USB cable on a slip ring
2.2 Programming the flight controller on the drone via signal circuits on a slip ring
2.3 Programming the flight controller on the drone via a regular USB cable but limiting the
drone's rotation around yaw while connected to avoiding the cable getting twisted.

3. 3 degrees of freedom, where yaw is unlimited while pitch and roll should be somewhere between 20-45 degrees.

Solutions:
3.1 Gimbals.
3.2 Ball bearing/ ball joints.

3.3 Universal joints.
4. Mounting the drone on/off the drone should be easy. At the same time, it is very important that the drone is securely mounted to the platform, so it does not fall off/ fly away. Should not add much weight to the drone.

Solutions:
4.1 Screws.
4.2 Clamp mechanisms.
4.3 “Child secure bottle” idea.
4.4 Magnet.
4.5 Hood pins.

5. The interface should include: power on/off control, usb/ethernet connection to be able to program, maybe some lights to indicate power on/off and connection to the drone.

Solutions:
5.1 Appliance inlet with an illuminated switch
5.2 Microcontroller hidden within some sort of box to protect it from harm. On/off switch or
button connected between the power supply and the microcontroller. A she to male USB-stick connection to connect the PC to the microcontroller/whatever you program on. Two lights connected to the microcontroller which turns on when they get signals “power on” and “device connected”. Text over the switch, USB connection and the two lights.

Evaluating the solutions and coming up with concepts:

The functions and their solutions are listed in a certain order: the bottleneck first and then in order according to importance. The idea is to decide the solution for the most difficult and challenging problems first and then come up with solutions for the smaller challenges in a manner that suits the main issues.

1. Supply the drone with power

1.1 Slip ring
A slip ring would be able to supply the drone with power even when the drone is rotating, while also not having the power cords getting entangled. Slip rings comes in various versions and it is important to find one that meets the requirement to deliver 30-40 amperes and has a through bore. There will still be wires around the drone and even though they will not be twisted up they might still be in the way.
Score: 9/10

1.2 Battery
The cons to using a battery would be that the all the components on the drone would be supplied with the exact same amperage and voltage values when connected to the platform, compared to when flying freely. The obvious downside, which is quite huge, is that the flytime when connected to a battery is not very long, so the battery would have to be replaced frequently and charged.

Score: 3/10

1.3 Wireless charging

The very idea of charging wirelessly is very clever and smooth, but doing it in practice on the other hand is not necessarily so easy. It would possibly have to be done by spools and might be very difficult to apply.
Score: 4/10

Conclusion: using a slip ring is the best alternative.

2. Programming:

2.1 USB on slip ring
If a slip ring is to be used one might as well chose one that is equipped with a USB cable. The USB cable would rotate in accordance with how the drone moves in the same way as the other slip ring wires do.
Score: 9/10

2.2 Signal wires on slip ring
If the slip ring is not supplied with a USB cable it still might have signal wires that could work. The problem would be how to connect it to the flight controller/micro controller.
Score: 4/10

2.3 USB directly from computer
Score: 3/10

Conclusion: USB via slip ring is the best solution.

3. Degrees of freedom:

3.1 Gimbals
The gimbal system has the risk of locking itself which takes away one degree of freedom.
Score: 6/10

3.2 Ball bearing/ball joint:
This could have been a very good option. The movements would be very smooth and coherent, as there would be no irregular movements. The demand of including all three degrees of freedom would be accomplished, full rotation in yaw while tilt ratio on pitch and roll would be alike. However, none of the ball joints we found had a high enough pivot angle to satisfy the requirements.
Score: 5/10

3.3 Universal joint
The joint seems to handle up to 30 or more degrees of pivoting angle. Although it might not be as seamless as desired, perhaps a custom made one could suit our needs.
Score: 8/10

Conclusion: The Universal joint is the best option.

4. Mounting:

4.1 Screws
Using screws to mount the drone on to the platform would certainly hold the drone in place and the “how-to” would be quite easy. The downside to this solution is that it might be to time consuming to mount the drone on and off the platform. By using only one screw at the end of the platform that goes into a hole on the drone, then tighten it with a nut, it might not be to time consuming. The solution can also easily be used to mount on a landing gear for when the drone is not connected to the platform.
Score: 9/10

4.2 Clamp
A clamp mechanism would make it both quick and easy to mount the drone on and off. However, the clamp would have to be designed so that it is able to hold the drone steady and connected to the platform even when the drone is fully powered up.
Score: 7/10

4.3 “Child securing” bottle idea
When trying to open a bottle of red spirits or chlorine, the mechanism within the lid is designed for it to be difficult for children to open; one has to press down while turning the lid. This idea could be transferred into a quick mounting solution. The problems here might be wear and tear without any clear signs of malfunction. Since the screw threads are not visible from the outside the drone could either suddenly take off in the middle of testing or trouble unmounting the drone.
Score: 5/10

4.4 Magnet
A magnet would be a quick way to mount and unmount the drone. Possible problems here is that the magnet would have to be quite strong to make sure the drone stays in place. The magnet might affect with how the drone moves, depending on the material on the drone. There might also be interference regarding the electrical components and a safety hazard for getting fingers stuck between the magnets.
Score: 5/10

Conclusion: Using a screw is the best idea.

Due to the drone not being part of the initial criteria of this thesis, it is not included in this product development section.

Results

The platform

The drone platform has undergone several changes during this project. Although it would have been more desirable to keep the initial design it was necessary to simplify it due to the requirements of some components and criteria. The platform itself consists of several small parts joined together. At the lower half there is a baseplate with a square shape. It acts as the foundation of the platform and is dimensioned at 260mm x 260mm x 5mm. It is made from steel. Through the baseplate there are several ventilation holes working as inlets for airflow. There are also screw holes to mount the power supply. The figure below shows how the holes are distributed across the base plate. The larger holes are for airflow and the seven small ones are for mounting the PSU.

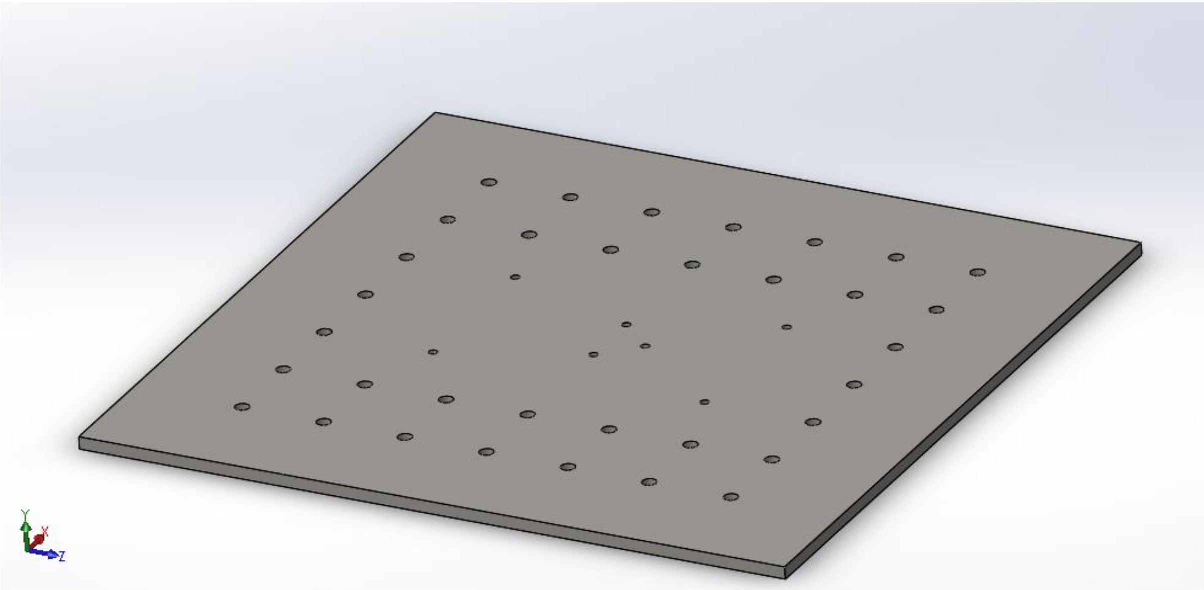

Figure 10: Base plate of the platform.

On top of the base plate are four steel walls put together to form a room that can house several components. These components are the power supply unit, the power inlet switch with connectors, the usb interface for computer to microcontroller connection and a fuse. The dimensions of the walls are two 250mm x 150mm x 5 mm and two 260mm x 150mm x 5mm boards. There are also small holes in the top corners of the long walls which work as exhausts for airflow. The figure below shows the holes for usb connection and power inlet in the right side as well as all the holes necessary for hinges and ventilation. The front wall has holes for the lid locking mechanism.

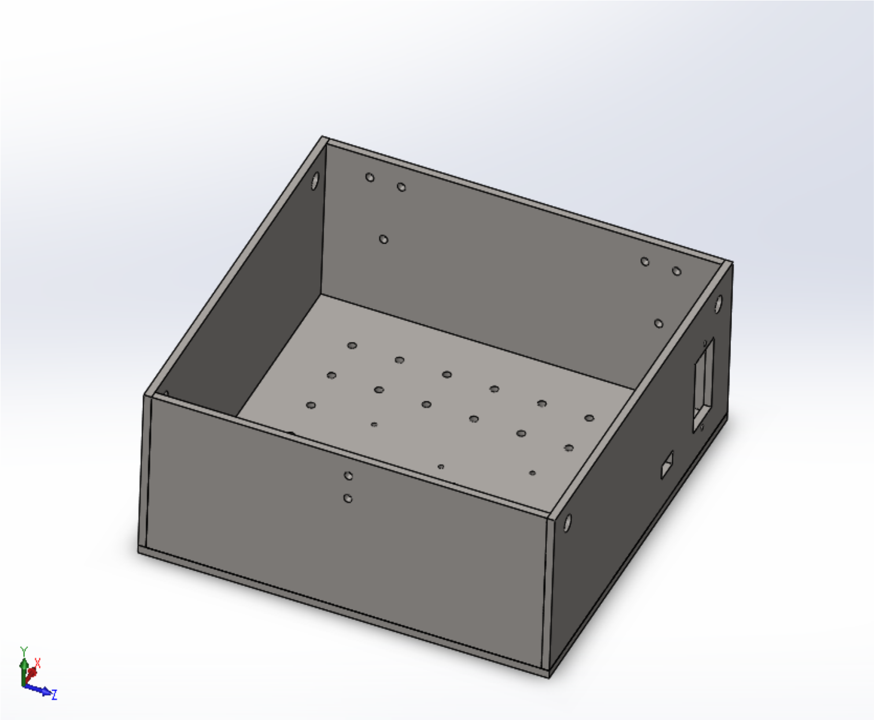

Figure 11: The box for housing the PSU and other components.

Enclosing the housing is a steel top lid with the dimensions 260mm x 260mm x 5mm. The top lid also has a hole in the center which allows for easy wiring up to the top half of the platform. On top of the top lid, and placed just around the hole, is a steel pipe that has an outer diameter of 70mm, and an inner diameter of 58mm. There is also a cut 55mm down from the top of the cylinder to lock the rotation of the slip ring. The lid is designed with two hinges in the back and an eccentric lock with the possibility of a padlock. This way one can easily open the lid to perform maintenance on the electrical system while also locking it afterwards to avoid that students open it during exercises.

The entire construction is designed to be made from steel. This is because steel is easy to weld together, and it is heavy enough to support the forces applied to the platform. Although it would be best to produce a steel product, the prototype for this project was made from veneer. The figure below is a model of the platform without any of the components or joints.

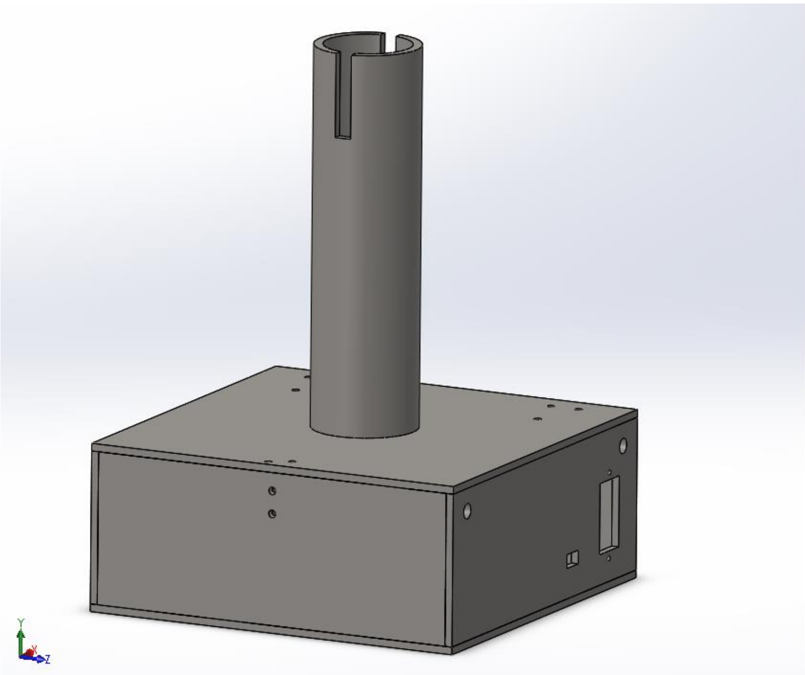

Figure 12: Complete drone platform without components.

Components

To supply the drone with power there are several necessary components which were also mentioned earlier: a slip ring, a power supply, an appliance inlet (included a fuse drawer and fuses) and a C13 IEC outlet cable. The signal is sent through USB-cables. The Teensy 3.2 microcontroller that is used on the drone is equipped with a micro USB port. Since the USB cable on the slip ring is USB A it is required to have an adapter. The same USB A type cable leads out from the other side of the slip ring. While this is the correct type of cable for connecting to a computer, it is too short. Therefore, it is needed to use an USB A extension cable. It is not ideal to have so many links because it can cause a delay in sending and receiving data. It may also potentially lead to a loss of power sent to the microcontroller through the USB port, but hopefully this loss is so small that it will work fine.

C14 IEC Appliance Inlet

The C14 appliance inlet from Schurter with part number DD11.0124.1111 is IEC rated with a load capacity of 10 amperes and 250 VAC. It has a 2-pole line switch and a fuse holder in the front. (48) It being a double pole line switch allows for it to handle 240-volt circuits. (49) An extra security layer is added by the fuse drawers. The on/off switch, also known as a rocker switch, has illumination and will turn green when turned on (48). It has three ports: L, N and PE, which fits the PSU perfectly. (50)

Figure 13: IEC appliance inlet C14, with line switch 2-pole, fuse holder 1- or 2-pole. (51)

It can be mounted with screws either in from the front or on the rear side. The thickness of the panel cannot exceed 2mm if it attached from the rear side. If it is installed from the front on the other hand the panel can be maximum 8mm. The cable going from the wall socket to the switch is a C13 cable.

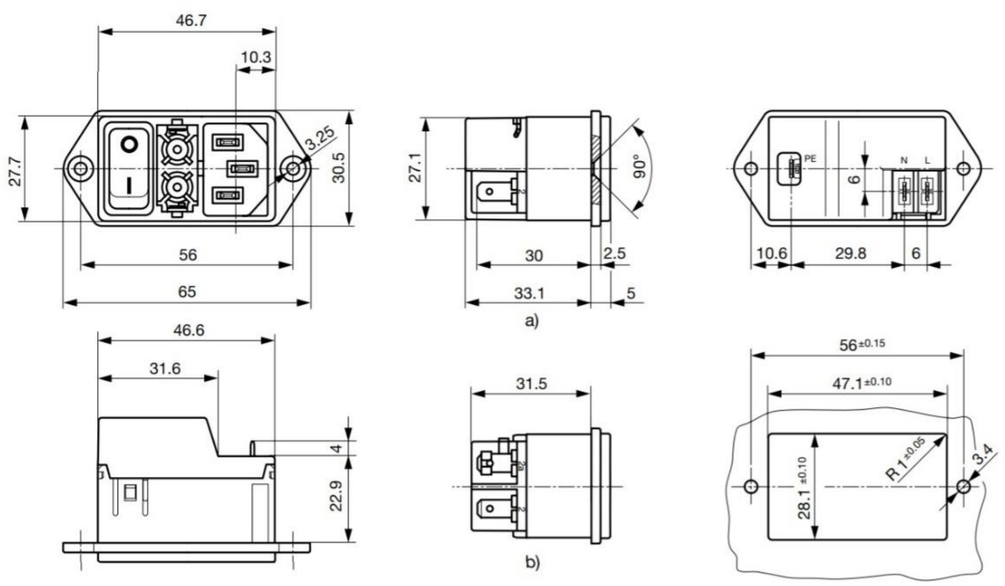

Figure 14: The dimensions of Schurter C14 IEC appliance, part number DD11.0124.1111 (48)

The fuse holder fits a 2-poled fuse drawer that uses 5x20mm fuses (48) (52). Initially we went with a 1.25A slow-blow fuse but this could quite well have been replaced with a higher current fuse, if it does not exceed 5A (54).

Switched mode power supply

The TXH 120-112 switch-mode power supplier from Traco Power has an output voltage nominal at 12 voltages and a maximum output current at 10 amperes, which together will provide a maximum output power of 120 watts (54).

Figure 15: TXH 120-122 switch-mode power supplier from Traco Power (55)

Since the drone is powered by a 3s LiPo battery, delivering 11.1 volts, when not connected to the platform, it is convenient to supply it with at least close to same voltage when connected to the PSU. The slip ring has 4 circuits at 10A each, so it could have been possible to have a PSU that delivered more power, by just adding more amperes and dividing it to multiple

circuits (56). However, that would have been more expensive and the PSUs with a higher power is usually bigger in physical size. The appliance inlet would also have to be able to supply more power. After some consideration we concluded that since the drone is not supposed to elevate when attached to the platform, the motors do not have to run on max speed and 120 watts should be sufficient. The flight controller does not drain much power, at an absolute maximum: 5V x 2A = 10W, so it would be 110W divided on the four motors and the receiver (57).
The power supplier weighs 390 grams, is 137mm long, 82mm wide and 38mm high. It has three AC in poles: L (line/hotline), N (neutral) and FG (frame ground). Nominal voltage input can be 100-240VAC. Input current at full load is 1A at 230VAC, and the recommended circuit breaker is 5A. The 12-volt output is fixed and has a maximum ±2 % voltage set accuracy, meaning the output voltage can range between 11.76-12.24V. The efficiency is at 90%, which is considered very high. There is no requirement for a minimal load. (58)

Datasheet and installation instructions can be found in the appendix.

Senring slip ring

The SNU11-0410-04S slip ring has a 12.7mm through hole and an outer diameter of 56mm. It consists of one USB 2.0 channel, 4 power circuits at 10 amps normal current and 4 signal circuits at 2 amps. (56) The 10A circuits has a 15 amps peak current that should not be exceeded (information received on email from Senring). Having a USB connection makes it possible to connect the flight controller on the drone to the computer for programming, even when the drone is hovering on the platform.

Figure 16: Approximately how the SNU11-0410-04S slip ring looks like. USB A 2.0 male in both ends, 4 circuits for signal and 4 for power. (59).

One of the initial requirements given was that the slip ring needed to be able to deliver 30-40 amps. The 4 power circuits, on a total of 40 amps, delivers enough electricity to power all 4 motors on the drone. The extra 4 signal circuits can later be used to receive and transmit data to an extra IMU placed on the top of the platform in addition to the one on the drone, if desired (56). The absolute max speed is 600 rpm but working at 250 rpm max is recommended (information received on email). More detailed figures on how to install the slip ring and its construction drawing can be found in the appendix.

Universal joint

The joint that connects the platform to the drone is a universal joint. Existing models of universal joints normally operate on low angular misalignment and do not offer a seamless motion in angles up to 40 degrees. This resulted in us modelling a custom universal joint which was then 3D-printed in ABS plastic. The joint itself consists of four main parts, one axle, two yokes and one center piece. The axle is 12mm in diameter and is connected to both the slip ring and the lower yoke. The slip ring connects to the axle by four M3 screws, and it is locked to the lower yoke by a 5mm locking pin. Both the lower and upper yoke is connected to the center piece by two 5mm locking pins. Lastly, the upper yoke connects to the drone and is held in place by a fourth 5 mm locking pin. The figure below shows all the parts of the joint assembled. (34)

A more detailed constructional drawing can be found in the appendix.

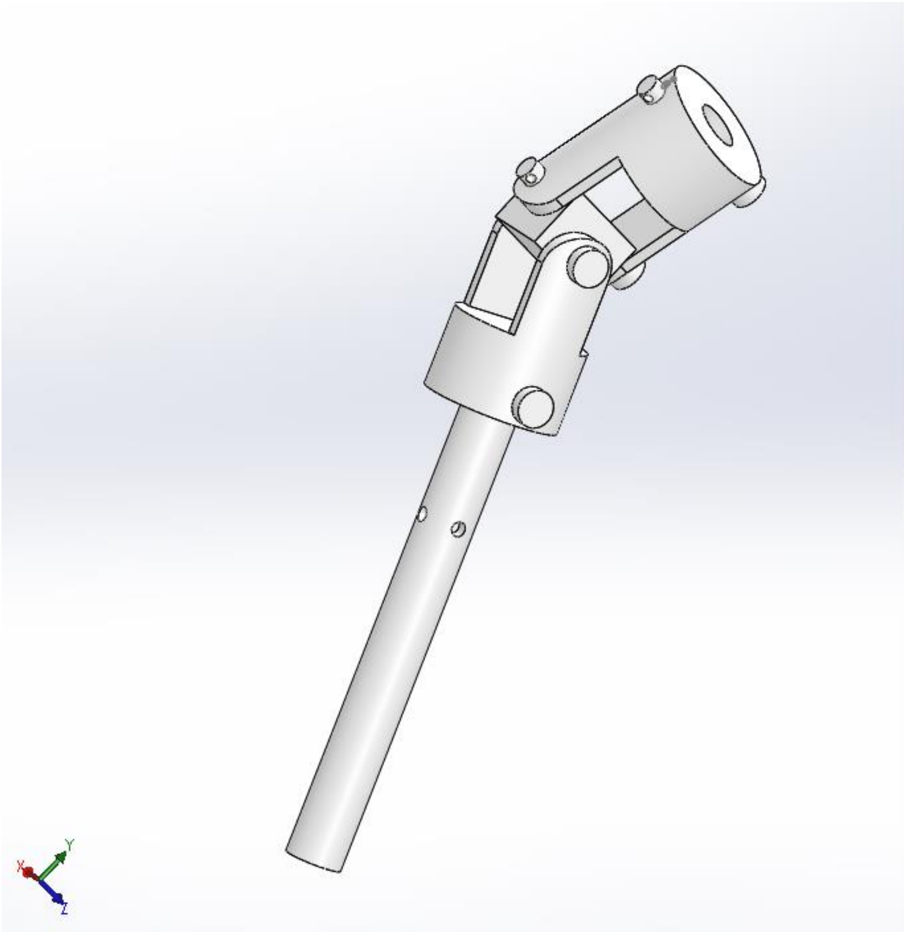

Figure 17: The universal joint with axle.

Drone

The Frame

When building a quadcopter, it is normal to just purchase and use a finished frame from the store. However, to be able to mount all the components where we want them it was better to design our own frame. This way we could make it so that our components fit perfectly with the frame and all the screw holes needed could simply just be designed in. All the parts were modelled up in SolidWorks before being 3D printed in ABS plastic. The drone frame needed to have room for: four motors with propellers, four ESCs, one PDB, one battery, one receiver and one Teensy prop shield with a Teensy 3.2 stacked on top. Ideally the center of mass should be where the drone is connected to the platform, and in the center of the drones xy-plane. So, this were taken into consideration when designing the frame. The frame, without the components attached, weighs 108.7 grams, measures 214x214mm at its widest and 81mm in height. Figure 18 shows how the frame looks fully assembled. When we were designing we also had to take into consideration how the 3D-printer can print. 3D printing in free air without support material is impossible, so the frame had to be divided into several parts for printing before assembling them.

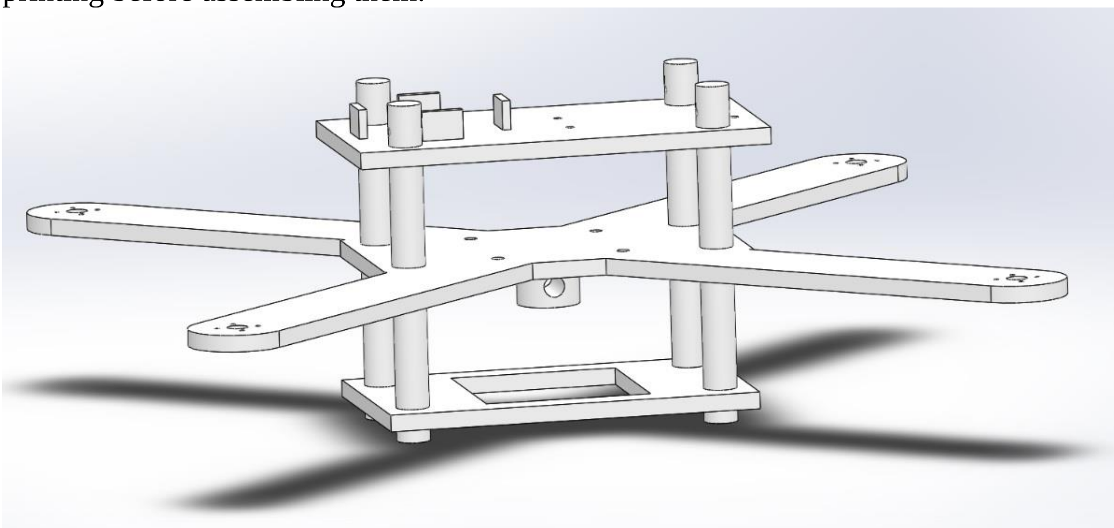

Figure 18: The drone frame assembled. 1st floor for battery, 2nd floor for PDB, ESC and motors, and 3rd floor for receiver and flight controller.

The frame consists of three floors, connected to each other by four long poles, reaching from below the 1st floor (with a wider diameter in the bottom) up until over the 3rd floor. Between the floors, hollow piles are pulled through the long poles, to ensures that the floors are given a certain distance between each other and that this distance is maintained. On the top, above the 3rd floor, a top hat is pulled over the long pole, and a screw with a nut in the end is screwed through the top hat and the pole, making everything tightened together. Figure 19 gives a more graphical illustration of how the poles are connected to each other.

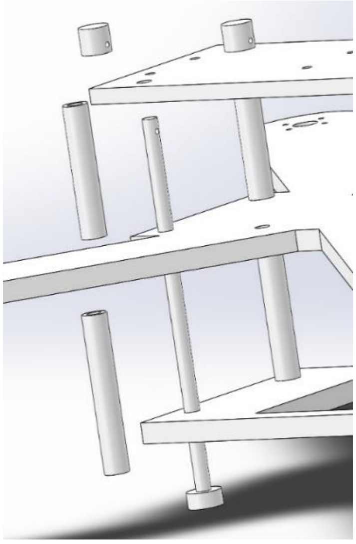

Figure 19: The long pole goes through all three floor on the drone frame. Than the hollow poles are fed onto the long pole, dividing the floors from each other. At the top of the 3rd floor a top hat is placed over the long pole. A screw and a nut will then look e

On the ground floor (1st floor) there is room for the battery to be placed. Since the drone will be power by the power supply when attached to the platform there is no real use for the battery in that situation. Therefore, the frame is designed so that to mount the drone to the platform the battery must be removed. With the battery removed the top of the platform will be able to pass through the square hole in the 1st floor, which you can see in figure 20, up to the underside of the 2nd floor. This way the connection between the drone and the platform is as close as possible to the mass center. There is enough room to fly with also larger batteries than the one we have chosen, if the battery's dimensions are within 67x50x20mm or 27x90x20mm. Since the battery cannot be screwed onto the frame velcro will be used to fasten the battery when in flight mode. On each of the corners there are holes to be able to attach the 1st floor to the other floors.

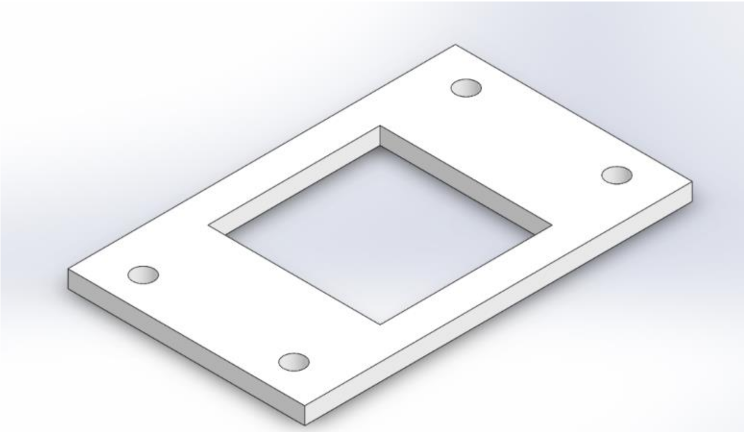

Figure 20: The drone frame's 1st floor, with a square hole for the top of the drone to come through. Holes on the corners to be able to attach to the other floors.

The 2nd floor is a bit more detailed. Underneath, in the center, is where the drone will attach to the platform (see figure 21).

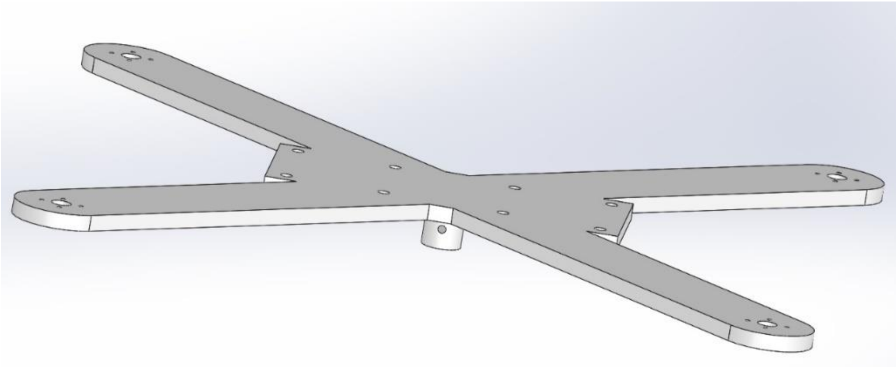

Figure 21: Drone frame's 2nd floor seen from the side. Underneath, in the middle, the tap to attach the drone to the platform can be seen.

Figure 22 shows the 2nd floor from above. There are four holes in the middle to mount the PDB with screws. Like on the 1st floor there are holes in the corners to assemble all the parts. The arms form a square and on the edges, and is where the motors will be mounted, each with four screws. Underneath the motor a small part is going a little further down and needs room to turn around, therefore a hole in the center of the four motor screw holes are made. Obliquely across from each other the distance is approximately 262mm from one motor to another. The arms needed to be spread that far out, if not the propellers would not have had enough room to rotate. The ESCs will lay on the arms. These must be fastened with double sided tape to the arms and then extra secured with velcro.

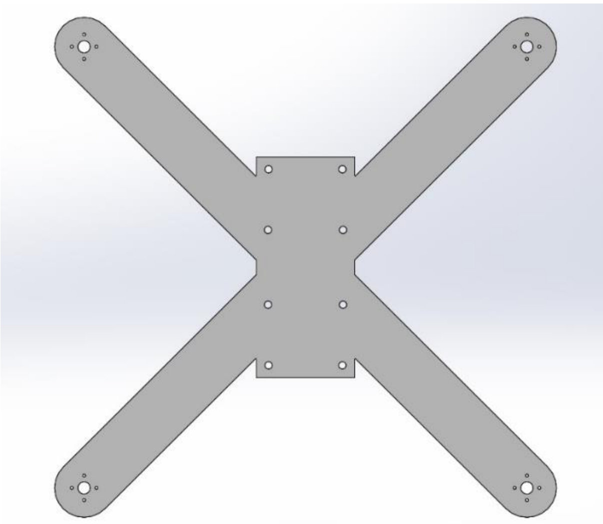

Figure 22: Drone frame's 1st floor seen from above.

On the 3rd floor the receiver and the flight controller, meaning the Teensy 3.2 and the Teensy prop shield, will be found. Figure 23 shows the 3rd floors layout. The Teensy prop shield will be mounted with screws, and the four holes needed is put on one side of the floor. On top of the Teensy prop shield the Teensy 3.2 will be soldered on. The receiver does not have screw holes so, to be sure that it stays on the drone, four walls has been raised on the other side of the 3rd floor. Within these four walls the receiver will be mounted with double sided tape to the floor. As an extra safety velcro will also be used. Since the antenna comes out on one of the sides, and for making it possible to dismantle if necessary, the walls do not fully extend to each other. On all four corners are the holes for the main poles.

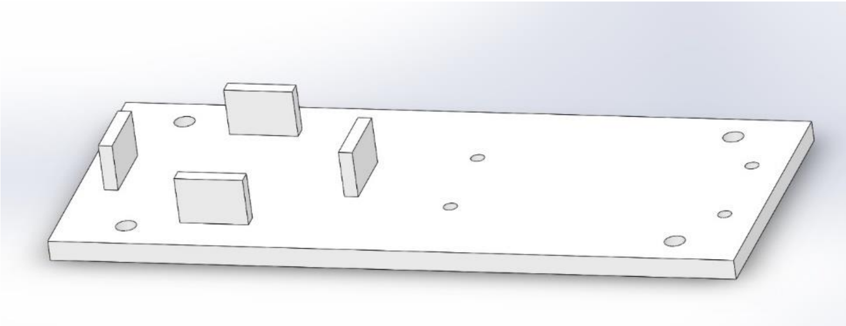

Figure 23: Drone frame's 3rd floor.

More detailed constructional drawings with dimensions can be viewed in the appendix.

Figure 24 shows how the drone is connected to the platform. The universal joint reaches through the 1st. Floor on the drone and is attached on the tap under the drone's 2nd floor. A screw with a nut on the end is making sure the drone stays attached.

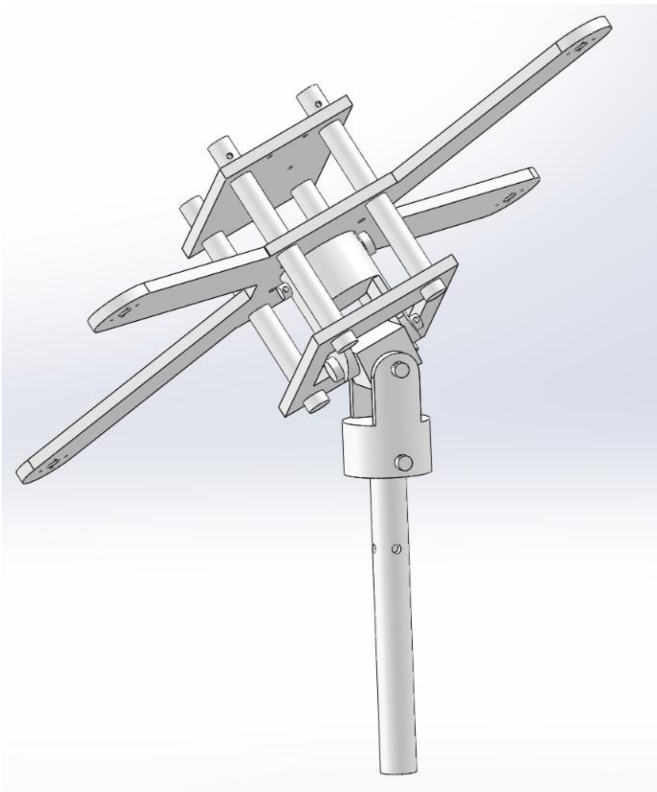

Figure 24: Drone connected to the platform

Components

Teensy 3.2

The Teensy 3.2 will be the drones processing unit, and combined with the Teensy prop shield they will work as the drone's flight controller.
The Teensy 3.2 development board is light weighted and small (35x18mm), as shown in the figure 25 below. Perfect for a drone that ideally should not weigh more than 250 grams. (60)

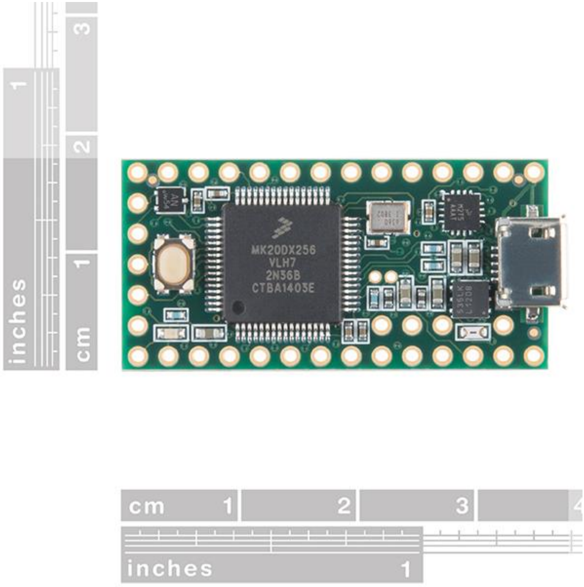

Figure 25: Teensy 3.2 dimensions (60)

It features 64Kb RAM, 265Kb flash memory, 2Kb EEPROM 34 digital I/O (VO: 3.3V, VI: 5V tolerant) and 21 analog inputs, among more (61). To program, simply connect a micro USB to the microcontroller and type away. You can program using C in a program of your own choosing or by installing the Teensyduino add-on for the Arduino IDE (60). The Teensyduino add-on latest version (1.40) is compatible with the newest Arduino version (1.8.5) as well as some of the older versions. It can be downloaded on Windows, MACs and Linux (62). Complete list of compatibility and a "how to" is in the appendix. When using the Tennsyduion all the standard Arduino functions such as digitaleWrite, pinMode, analogRead etc. are compatible (63).

Further technical specifications and pinout sheet is found in the appendix.

Teensy Prop Shield

The Teensy Prop Shield is compatible with the Teensy 3.2 and is simply stacked on top off or underneath the microcontroller. The shield will work as the flight controller's inertial measurement unit (IMU). With its Freescale 10DoF motion sensors on board; one precision pressure/altitude and temperature gauge, 3-axis digital angular gyroscope and the combined 6-axis linear accelerometer and magnetometer, the shield is well equipped. Like the Teensy 3.2 this shield is small (see figure 26 below), but a little bit longer than the 3.2 and with mounting holes in each of the four corners. This makes it ideal to put the Teensy 3.2 on top of the shield instead of on underneath to easily attach them to the drone frame. (64)

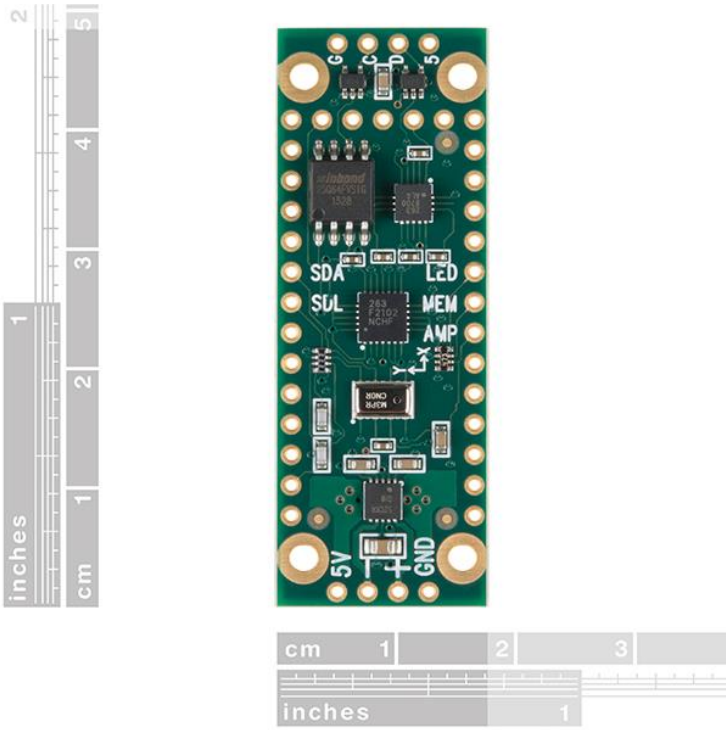

Figure 26: Teensy Prop Shield dimensions. (64)

The precision altimeter is fitted into the Xtrinsic MPL3115A2. A MEMS (Micro-Electro-Mechanical Systems) pressure sensor is used to collect the correct pressure/altitude data. Even though we will only use it for pressure/altitude it can also measure temperature. The digital interface featured is inter-integrated Circuit (I^{2}C), which operates up to 400 kHz, and the analog to digital converter (ADC) has a 24-bit resolution. Pressure is measured in Pascals and altitude in meters, with resolution down to 10cm. Both have 20bit compensated direct readings. The Xtrinsic MPL3115A2 have a power saving mode but when in active mode, keeping a steady 0.1m output resolution, the current draw is 0.04 mA/measurement-second. It is possible to activate modes for interrupting or automatically collect data, such as for cycle timing or poll-only. (65)

The 3-axis digital angular gyroscope on the Teensy Prop Shield is a FXAS21002C. Given the 3-axis it can detect angular movement in yaw, pitch and roll. The full-scale range can be configured to be ± 250, ±500, ±1000 or ±2000 dps (°/s) and the output data rates (ODR) lies between 12.5 to 800 Hz. Both digital interfaces, Serial Peripheral Interface bus (SPI) and Inter-Integrated Circuit (I^{2}C), are possible to use. I^{2}C rates from 100 to 400 kHz while SPI comes in 3- and 4- wire modes and can go up to 2 MHz. The analog to digital converter (ADC) has a 16-bit resolution. A low power standby mode is featured and the time from standby mode to active mode is only 60ms. While in active mode the current consumption is 2.7mA. It also has a low-pass filter (LPF) that makes it possible for the host application to restrict the digital signal bandwidth. The FXAS21002S can be set to generate an interruption when or if a user-programmable angular velocity limit is exceeded on one of the 3-axis. (66)

The 3-axis linear accelerometer and the 3-axis magnetometer are both featured on the FXOS8700CQ. Serial Peripheral Interface bus (SPI) and Inter-Integrated Circuit (I^{2}C) can be used. The analog to digital converter (ADC) resolution is 14 bits for the accelerometer 14 and 16 bit for the magnetometer. Full-scale ranges on the accelerometer can dynamically be set to ±2 g, ±4 g or ±8 g, while the magnetometer has a fixed ±1200μT full-scale range. The sensors can output data rates ranging from 1.563 to 800 Hz, depending on user preference. It can interleave magnetic and acceleration data for both individual sensors at a maximum rate of 400Hz each. A low power standby mode, lowering the ODR, is embedded and can be activated for both sensors and will switch between awake and sleep mode, when necessary, to save power. The FXOS8700CQ have some built-in programmable event features, for both the magnetometer and the accelerometer, that helps detecting different kinds of changes. Examples are: freefall and motion, orientation and vector magnitude (67).

More detailed information about the Teensy prop shield, the Xtrinsic MPL3115A, the FXAS21002 and the FXOS8700CQ can be found in the Appendix.

Arrowind 1806 brushless motors

We have chosen two CCW and two CW motors brushless motors of the type 1806 2280KV. They look and work identical but the prop nuts on top are different: the red is for counter clockwise propellers and the black is for clockwise propellers, as seen in figure 27 (68) (69). The motor diameter is 23mm, the rotors diameter is 18mm and each motor weighs 18 grams (69) (70). There is four holes for mounting and the package comes with 12x16 fixing screws in 3 different lengths (69). The propellers used with them is Dalprop Blade 5030 (71).

Figure 27: Arrowind 1806 brushless motor. The one with red prop nut is for CCW spinning while the one with black prop nut is for CW spinning. (68) (69).

The reasons why we chose the Arrowind 1806 motor was low price and the convenience that they sold it at a local hobby-store where all the other drone components, except for the flight controller, also were bought. The weight and size seemed right for our use, and it was a great fit for a 250-race quad (69). Unfortunately, there is no datasheet for the exact motor we chose, neither on the internet or included in the packaging. However, the specifications should be at least roughly equal to other 1806 motors with 2280kv, such as EMAX MT 1806 KV2280 and Tarot MT1806 2280KV. They are all the same sizes and weight and they have the same KV. Comparing both EMAX and Tarot motors at 11.1 voltage and 8A using 5030 carbon fibre prop both get a 380g thrust (70) (72).

The maximum power supplied to the PDB from the power supplier through the slip ring is 120W (10A and 12V). Since the quadcopter is not supposed to elevate when it is attached to the platform it is no disadvantage that the supply is not higher. It is not easy to say exactly how much thrust each motor will provide without testing them, since the sample test rapports only is valid for 7.4V (2s LiPo) and 11.1V (3s LiPo) while we will have 12V, when connected to the platform. However, an approximate estimate shows that if supplying these motors with 2A and 12V each, using 5030 propellers, the thrust on each motor will be somewhere between 140-180 grams (72). Total thrust will then be 560-720-grams total, which is more than enough to test and program.

Arrowind 12A ESC

The Arrowind 12A ESC (figure 28) is based on Simonk firmware. It is 25mm long, 20mm wide and 7mm high. Included wires the ESC weighs 9 grams. (73)

Figure 28: Arrowind 12A Simon Series ESC (73).

The ESC is equipped with low-voltage and over-heat protection as well as a self-check function. It can handle a burst in current at 15A and the continuous current is 12A. 2-3 cell Li-xx (LiPo or LiFe) batteries is suitable for this ESC. These specifications make this ESC a good match for our motors. The Arrowind has a built-in linear BEC (battery eliminator circuit) with 1A/5V output. One of these will be used to supply the receiver. The ESC can be programmed via a program card or a transmitter. It is compatible with various transmitters (74).

User instructions can be found in the Appendix.

Mateksys FCHUB 6S PDB

The power distribution board (PDB) chosen for the job is Mateksys FCHUB 6S. It has four ESC soldering tabs one each corner, suitable for a x-type frame such as ours. The PDB has a continuous current at 120A (4x30A), but can handle a 184A (4x46A) maximum/burst current. More than enough to supply the quadcopter’s components. 3-6S LiPo batteries are most suitable for this PDB. Built in is a transient-voltage-suppression (TVS) protection, which allows for a 27-volt maximum input. On each corner (see figure 29) there are mounting holes to easily attach the PDB to the drone frame. The dimension is 36x46x4mm and the weight is 8.5 grams. (75)

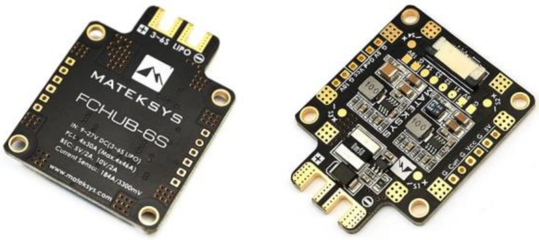

Figure 29: Mateksys FCHUB 6S PDB front and back (76)

On board is two battery eliminator circuits (BEC), one 5V and one 10V output. The 5V BEC is mainly for supplying flight controller, receiver, servo or an on-screen display (OSD). It has a 1.5A continuous current and a maximum current at 2A. This will be used to supply the Teensy 3.2 with the power. If a camera is to be added on the drone later the 10V BEC would be a good way to power it, with the same continuous and maximum current as the 5V BEC. (75)

The Mateksys FCHUB 6S manual is attached in the appendix.

Receiver and Transmitter:

The Spektrum AR610 6-Channel DSMX Coated Air Receiver and DX6e 6CH transmitter are both borrowed from the school and due to previous experience with this specific brand it was requested by our supervisor that we chose these models for convenience.

The AR610 is a full range sport receiver with 6 channels: throttle, aileron, auxiliary 1, gear, rudder and elevator. It small in size and only weighs 9 grams. The length, width and height are 36.6mm, 26.7mm and 12.7mm respectively. It requires 3.5-9.6V input, something the BEC on one of the ESCs will supply. The resolution on the AR610 is 2048. It offers flight log and is compatible with telemetry. (77)

Figure 30: Spektrum AR610 6-Channel DSMX Coated Air Receiver (78)

Spektrum has designed their own technology for transmitting; DSMX, which is a wideband frequency-agile 2.4GHz signal protocol. (77)
The transmitter, Spektrum DX6, matches the receiver with 6 channels, a DSMX protocol, 2.4GHz frequency wideband and it has a built-in telemetry. It also has a multirotor flight mode setup and a 250-model memory. If the master transmitter so chooses it can let the secondary transmitter take the control. This offers a safe way for someone to learn how to fly. (79)

Figure 31: Spektrum DX6e 6CH Transmitter (79)

The gimbals on the DX6e are spring configured. By sliding a switch, you can easily change the configurations to suite the type and mode you wish to fly with. (79)

Battery and Battery Charger

To power the drone when not connected to the platform we chose a 3s 450mAh - 75C - Gens Ace Tattu XT30 Long LiPo battery. The main reason we ended up with this battery was size and weight. It only weighs 45 grams and its length, width, height is 63mm, 16mm, 21mm respectively. (80)

Figure 32: 3s 450mAh - 75C - Gens Ace Tattu XT30 Long (80)

The battery's rated capacity is 450mAh and since it is a 3S LiPo battery it delivers 11.1 voltage. Max current discharge is 33.75A (75C) while max burst discharge is 67.5A (150C). It has a JST-XHR balance plug for charging and a XT-30 discharge plug. Recommended charge rate for this battery is between 1-3C and maximum 5C.
C-rate = Current / Rated Capacity
-> Current = C-rate x Rated Capacity

For our battery:
1C: Current = 1 x 0.45A = 0.45A
3C: Current = 3 x 0.45A = 1.35A
5C Current = 5 x 0.45A = 2.25A

The battery should be charged at 0.45- 1.35A, but can handle up to 2.25A. (7)
We therefore ended up with the SkyRc E430 LiPo/Life Balance Charger 2-4S 220V. The charge current can be set to 1A, 2A or 3A, depending on the battery connected. Our battery should be charged at the 1A setting, and maximum on the 2A. This charger is suitable for 2-4S LiPo or Life batteries and can then easily be used with other batteries than ours as well. The charger is equipped with XH-balance outputs, which suits our battery. (81)

Figure 33: SkyRc E430 LiPo/Life Balance Charger 2-4S 220V (81)

Wiring diagram

Overview

The battery, or power supply when that is used, is connected to the PDB transferring amperes and voltages. From the PDB all four ESCs draws power from each corner. The microcontroller is connected to the 1.5/5V BEC embedded on the PDB. Each of the ESCs are connected to their respective motor, to provide them with power. The motors are positioned so that the clockwise turning motors are diagonally directly opposite each other, and the same for the counter clockwise motors. Since the receiver needs 5V and the microcontroller only can give 3.3V one of the ESCs are connected to the receiver via the featured 1A/5V BEC on the ESC. All the signals are connected via the flight controller. The four ESCs is linked up to it and so is the receiver. The flight controller consists of both Teensy 3.2 and Teensy prop shield. The Teensy 3.2 is stacked on top of the prop shield and it is both supplying the shield with power and communicating with it. Figure 34 below gives a graphical overview of how all the components are linked together.

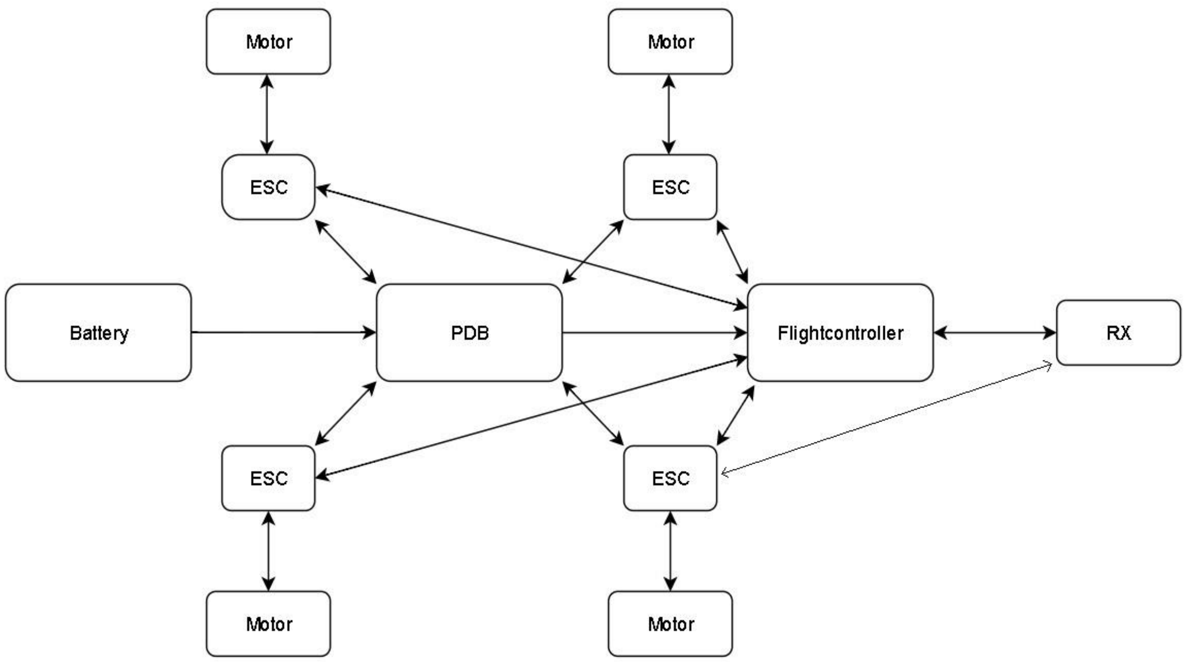

Figure 34: a roughly sketched graphical representation of how all the components are connected.

Pin Connections - PDB

Figure 35: PDB

Battery/Power supply: on the + and - in front
When connected to the power supplier: 12V and 10A (minus losses in amperes along the way).

ESC x 4: one on each corner, + and -, ESC 1, ESC 2, ESC3 and ESC 4.

Microcontroller: Ground and 5V (BEC)

Microcontroller

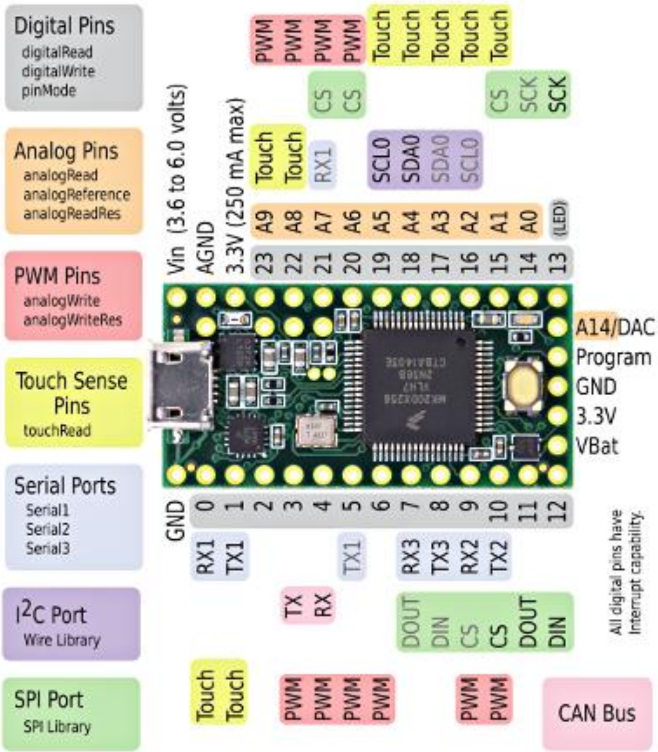

Figure 36: Tensy 3.2 pin layout.

Connections:

Power: Vin and Ground from PDB

ESC x 4: The PWM ports 20-23

Receiver: PPM via port 9 (82)

Prop shield: ports 2, 5, 6, 7, 11, 12, 13, 18 and 19 are reserved.

ESC

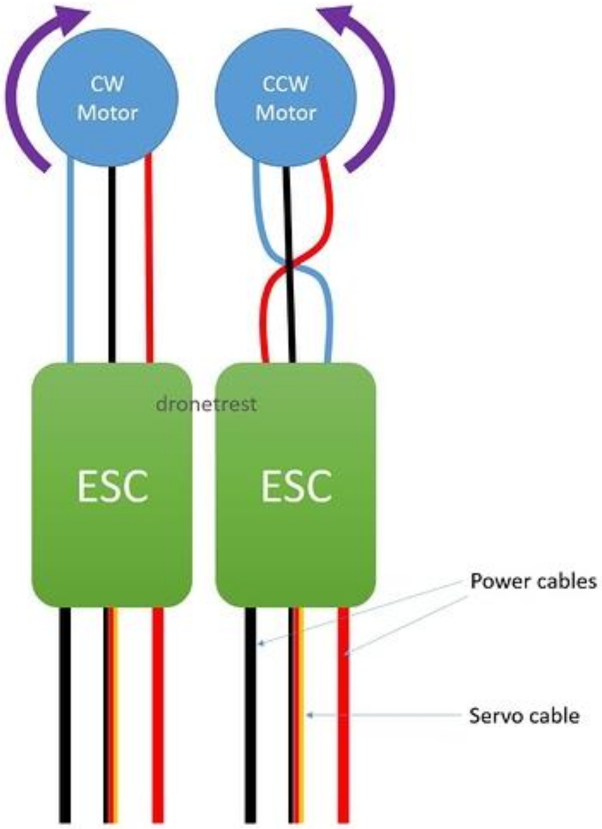

Figure 37: CW and CCW motors connected to ESC

ESC 1 and 3 is supplying the clockwise (CW) spinning motors, which is positioned diagonally directly opposite each other. When connecting a CW motor all the wires are simply just connected to the opposite wire.

ESC 2 and 4 is powering the counterclockwise spinning motors. Figure 35 shows that when connecting ECS to CCW motors the ESC's left wire is connected to the motors right wire, the ESC's right wire is connected to the motors left wire and the middle wires are connected to each other.

The signal wire in each servo cable (see figure 37) will connect the ESCs to the Teensy 3.2.

One of the ESC's BEC will supply the receiver with power. So, from one of the ESC to the RX the power cables within the servo cable will be connected to the RX.

Receiver

The receiver is connecting to one of the ESCs for power: 5V/1A. (74) A signal wire is connected between the RX and the Teensy 3.2 using PPM. PPM instead of PWM to avoid 6 wires, one for each channel.

Tests

Teensyduino

First, we downloaded and extracted the Arduino software, version 1.8.5, to a Windows 64-bit system. Than we downloaded the Teensyduino program, version 1.40, and added the library files to the Arduino software. We than connected the Teensy 3.2 to the computer via a USB cable, started up the Arduino 1.8.5 and selected "*Teensy 3.2 / 3.1*" under "*Tools*" -> "*Board Menu*". Initially the Teensy 3.2 comes with a LED blinking program, so when we connected the Teensy to the computer the orange LED on the Teensy 3.2 started blinking. We deleted the blinking program, saw that the LED stopped blinking and then loaded a new LED-blinking program to see that the Teensyduino was working properly; it did. This shows that at least some of the standard Arduino functions, such as *pinMode*, *DigitalWrite* and *delay* are compatible with the Teensyduino. Figure 38 is a partly screenshot showing the code used.

Figure 38: LED blink_slow program successfully uploaded to the Teensy 3.2.

Slip Ring USB connection

The test described in the previous chapter “Teensyduino”, was performed using the slip ring’s USBs. One of the USBs was connecting directly to the computer and the other one was, with the use of a Micro USB to USB A adapter, connected to the Teensy 3.2. There were no delays or problems in the progress and the slip ring’s USB worked seamlessly.

Arrowind Brushless Motors

To test that the motors at least could receive power we connected it to a regular Duracell Ultra Power 6LR61 9V battery. Since this only delivers maximum 250 mA the motors did not spin the way they are supposed to, but there was life in the engines. (83)

Slip Ring Power Wires

The little experiment described in the previous chapter “Arrowind Brushless Motors” was tested using the power wires embedded on the slip ring. Since the current was so low the test did not show if the slip ring is capable to delivering 10A, but it at least shows that the wires within the slip ring are connected correctly and power can pass through.

Static Analysis

We conducted a static analysis on the fully defined and mated assembly of the drone platform. The analysis was done given two load conditions. One was when the platform was subject to a 2kgf working on the top of the cylinder and in 270 degrees direction. The force was set higher than normal to add some safety margins. The second was when the platform was subject to a 7.1 N force working on the top of the cylinder and in 180 degrees direction. The force of the second load condition was calculated using the thrust exhorted by the motors. For both the load conditions, the base plate was fixed in geometry.

The quadcopter’s four motors each produce a force, which in the manufacturer's thrust tables is listed in grams. However, the correct unit is Newton. Below is an illustration, figure X, on how the force works on the platform when flying parallel to the xy-plane.

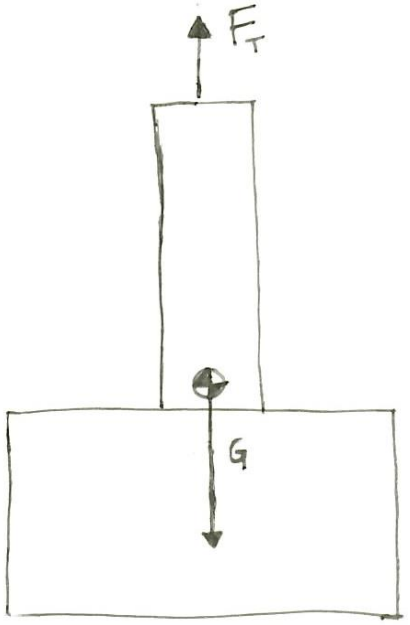

Figure 39: Where and in which direction the quadcopter's force is working when flying parallel to the xy-plane.

Ft = the quadcopter's total force

Each motor can lift 180 grams when connected to the platform (ref: page XX, Theory, Drone components, Arrowind 1806 brushless motors). Recalculating it to Newton:

Lift weight = 180 g x 4 = 720 g

Newton's 2nd Law states that: F = a x m, where the acceleration of gravity = g (?)

-> Ft = m x g = 0.72 kg x 9.81 m/s2 = 7.1N

(84)

The material tested in the static analysis is cast alloy steel. Steel is an isotropic material with the following specifications:

Elastic Modulus:	190.000 MPa
Poisson's Ration:	0.26
Shear Modulus:	78.000 MPa
Mass Density:	7300 kg/m^3
Yield Strength:	241.2752 MPa

The results of the analysis concluded that the forces applied to the platform are safely within the material and design's parameters.

The results of the stress under load condition one yielded a max stress of 1.893 MPa located at the weld between the cylinder and the locking plate.
The results of the stress under load condition one yielded a max stress of 1.893 MPa located at the weld between the cylinder and the locking plate.

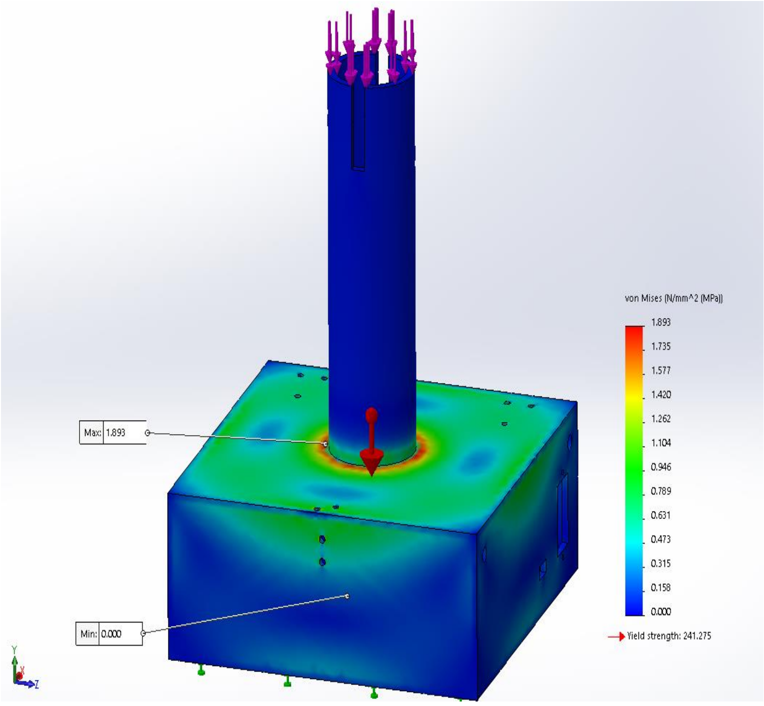

Figure 40: Stress results under load condition one.

The results of the displacement under load condition one yielded a displacement of 0.008 mm located at the lower half of the cylinder.

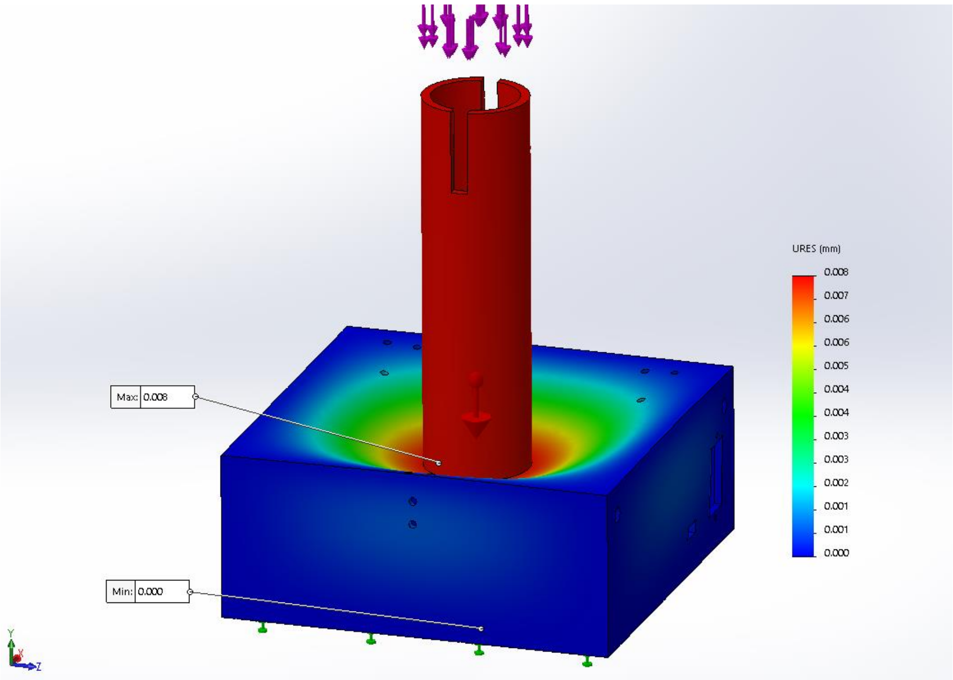

Figure 41: Displacement results under load condition one.

The results of the stress under load condition two yielded a max stress of 2.937 MPa located at the weld between the cylinder and the locking plate.

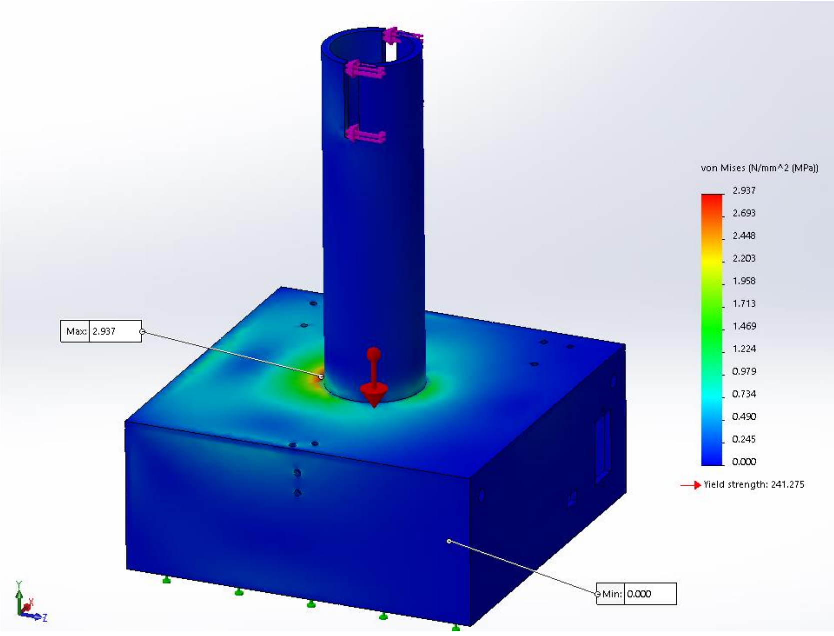

Figure 42: Stress results under load condition two.

The results of the displacement under load condition two yielded a displacement of 0.021 mm located at the top half of the cylinder.

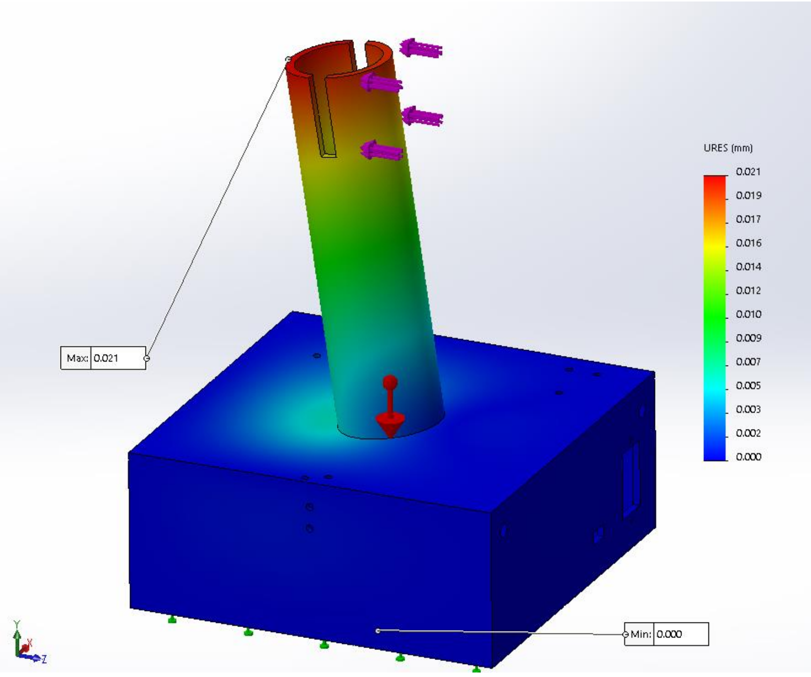

Figure 43: Displacement results under load condition two.

Discussion

The Platform

Material

Initially we wanted to make the platform with a steel base plate, to ensure stability. The rest of the structure however, were supposed to be made from aluminium. Aluminium is a less dense metal than steel and has good heat absorption characteristics, which means it could work as a heat sink for the PSU. We had also checked that by using a special technique of TIG welding the two metals could be joint together. However, this type of TIG welding is not possible to perform in the welding lab at the University of Agder. This meant that we had select a material that was simpler to weld. This led to the design being completely made from steel. This however, caused the platform to be heavier than originally intended. On the one hand this results in the platform being positively more stable and rigid, but on the other hand the platform becomes more inconvenient to move from the storage to the lab during exercises. Perhaps the weight could be lessened by changing the dimensions of the walls and side plates, if the platform still retained its stability under load. Another positive effect of the added weight is that the platform would not always only be subject to the load from the quadcopter. Accidents do happen, and a heavier platform would be more secure against students overturning it. With that said, we would still prefer the platform being in both aluminium and steel, to keep the weight at around 5 kilograms and allow the structure to act as a heatsink.

New Design

The platform went through some substantial changes during the later stages of the project. Initially the design started out with a circular shaped base plate made out of steel. The housing for many of the components was a minimalistic quadratic shaped box placed at the center of the base plate. Lastly, leading up from the top of the box was a cylinder much like the one in our current design. However, when we received the power supply unit and studied the installation instruction sheet that came with it, we discovered that the unit had some demands that were unaccounted for. It needed to have 5 cm of free space on both sides as well as above it. This meant that it was necessary to extend the wall's lengths and heights to make the box larger. With the updated dimensions, we felt that the aesthetics of the platform were subpar to the previous design when still using a circular shaped plate as a foundation. On the one hand we could have increased the diameter of the base plate to accommodate the new box, but on the other hand that would result in a too large of a design to fit easily in storage. This led to a redesign of the foundation, where we changed its shape from a circular to a square plate. It is possible that the new design does not offer enough free space for the motors to work perfectly according to air flow. Although, the cylinder still reaches up 25 cm, so there is still some free space between the box lid and the drone. Some practical tests with the drone hovering on the platform would be beneficial for further development of design, if needed. One last thing to consider is that the new shape may offer less natural counteracting momentum due to the shorter diameter of the foundation, but this should not be a problem due to the platform's added weight in the updated design.

Open and closing mechanism

We wanted to have a design where it was easy to conduct maintenance while still hiding dangerous components during use. This led to the hinge and locking mechanism feature on the box lid. The locking mechanism is an eccentric lock with the possibility of securing it further from prying hands by the use of a padlock. On the one hand this might not be as appealing aesthetically as other solutions, but on the other hand it offers a user-friendly function to the maintenance aspect of the platform. When needed, one can simply open the lock and tilt the cylinder on the side to gain access to the wiring, usb interface and power features. However, it would be convenient if the cylinder had some sort of support bracket on the side, so that it could rest securely during maintenance. As the design is now, one must be careful when tilting the cylinder as to not damage the universal joint and slip ring. Alternatively, it might convenient enough just to support the cylinder with something like a book when in tilted position. As the rest of the box is welded together as one unit, it is possible that the hinges do not offer the same amount of stability as it would if the lid was welded to the lower part of the box. We have taken this into consideration when designing this feature. By placing to robust hinges in the back as well as the eccentric lock in front, the lid becomes firmly secured to the rest of the box when tightened.

Universal joint

The selection process of a well-functioning joint that would connect the quadcopter to our platform was difficult. Initially we wanted to use an existing application to simplify the process of acquiring several platforms. We looked at different types of joints ranging from spherical bearings, gimbals and different universal joints typically meant for axles on vehicles. The spherical bearings offered the desired mobility in rotational axes but had too much restrictions on angular misalignment. Gimbal joints offered a great solution in joining the center of rotation with the center of mass for the quadcopter, but the risk of achieving a gimbal-lock and in result losing a degree of freedom, did not come as a good enough solution. The universal joints offered the same rotation and mass advantages as the gimbal. Also, the movement of the joint, although better than the spherical bearings, was up to par with what we wanted it to feel like. Therefore, we modelled a custom design instead and printed a prototype out of ABS plastic in a 3D-printer. The mobility of the joint turned out much more seamless than the existing universal joints. On the one hand this better fulfilled the criterion of a seamless 3DOF motion, but on the other hand it became necessary to restrict the joint so that it does not tilt too many degrees in either direction. Sadly, restricting the joint is not something we managed to accomplish during the project, but our idea of how it could be solved would be by adding a metallic ring from the edges of the cylinder and up to the joint. The height of the ring would determine at what angle the joint would rest on it, and in doing so restricting the joint's maximum pivoting angle. A concern is the yield strength of the ABS plastic, given that the most stressed part of the joint is the 5 mm locking pins as they are the ones binding the joint together. Another concern would also be the torsion exerted on the axle. Although, the design of the joint could be produced in metal instead, which would add to the strength of the joint and axle, as well as the durability. Furthermore, the design of the top half of the joint should offer an easy connection for mounting and dismounting the drone if there are no components blocking the locking pin. Also, even though we have not designed it for this project, the same mechanism could be used on an independent landing gear for the drone, offering a secure way to land and take off when being disconnected from the platform. Lastly, the axle located in the lower half of the joint should offer an easy installation onto the slip ring.

Slip Ring

One major flaw in our design is that we originally though the slip ring could work as a bearing solely ensure free rotation in yaw. The slip ring should however not bear any loads and it is therefore necessary to incorporate a ball bearing to the design. This could be a flanged ball bearing mounted under the slip ring, connected to the universal joint by the lower end of the axle that goes through the slip ring. The flanged bearing would be mounted either to mounts welded to the cylinder wall or to the lock plate/lid of the box. The cables that are part of the slip ring are both many and long. On the one hand this is very convenient when connecting the slip ring to both the usb interface on the wall as well as the power supply unit, but on the other hand they may prove to be too long at the top. It is a possibility that the long cables may hinder the seamlessness of the universal joint unless shortened. The USB cable is designed to have as few links as possible, but due to the cables on the slip ring, it is necessary to at least have separated into four parts (By the extender cable from a computer to the wall, from the wall to the slip ring and from the slip ring to the USB A/Micro USB adapter at the Teensy).

Power Supply

Since the quadcopter is supposed to hover when being connected to the platform, and not fly, we deemed it unnecessary to supply it with the 40 amps we initially planned. We chose a 10-amp power supply running at 12 volts yielding 120 watts instead. This means that the motors have approximately 110 watts shared among them, which should be enough to hover. To ensure that no more than 10 A runs through the circuit in the slip ring we have also put a 10 A manual fuse between it and the power supply. It might be more convenient to install an automatic fuse instead to avoid having to open the lid should the fuse blow out.

Ventilation

Ventilation for the power supply unit was an aspect we had to take into consideration. The specifications state that the PSU uses natural air convection cooling. Therefore, we added ventilation holes both in the base plate and the top corners of the walls to allow for airflow through the box. Should this type of cooling be insufficient, it might be a good solution to add a standard computer case fan to the bottom half of the box, pulling in fresh air. One would have to install some inlet filters to avoid too much accumulation of dust within the box, as well as suspend the mounting for the PSU to a higher point. It could also be a solution to enlarge the ventilation holed in the base plate, although it would in that case be necessary to ward off the holes as to avoid getting fingers stuck in them when moving the platform.

Drone

Frame Design

We have designed the drone frame to be as compact and simple as possible while still offering enough room for all of the components and the propellers. It has also been important to design the frame symmetric to have an equal distribution of weight, and thus placing the center of mass in the origin of the xy-plane. This should allow for the drone to conduct stable flight, but it will require some flight tests to determine whether the frame is well designed or if it needs some adjustments. The materials used for the frame is the same ABS plastic as used in the universal joint. While on the one hand it offers a very light weight frame, it may on the other hand prove too brittle, as it should endure some minor bumps in the ground without breaking apart. Some additional features like more substantial propeller guards and frame shields for the components located at the top level might also be desirable to add to the design of the drone.
Lastly, if a landing gear matching the universal joint connection were to be made, one would have to take into consideration that it would occupy the designated location for the battery.

Microcontroller

What is great about the Teensy 3.2 microcontroller is that it is small in size. It also stacks perfectly with the Teensy prop shield, making it possible to use it as a flight controller. The Teensy is compatible with the Arduino software as well as being C++ programmable. This makes it very versatile when it comes to programming across multiple platforms. We could have possibly gone for the more advanced Teensy 3.6 microcontroller, but we feel the 3.2 is sufficient for controlling, as well as being a suitably sized for a small drone.

Power supply

One major deciding factor in choosing a battery for the quadcopter was weight. Although, by gaining the lower weight from choosing a smaller battery, it also reduced the flight time. The design allows for a larger battery, but it is then important to bear in mind the added weight. If the flight is conducted inside there should be no problems, although flying drones weighing more than 250 grams outside require specific RO licences. The PDB should be more than powerful enough for this design as the electrical current limitations exceed the motors' needs. Hopefully the ESCs can distribute the supplied current evenly among the motors. If the they do not, there are more extensively programmable ESCs on the market that it is possible to upgrade to.

Controller

The controller used for the drone is very advanced. On the one hand it might be more advanced than necessary for the drone, but on the other hand it offers handy features such as the trainee function that can work as a safe way of learning someone to control a model aircraft. One feature that we did not include on the platform was an integrated joystick, but to avoid having two controllers per platform, similar features should be possible to implement from the software that gets developed for the programming exercises.

Tests

We did not manage to test all of the components of the platform and drone prior to this thesis's due date. But, we were able to conclude that the USB on the slip ring worked the way we wanted it to. However, more test should have been done to establish how well the slip ring supplied the drone with power. We tested the Arduino teensy program that can be downloaded and integrated with the Arduino software. Further testing of programming is needed to conclude how well it performs, but we easily managed to establish contact with the Teensy microcontroller.

The load condition test could also have been done to a greater extent, but we managed to ensure that the platform tolerates the forces working on it when operating. Worth mentioning is that we did not include the welds, but the assembly was fully defined and fully mated prior to the study.

Conclusion

There still is some work that needs to be done. Although the platform is mostly complete, there is still need for a ball bearing supporting the axle that performs the yaw motion, to relieve the slip ring of any stress. We are satisfied with how we solved the power supply for the platform, as well as how we managed to distribute the power to the drone. The slip ring we chose simplified the process by having an integrated USB connector in addition to power cables. The universal joint we made for the platform also seems to perform well, even though it needs further testing regarding its strength. The universal joint still need a mechanism to restrict the extent of its angular misalignment. The components selected for the drone are small and compact, while still fulfilling their tasks. The PDB installed is designed to handle stronger currents, and can handle distributing power enough for the motors to operate at 100% capacity. The Teensy Microcontroller is well suited for the drone in both size and functionality and should operate great as a flight controller. Further development can easily be done to the ventilation system if needed, should the PSU reach too high temperatures. We are also satisfied with how easy it is to open up the platform to do maintenance, while still leaving it locked and safe during use. In all we can conclude that we have designed a good 3DOF platform suitable for use in exercises.

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83: Cell Tech “www.celltech.fi” [Online], Available:
http://www.celltech.fi/fileadmin/user_upload/Celltech/Prod.sheets/Duracell_Ultra-Power_9V.pd
[Accessed November 2017]

84: Book - Authors: John Haugan and Eidmund Aamot, Title: Gyldendals Tabeller og Formler i Fysikk - Fysikk 1 og Fysikk 2, Publisher: Gyldendal Undervisning, Edition: 2d edition, Year: 2013

Appendix

Altimeter

Freescale Semiconductor
Data Sheet: Technical Data
An Energy Efficient Solution by Freescale

Document Number: MPL3115A2
Rev 3.0, 12/2013
RoHS

Xtrinsic MPL3115A2 I²C Precision Altimeter

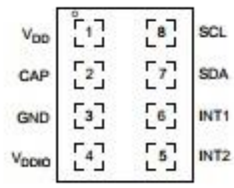
The Xtrinsic MPL3115A2 employs a MEMS pressure sensor with an I²C interface to provide accurate Pressure/Altitude and Temperature data. The sensor outputs are digitized by a high resolution 24-bit ADC. Internal processing removes compensation tasks from the host MCU system. Multiple user-programmable, power saving, interrupt and autonomous data acquisition modes are available, including programmed acquisition cycle timing, and poll-only modes. Typical active supply current is 40 µA per measurement-second for a stable 10 cm output resolution.

The MPL3115A2 is offered in a 5 mm x 3 mm x 1.1 mm LGA package and specified for operation from -40 °C to 85 °C. Package is surface mount with a stainless steel lid and is RoHS compliant.

MPL3115A2
50 to 110 kPa

LGA PACKAGE
5.0 mm x 3.0 mm x 1.1 mm

Top View



Pin Connections

Features

- 1.95 V to 3.6 V Supply Voltage, internally regulated by LDO
- 1.6 V to 3.6 V Digital Interface Supply Voltage
- Fully Compensated internally
- Direct Reading, Compensated
  - Pressure: 20-bit measurement (Pascals)
  - Altitude: 20-bit measurement (meters)
  - Temperature: 12-bit measurement (degrees Celsius)
- Programmable Events
- Autonomous Data Acquisition
- Resolution down to 0.1 m
- 32-Sample FIFO
- Ability to log data up to 12 days using the FIFO
- 1 second to 9 hour data acquisition rate
- I²C digital output interface (operates up to 400 kHz)

Application Examples

- High Accuracy Altimetry
- Smartphones/Tablets
- Personal Electronics Altimetry
- GPS Dead Reckoning
- GPS Enhancement for Emergency Services
- Map Assist, Navigation
- Weather Station Equipment

ORDERING INFORMATION

Device Name	Package Options	Case No.	# of Ports			Pressure Type			Digital Interface
			None	Single	Dual	Gauge	Differential	Absolute	
MPL3115A2	Tray	2153	•					•	•
MPL3115A2R1	Tape & Reel (1000)	2153	•					•	•

freescale
Xtrinsic

2 Mechanical and Electrical Specifications

2.1 Mechanical Characteristics

Table 2. Mechanical Characteristics @ V_{DD} = 2.5 V, T = 25 °C unless otherwise noted[1]

Ref	Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Pressure Sensor							
1	P_{FS}	Measurement Range	Calibrated Range	50		110	kPa
			Operational Range	20		110	kPa
2		Pressure Reading Noise	1x Oversample[2]		19		Pa RMS
			128x Oversample[2]		1.5		Pa RMS
3		Pressure Absolute Accuracy	50 to 110 kPa over 0 °C to 50 °C	-0.4		0.4	kPa
			50 to 110 kPa over -10 °C to 70 °C		±0.4		
4		Pressure Relative Accuracy	Relative accuracy during pressure change between 70 to 110 kPa at any constant temperature between -10 °C to 50 °C		±0.05		kPa
			Relative accuracy during changing temperature between -10 °C to 50 °C at any constant pressure between 50 kPa to 110 kPa		±0.1		
5		Pressure/Altitude Resolution[3][4][5]	Barometer Mode	0.25	1.5		Pa
			Altimeter Mode	0.0625	0.3		m
6		Output Data Rate	OST[6] Mode		100		Hz
			FIFO Mode			1	Hz
Temperature Sensor							
7	T_{FS}	Measurement Range		-40		+85	°C
8		Temperature Accuracy	@ 25 °C		±1		°C
			Over Temperature Range		±3		
9	T_{OP}	Operating Temperature Range		-40		+85	°C
10		Board Mount Drift	After solder reflow		±0.15		kPa
11		Long Term Drift	After a period of 1 year		±0.1		kPa

1. Measured at 25 °C, over 50 kPa to 110 kPa.
2. Oversample (OSR) modes internally combine and average samples to reduce noise.
3. Smallest bit change in register represents minimum value change in Pascals or meters. Typical resolution to signify change in altitude is 0.3 m.
4. At 128x Oversample Ratio.
5. Reference pressure = 101.325 kPa (Sea Level).
6. OST = One Shot Mode.

Freescale Semiconductor
Data Sheet: Technical DataTechnical Data
An Energy-Efficient Solution by Freescale

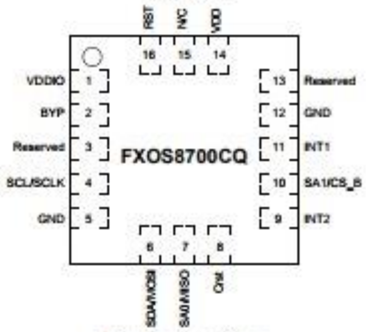
Document Number: FXOS8700CQ
Rev. 5.0, 05/2015
√RoHS

FXOS8700CQ, 6-Axis Sensor with Integrated Linear Accelerometer and Magnetometer

FXOS8700CQ

CASE 98ASA00318D
16 LEAD QFN
3 mm x 3 mm x 1.2 mm

Top View



Pin Connections

FXOS8700CQ is a small, low-power, 3-axis, linear accelerometer and 3-axis, magnetometer combined into a single package. The device features a selectable I²C or point-to-point SPI serial interface with 14-bit accelerometer and 16-bit magnetometer ADC resolution along with smart-embedded functions. FXOS8700CQ has dynamically selectable acceleration full scale ranges of ±2 *g*/±4 *g*/±8 *g* and a fixed magnetic measurement range of ±1200 µT. Output data rates (ODR) from 1.563 Hz to 800 Hz are selectable by the user for each sensor. Interleaved magnetic and acceleration data is available at ODR rates of up to 400 Hz. FXOS8700CQ is available in a plastic QFN package and it is guaranteed to operate over the extended temperature range of -40 °C to +85 °C.

Features

- Complete 6-axis, e-compass hardware solution
- 1.95 V to 3.6 V VDD supply voltage, 1.62 V to 3.6 V VDDIO voltage
- ±2 *g*/±4 *g*/±8 *g* dynamically selectable acceleration full-scale range
- ±1200 µT magnetic sensor full-scale range
- Output data rates (ODR) from 1.563 Hz to 800 Hz for each sensor, and up to 400 Hz when operated in hybrid mode with both sensors active
- Low noise: < 126 µg/√Hz acceleration noise density at 200 Hz bandwidth, < 100 nT/√Hz magnetic noise density at 100 Hz bandwidth
- 14-bit ADC resolution for acceleration measurements
- 16-bit ADC resolution for magnetic measurements
- Low power: 240 µA current consumption at 100 Hz, and 80 µA at 25 Hz with both sensors active
- Embedded programmable acceleration event functions:
  - Freefall and motion detection
  - Transient detection
  - Vector-magnitude change detection
  - Pulse and tap detection (single and double)
  - Orientation detection (portrait/landscape)
- Embedded programmable magnetic event functions:
  - Threshold detection
  - Vector-magnitude change detection
  - Autonomous magnetic min/max detection
  - Autonomous hard-iron calibration
- Programmable automatic ODR change using Auto-Wake and return to Sleep functions to save power. This function works with both magnetic and acceleration event interrupt sources.
- 32-sample FIFO for acceleration data only
- Integrated accelerometer and magnetometer self-test functions

freescale Sensors

4 Device Characteristics

4.1 Mechanical characteristics (accelerometer)

Table 2. Mechanical characteristics @ VDD = 2.5 V, VDDIO = 1.8 V T = 25 °C unless otherwise noted.

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Measurement range(1)	±2 *g* mode	FS_{ACC}		±2		*g*
	±4 *g* mode			±4		
	±8 *g* mode			±8		
Sensitivity	±2 *g* mode	SEN_{ACC}		4096		LSB/*g*
				0.244		mg/LSB
	±4 *g* mode			2048		LSB/*g*
				0.488		mg/LSB
	±8 *g* mode			1024		LSB/*g*
				0.976		mg/LSB
Sensitivity change with temperature(1)	±2 *g*, ±4 *g*, ±8 *g* modes	TCS_{ACC}		±0.01		%/°C
Sensitivity accuracy	@ 25 °C	$SEN\text{-}TOL_{ACC}$		±2.5		$\%SEN_{ACC}$
Zero-*g* level offset accuracy(2)	±2 *g*, ±4 *g*, ±8 *g* modes	OFF_{ACC}		±20		mg
Zero-*g* level offset accuracy post-board mount(3)	±2 *g*, ±4 *g*, ±8 *g* modes	$OFF_{ACC\text{-}PBM}$		±30		mg
Zero-*g* level change versus temperature	-40 °C to 85 °C(1)	TCO_{ACC}		±0.2		mg/°C
Nonlinearity (deviation from straight line)(4)(5)	Over ±1 *g* range normal mode	NL_{ACC}		±0.5		$\%FS_{ACC}$
change(6) X Y Z	Set to ±2 *g* mode	$STOC_{ACC}$	 +192 +270 +1275			LSB
Output noise density(4)(7)	ODR = 400 Hz, normal mode	$ND_{ACC\text{-}NM}$		126		µg/√Hz
	ODR = 400 Hz, low-noise mode(1)	$ND_{ACC\text{-}LNM}$		99		µg/√Hz
Operating temperature range		Top	-40		+85	°C

1. Dynamic range is limited to ±4 *g* when in the low-noise mode.
2. Before board mount.
3. Post-board mount offset specifications are based on a 2-layer PCB design.
4. Evaluation only.
5. After post-board mount corrections for sensitivity, cross axis and offset. Refer to AN4399 for more information.
6. Self-test is only exercised along one direction for each sensitive axis.
7. Measured using earth's gravitational field (1 *g*) with the device oriented horizontally (+Z axis up) and stationary.

4.2 Magnetic characteristics (magnetometer)

Table 3. Magnetic characteristics @ VDD = 2.5 V, VDDIO = 1.8 V T = 25 °C unless otherwise noted.

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Measurement range		FS_{MAG}	±1200			µT
Sensitivity		SEN_{MAG}		0.1		µT/LSB
Sensitivity change versus temperature		TCS_{MAG}		±0.1		%/°C
Zero-flux offset accuracy(1)		OFF_{MAG}		±10		µT
Zero-flux offset change with temperature		TCO_{MAG}		±0.8		µT/°C
Hysteresis(2)(3)		$HYST_{MAG}$		±0.5		$\%FS_{MAG}$
Nonlinearity(3) Deviation from best-fit straight line		NL_{MAG}		±1		$\%FS_{MAG}$
Temperature sensor sensitivity				0.96		°C/LSB
Magnetometer output noise	ODR = 800 Hz, OSR = 2	$Noise_{MAG}$		1.5		µT-rms
	ODR = 400 Hz, OSR = 4			1.2		
	ODR = 200 Hz, OSR = 8			0.85		
	ODR = 100 Hz, OSR = 16			0.6		
	ODR = 50 Hz, OSR = 32			0.5		
	ODR = 12.5 Hz, OSR = 128			0.35		
	ODR = 6.25 Hz, OSR = 256			0.3		
	ODR = 1.56 Hz, OSR = 1024			0.3		
Self-Test output change(1)(4)	X-axis	$STOC_{MAG}$	1161			LSB
	Y-axis		-1130			LSB
	Z-axis		-43			LSB
Operating temperature range		Top	-40		+85	°C

1. After m-cell has been factory trimmed
2. Hysteresis is measured by sweeping the applied magnetic field from -1000 µT to 1000 µT and then back to -1000 µT. The difference in the two readings at -1000 µT divided by the swept field range is the hysteresis figure, expressed in% of the full-scale range (FS_{MAG}).
3. Tested over a ±1000 µT measurement range.
4. Minimum offset is shown with polarity. This means that the actual offset can be a smaller number for negative figures.

4.3 Hybrid characteristics

Table 4. Hybrid characteristics @ VDD = 2.5 V, VDDIO = 1.8 V T = 25 °C unless otherwise noted.

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Maximum output data rate in hybrid mode		ODR_{max}		400		Hz
Operating temperature range		Top	-40		+85	°C
Output data bandwidth		BW		ODR/2		Hz

4.4 Electrical characteristics

Table 5. Electrical characteristics @ VDD = 2.5 V, VDDIO = 1.8 V T = 25 °C unless otherwise noted.

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Supply voltage		VDD	1.95	2.5	3.6	V
Interface supply voltage		VDDIO	1.62	1.8	3.6	V
Low-power acceleration mode	ODR = 12.5 Hz	$Idd_{ACC-LPM}$		8		µA
	ODR = 100 Hz			35		
	ODR = 400 Hz			130		
Normal acceleration mode	ODR = 50 Hz	Idd_{ACC-NM}		35		µA
	ODR = 200 Hz			130		
	ODR = 800 Hz			240		
Hybrid mode	ODR = 200 Hz Accelerometer OSR = 4 Magnetometer OSR = 2	$Idd_{ACC+MAG}$		440		µA
	ODR = 100 Hz Accelerometer OSR = 4 Magnetometer OSR = 2			240		
	ODR = 25 Hz Accelerometer OSR = 4 Magnetometer OSR = 2			80		
Magnetic mode	ODR = 400 Hz, OSR = 2	Idd_{MAG}		575		µA
	ODR = 12.5 Hz, OSR = 2			40		
Current during boot sequence, 0.9 mS max duration using recommended regulator bypass capacitor	VDD = 2.5 V	Idd_{BOOT}			3	mA
Value of capacitors on BYP and magnetic reset pins	-40 °C to 85 °C	C_{BYP}, C_{RST}	75	100	470	nF
Standby mode current @ 25 °C	Standby mode	Idd_{STBY}		2		µA
Standby mode current over-temperature range	Standby mode	Idd_{STBY}			10	µA
Digital high-level input voltage RST pin		VIH_{RST}	1.04			V
Digital low-level input voltage RST pin		VIL_{RST}			0.68	V
Digital high-level input voltage SCL, SDA, SA0, SA1		VIH	0.75*VDDIO			V
Digital low-level input voltage SCL, SDA, SA0, SA1		VIL			0.3*VDDIO	V
High-level output voltage INT1, INT2	I_O = 500 µA	VOH	0.9*VDDIO			V
Low-level output voltage INT1, INT2	I_O = 500 µA	VOL			0.1*VDDIO	V
Low-level output voltage SDA	I_O = 500 µA	VOL_{SDA}			0.1*VDDIO	V
SCL, SDA pin leakage	25 °C			1.0		nA
	-40 °C to 85 °C			4.0		
SCL, SDA pin capacitance				3		pf
VDD rise time			0.001		1000	ms
Boot time(1)		T_{BOOT}			1000	µs
Turn-on time 1(2)		$T_{POR \rightarrow ACT}$		2/ODR + 2		ms
Turn-on time 2(3)		$T_{STBY \rightarrow ACT}$		2/ODR + 1		ms
Operating temperature range		T_{OP}	-40		+85	°C

1. Time from VDDIO on and VDD > VDD min until I²C/SPI interface ready for operation.
2. Time to obtain valid data from power-down mode to Active mode.
3. Time to obtain valid data from Standby mode to Active mode.

https://cdn.sparkfun.com/datasheets/Dev/Teensy/fxos8700cq.pdf

Budget

Amount	Description and link	Price per piece	Total price NOK
1	Slip ring, Sparkfun https://www.sparkfun.com/products/13063	29.95$	240 kr
1	Slip ring, Senring http://www.senring.com/usb-conductive-slip-ring/SNU11.html Model: SNU11-0410-04S	145$ +35$(shipping) = 180$	1450 kr
2	CCW Motors, Elefun https://www.elefun.no/p/prod.aspx?v=30482	99 kr	198 kr
2	CW Motors, Elefun https://www.elefun.no/p/prod.aspx?v=31097	99 kr	198 kr
4	ESC, Elefun https://www.elefun.no/p/prod.aspx?v=30481	69 kr	276 kr
1	Propellers, Elefun https://www.elefun.no/p/prod.aspx?v=33964	25kr	25 kr
1	Propguard, Elefun https://www.elefun.no/p/prod.aspx?v=29928	29kr	29 kr
1	PDB, Elefun https://www.elefun.no/p/prod.aspx?v=36836	93 kr	93 kr
1	3S LiPo, Elefun https://www.elefun.no/p/prod.aspx?v=35499	131 kr	131 kr
1	Battery charger, Elefun https://www.elefun.no/p/prod.aspx?v=35349	235 kr	235kr

1	Teensy 3.2, Sparkfun https://www.sparkfun.com/products/13736	19.95$	16 0 kr
1	Teensy Prop Shield, Sparkfun https://www.sparkfun.com/products/13995	19.95$	16 0 kr
1	Teensy Header Kit, Sparkfun https://www.sparkfun.com/products/13925	1.50$	12 kr
1	RX, borrows from UiA		
1	TX, borrows from UiA		
1	Drone frame, 3D-print at UiA		
1	Base in steel and aluminium, made at UiA		
1	Universal joint, 3D print at UiA		
1	PSU, Elfa Distrelect https://www.elfadistrelec.no/no/switched-mode-stromforsyning-traco-power-txh-120-112/p/16994424?q=*&filter_Category4=%C3%85pne%20str%26oslash%3Bmforsyninger%20(AC%2FDC)&filter_Category3=AC%2FDC-omformere&filter_Utgangsstr%26oslash%3Bm%201=10.0%20A&filter_Buyable=1&page=2&origPos=742&origPageSize=50&simi=96.0	793 kr (eks mva)	91 2 kr
1	PSU deksel, Elfa Distrelect https://www.elfadistrelec.no/no/deksel-traco-power-txh-120-cov/p/16994433?q=TXH+120%E2%80%93COV&page=1&origPos=1&origPageSize=50&simi=94.0&no-cache=true	47.40 kr (eks mva)	55 kr
1	Appliance inlet C14 IEC, Elfa Distrelect https://www.elfadistrelec.no/no/inntak-c14-flatstift-mm-10-250-vac-svart-skruemontering-pe-schurter-dd11-0124-1111/p/16963557?q=169-63-557&page=1&origPos=1&origPageSize=50&simi=96.0&no-cache=true	155kr (eks mva)	17 8 kr
1	Fusedrawer, Elfa Distrelect https://www.elfadistrelec.no/no/sikringsholder-polet-schurter-4301-1403/p/16962955	17 kr (eks mva)	20 kr
2	Fuse, Elfa Distrelect https://www.elfadistrelec.no/no/sikring-20-mm-25-slow-blow-fst-schurter-0034-3118/p/13317425	2 kr (eks mva)	5 kr
1	Micro USB to USB A https://www.power.no/tv-og-tilbehoer/kabler-og-tilkobling/eletra-otg-micro-usb-usb-a/p-495950/	99 kr	99 kr

1	USB Extender, Elkjøp https://www.elkjop.no/product/tv-lyd-og-bilde/kabler-og-adaptere/F3U153BT18M/belkin-usb-2-0-forlengelseskabel-1-8-m	149 kr	149 kr
1	2 Hinges on platform to get access to PSU, Byggmax (38x150mm) https://www.byggmax.no/spiker-och-skruer/byggbeslag/hengsler-och-beslag/bladhengsel-p25233	50 kr	50 kr
1	Eccentric lock on platform, Jula https://www.jula.no/catalog/bygg-og-maling/beslag/port-garasjebeslag/hasper-og-eksenterlas/eksenterlas-343410/#tab02	40 kr	40 kr
1	Pads to have under the platform, Biltema http://www.biltema.no/no/Hjem/Innredning/Mobelknotter-beskyttere-og-ben/Mobelknotter-2000018060/ item: 86317	20 kr	20 kr
	TOTAL EXPENSES		**Kr 4.685**

C14 Appliance Inlet

IEC Appliance Inlet C14 with Line Switch 2-pole, Fuseholder 1- or 2-pole

Standard or Medical Fuse drawer

C14

70° C

Description
- Panel Mount:
  Screw-on version from front or rear side
- 3 Functions:
  Appliance Inlet Protection class I, Line Switch 2-pole, Fuseholder for fuse-links 5 x 20 mm 1- or 2-pole
- Quick connect terminals 4.8 x 0.8 mm

Approvals
- VDE Certificate Number: 40018283
- UL File Number: E93617

Characteristics
- Ultra-compact design. Ideal for low profile designs
- All single elements are already wired
- Fuse drawer meets requirements of medical standard IEC/EN 60601-1
  The fuseholder is accessible from the equipment front
  For added safety "Extra-Safe" fuse drawers are available
- Ideal for application with high transient loads
  Designed for standard and medical applications
- Suitable for use in equipment according to IEC 60950

Other versions on request
- Solder terminals
- Fuse drawer 1-pole, plus spare fuse case
- Fuse drawer 2-pole, with shorting bar
- Other rocker marking
- Line switch 1-pole
- Protection class II, 70°C

References
Alternative: version with line filter DD12
Alternative: version for snap-in mounting KM
Alternative: version for PCB mounting DD21

Weblinks
pdf-datasheet, html-datasheet, General Product Information, Approvals, CE declaration of conformity, RoHS, CHINA-RoHS, Mating Connectors, e-Shop, SCHURTER-Stock-Check, Distributor-Stock-Check, CAD-Drawings, Accessories, Wire Harnessing, Mounting instruction, Detailed request for product

Technical Data

Ratings IEC	10 A / 250 VAC; 50 Hz
Ratings UL/CSA	8 A / 250 VAC; 60 Hz [1]
Dielectric Strength	> 2.5 kVAC between L-N > 3 kVAC between L/N-PE (1 min/50 Hz)
Allowable Operation Temp.	-25 °C to 85 °C
Degree of Protection	from front side IP 40 acc. to IEC 60529
Protection Class	Suitable for appliances with protection class I acc. to IEC 61140
Terminal	Quick connect terminals 4.8 x 0.8 mm
Panel Thickness s	Screw-on mounting: max 8 mm Mounting screw torque max 0.5 Nm Rear side mounting: max 2 mm
Material: Housing	Thermoplastic, black, UL 94V-0

Appliance Inlet	C14 acc. to IEC 60320 UL 498, CSA C22.2 no. 42 (for cold conditions) pin-temperature 70 °C, 10 A, Protection Class I
Fuseholder	1 or 2 pole, Shocksafe category PC2 acc. to IEC 60127-6, for fuse-links 5 x 20 mm
Rated Power Acceptance @ Ta 23 °C	5 x 20: 2 W (1 pole)/ 1.6 W (2-pole) per pole
Power Acceptance @ Ta > 23°C	Admissible power acceptance at higher ambient temperature see derating curves
Line Switch	Rocker switch 2-pole, non-illuminated or illuminated, acc. to IEC 61058-1 Technical Details

[1] with cover 7 A, without cover 8 A

https://www.elfadistrelec.no/Web/Downloads/_t/ds/typ-DD11_eng_tds.pdf

Download Teensyduino, Version 1.40
Teensyduino is a software add-on for the Arduino software.

Teensyduino Files:

- Macintosh OS-X Installer
- Linux Installer (X86 32 bit)
- Linux Installer (X86 64 bit)
- Linux Installer (ARM / Raspberry Pi)
- Windows XP / 7 / 8 / 10 Installer

Other Files:

- Linux udev rules
- Windows Serial Installer

Teensyduino 1.40 supports Arduino versions 1.0.6 and 1.6.5-r5 and 1.8.1 and 1.8.2 and 1.8.3 and 1.8.4 and 1.8.5.
Future versions of Teensyduino will drop support for Arduino 1.8.2 and 1.8.3.
On Linux, PJRC tests X86 on Ubuntu and ARM on Raspbian. Other distros may work, but are not supported.

Install Step 1: Download & Extract Arduino

First, you must download the Arduino Software. Remember the location where you extracted the files.

Install Step 2: (Linux only) Install udev Rules

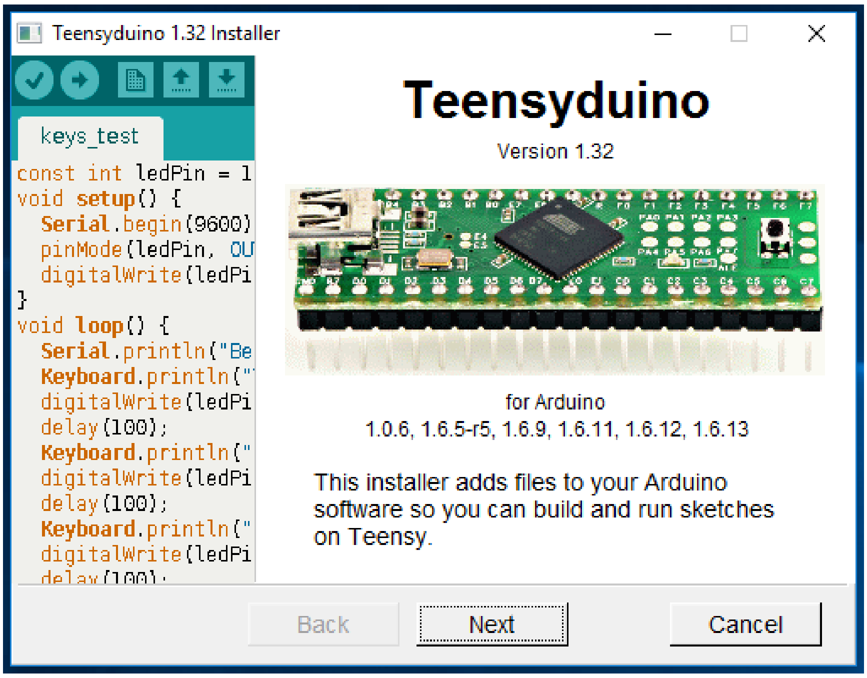
The udev rule file gives non-root users permission to use the Teensy device. More Linux tips below.
sudo cp 49-teensy.rules /etc/udev/rules.d/

Install Step 2: (Macintosh only) Pass Internet Download Question

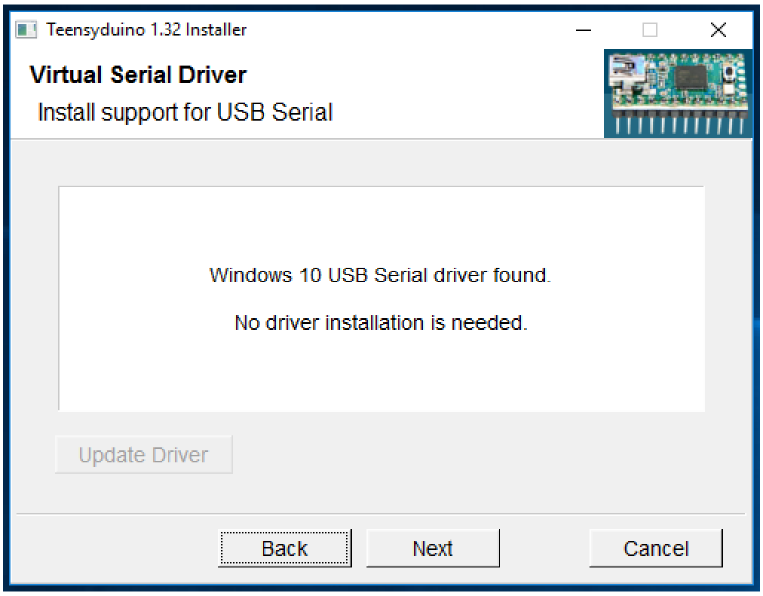
You must run Arduino at least once before adding Teensyduino, to confirm you wish to run a program downloaded from the Internet.
If Teensyduino modifies your copy of Arduino before you confirm, recent versions of OS-X may not allow you to run Arduino, or even tell you Arduino will damange your computer. Simply run Arduino first to clear the question about running a program downloaded from the Internet, before adding Teensyduino!

Install Step 3: Run Teensyduino Installer

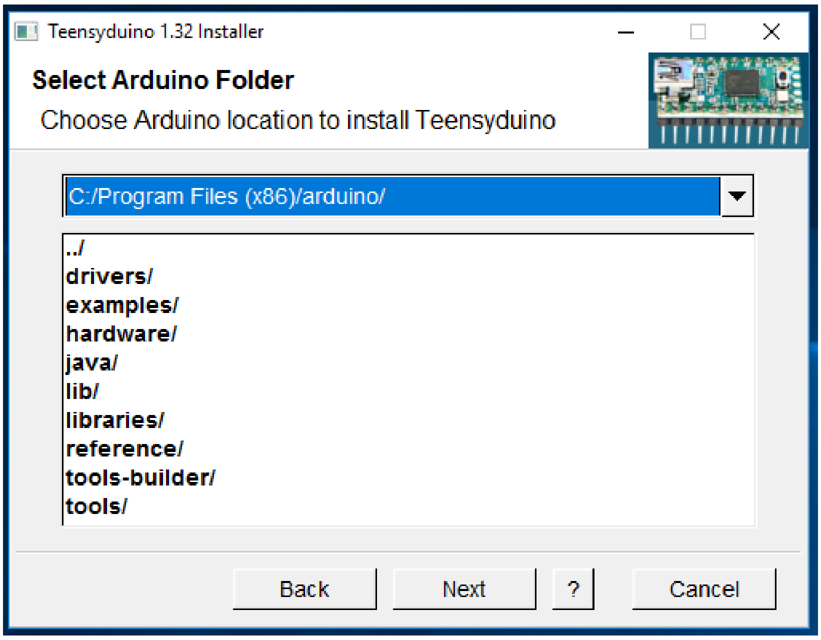
The Teensyduino installer adds the necessary support files to Arduino. Your copy of Arduino must be one of the supported versions listed on this first screen.



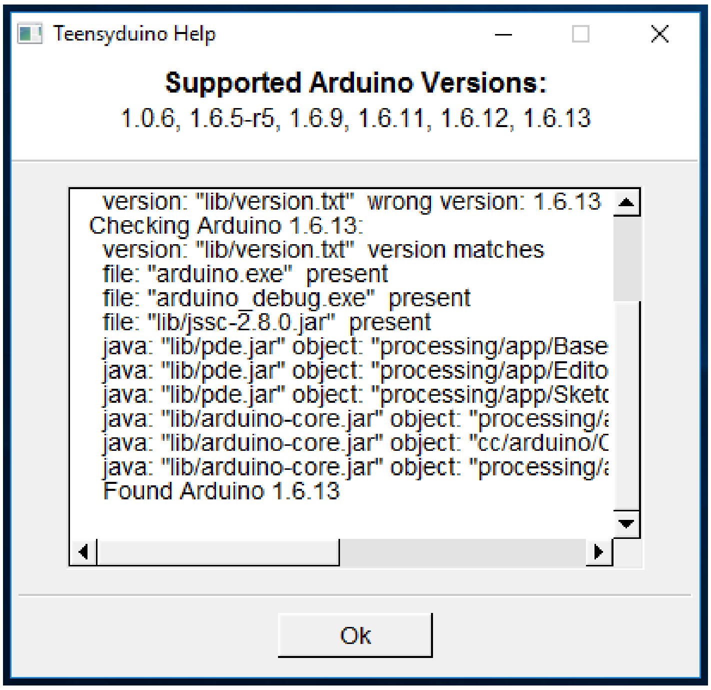
On Windows, this driver allows to you access the serial device type. This step is not necessary and does not appear on Mac OS-X and Linux. Windows 10 has the proper driver, which is automatically detected.



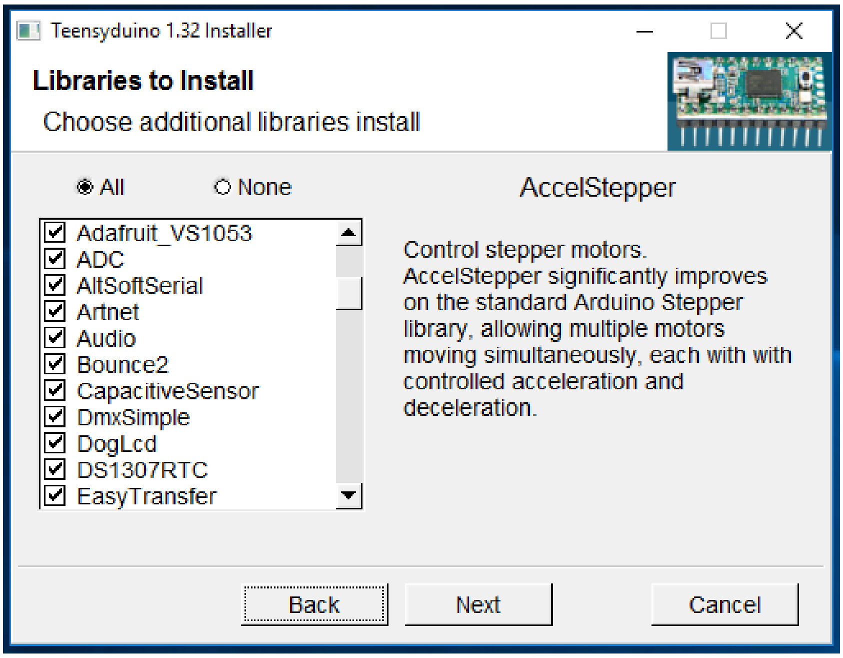
Select the location where you extracted the Arduino Software. On Windows, the location will default to the location where Arduino's installer places the software.
The Next button will only activate when a supported version of the Arduino Software is found.



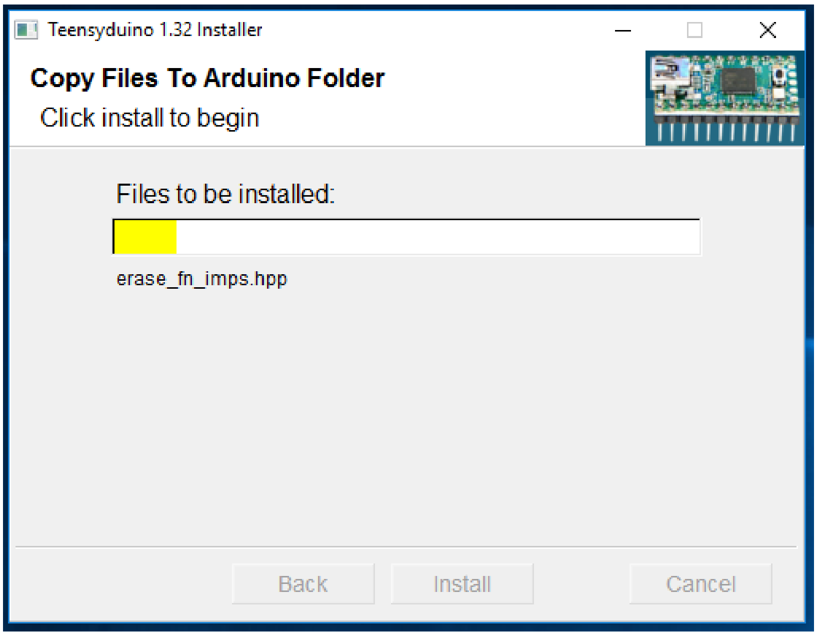
If the Next button will not activate, click the "?" button for more information.



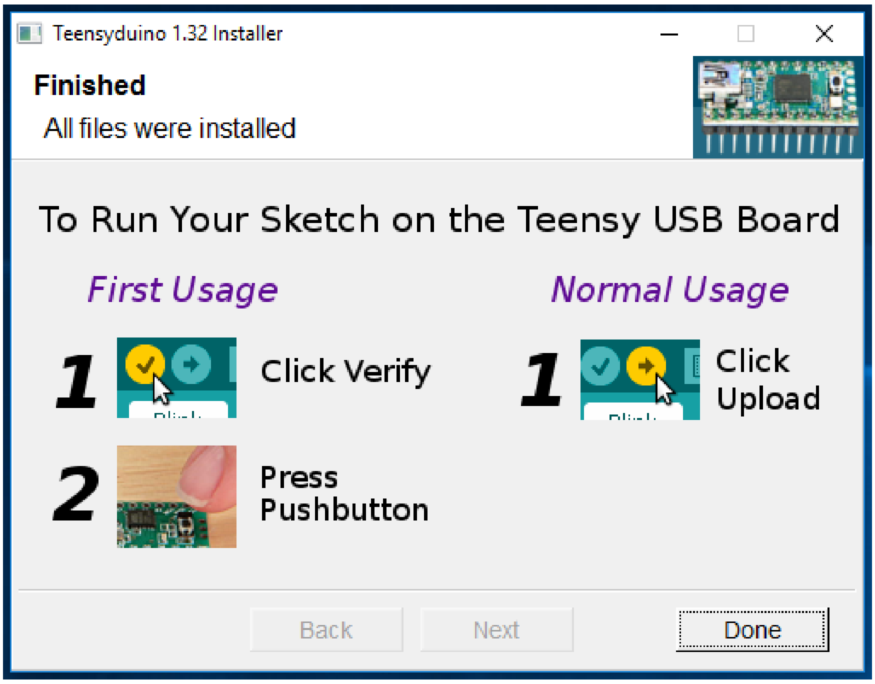
Teensyduino can automatically install many libraries that are tested and verified to work with Teensy. Usually it's best to allow the installer to add them all.



The installer will copy all the necessary files into your Arduino Software, when you click the "Install" button.



When installation is finished, you will see this final screen. Just click Done to quit the installer.



When using Arduino, be sure to select Teensy in the Tools > Boards menu. Arduino's File > Examples menu automatically changes to show the libraries and examples for the selected board.

(1)

1: https://www.pjrc.com/teensy/td_download.html

ESC User Instruction

ARROWIND ESC (FOR MULTICOPTER) - USER INSTRUCTIONS

www.arrowindhobby.com

1. Features

1.1: Based on Simonk firmware, further optimized to the perfect drive performance.
1.2: Low-voltage protection, over-heat protection and self-check functions.
1.3: Separate power supply for MCU and BEC, enhancing the ESC's ability of eliminating magnetic interference.
1.4: Parameters of the ESC can be set via program card or transmitter.
1.5: Throttle range can be set to be compatible with different receivers.
1.6: Equipped with built-in linear BEC or switch BEC.
1.7: Max speed: 210,000 rpm for 2-pole, 70,000 rpm for 6-pole, 35,000 rpm for 12-pole.

2.Product specification

Item	Continuous Current	Burst (10S) current	Li-xx Battery (cell)	Dimension L*W*H(mm)	Weight (g) wires Included	BEC Mode	BEC Output	Programmable
6A	6A	8A	2	22*17*7	5	Linear	0.8A/5V	YES
12A	12A	15A	2-3	25*20*7	9	Linear	1A/5V	YES
20A	20A	25A	2-3	52×26×7	28	Linear	2A/5V	YES
25A	25A	30A	2-3	52×26×7	28	Linear	2A/5V	YES
30A	30A	40A	2-3	52×26×7	28	Linear	2A/5V	YES
30A OPTO	30A	40A	2-6	67×26×10	25	—	—	YES
40A	40A	50A	2-6	73×28×12	41	Switch	3A/5V	YES
50A	50A	60A	2-6	73×28×12	41	Switch	3A/5V	YES
60A	60A	80A	2-6	73×36×12	63	Switch	5A/5V	YES
80A	80A	100A	2-6	86×38×12	81	Switch	5A/5V	YES

3. Instructions

3.1.Normal startup procedures

Move throttle stick to the bottom position and then switch on transmitter	Connect battery pack to ESC	The long "beep" sound should be emitted , means the bottom point of throttle range has been detected	Several "beep" tones should be emitted to present the amount of battery cells	When self-test is finished, a "♪ 1 2 3" tune should be emitted	Move throttle stick upwards to go flying

3.2.Throttle range setting procedures (when users change a transmitter, throttle range setting is recommended.)

Switch on the transmitter, move throttle stick to the top position	Connect battery pack to ESC	Two "beep" sounds should be emitted, means the top point of throttle range has been confirmed and saved	Move throttle stick to the bottom position (within 2s), a long "beep" sound should be emitted , means the bottom point of throttle range has been detected	Several "beep" tones should be emitted to present the amount of battery cells	When self-test is finished, a "♪ 1 2 3" tune should be emitted, Move throttle stick upwards to go flying

If the throttle stick is neither at the bottom position nor the top position after powered on, it will constantly make "beep" sounds.

4. Programmable parameters

4.1. Brake Type: There are six brake types including **OFF**, Low, Mid-low, Middle, Mid-high and High. The default is OFF.

4.2. Timing Mode: There are five options: Low: 0°, Mid-low: 8°, **Middle:15°**, Mid-high:23° and High:30°. The default is Middle: 15°. Low advance timing is recommended for high inductance and low KV motors. High advance timing is recommended for low inductance and high KV outrunner motors. For some high KV motors, if it shakes while rotating in high speed, the High timing mode is recommended.

4.3. Start Force: There are 13 options: 0.03、0.05、0.06、0.09、0.13、0.19、0.25、0.38、0.50、**0.75**、1.00、1.25、1.50. The default is 0.75. Select the corresponding start force according to the load of motor.

4.4. Curve Mode: There are four options: **Off**, Low, Middle, High. The default is off.

4.5. Control Frequency : 2 options: **8KHz** and 22KHz. The default is 8KHz. This option is the drive frequency of the motors.

4.6. Low-voltage Protection: 3 options: 2.8V/cell、**3.0V/cell**、3.2V/cell (If there are four options, the fourth option is off the low voltage protection). The default is 3.0V/cell. the system will automatically identify the battery cell. E.g. suppose there're 3 cells, if the voltage is lower than 9V, the system will work according to the current cutoff option.

4.7. Cutoff Mode: There are two options: **Soft-Cut** and Cut-Off. The default is Soft-Cut.

Soft-Cut option: Gradually reduce throttle power to 31% of the current power when the voltage is lower than the programmed low-voltage protection threshold. Cut-Off Option: immediate motor shutdown occurs in low-voltage.

When low-voltage protection, Push the throttle stick to the bottom position and then to the top position, the motor will be restarted. But since it is low-voltage condition, the output power is low or stopped at once.

5. Protection setting

5.1. Low-voltage Protection: Whether to shut down the motor immediately or to lower the power when the input voltage drops below the programmed low-voltage protection threshold depends on the values set as Cutoff Mode. (Please refer to D7 for Cutoff Mode)

5.2. Loss of Signal Protection: Power will be gradually lower to 0 when signal lost, and motor stops. Motor will resume to the current power when the signal is detected again.

5.3. Over-heat Protection: When the temperature increases to above 100 Celsius degree, power will be lowered gradually to less than75% of the full power. When the temperature increases to above 105 Celsius degree, power will be lowered gradually to less than 50% of the full power. When the temperature increases to above 110 Celsius degree, power will be lowered gradually to less than 25% of the full power. When the temperature increases to above 115 Celsius degree, power will be lowered gradually to less than 6.25% of the full power, and will resume when the temperature decreases.

6. Programming via program card

Step 1. Pull the PPM signal wire out from the receiver, and plug it into the program card jack. Please pay attention to the direction.

Step 2. Connect the ESC to the battery, after 2 seconds you will hear "♪ 2 3 1" tune.

Step 3. The program card automatically reads parameters from the ESC and the corresponding LED will be on.

Step 4. Button 1 is for choosing program items. Button 2 is for choosing different parameters for each item. Button 3 is 'write' button. All parameters can be viewed and modified by pressing corresponding and press button 3 to write the new parameters to the ESC.

Step 5. Cut off the power.

7. Programming via Transmitter

Step 1: Enter program mode

Switch the transmitter on→Pull the throttle stick to the top position→Switch the ESC on, wait 2 seconds, you will hear two "beep" sounds, which denotes that Max. throttle has been confirmed→Hold the throttle stick at the top position, and then wait 2 seconds until you hear tune "♪ 1 2 3 ♪ 1 2 3", that means you have entered the transmitter programming mode.

Step 2: Select program parameters

Hold the throttle stick on top position, there're 7 parameters can be set by using your transmitter. You would hear 7 different indicating sounds which correspond to 7 different parameters. Pull the throttle stick to the bottom position (full Off throttle) within 2 seconds after you hear the correspondent sound will brings you to the correspondent parameter setting status. The indicating sounds will repeat in turn as follow.

1. "beep-" (a short sound) which indicates the Brake Type
2. "beep-beep-" (two short sounds) which indicates the Timing Mode
3. "beep-beep-beep-" (three short sounds) which indicates the Start Force
4. "beep-beep-beep-beep-" (four short sounds) which indicates the Curve Mode
5. "beep——" (a long sound) which indicates the Control Frequency
6. "beep——beep-" (a long sound and a short) which indicates the Low-voltage Protection
7. "beep——beep-beep-" (a long sound and two short) which indicates the Cutoff Mode

Step 3: Select program values

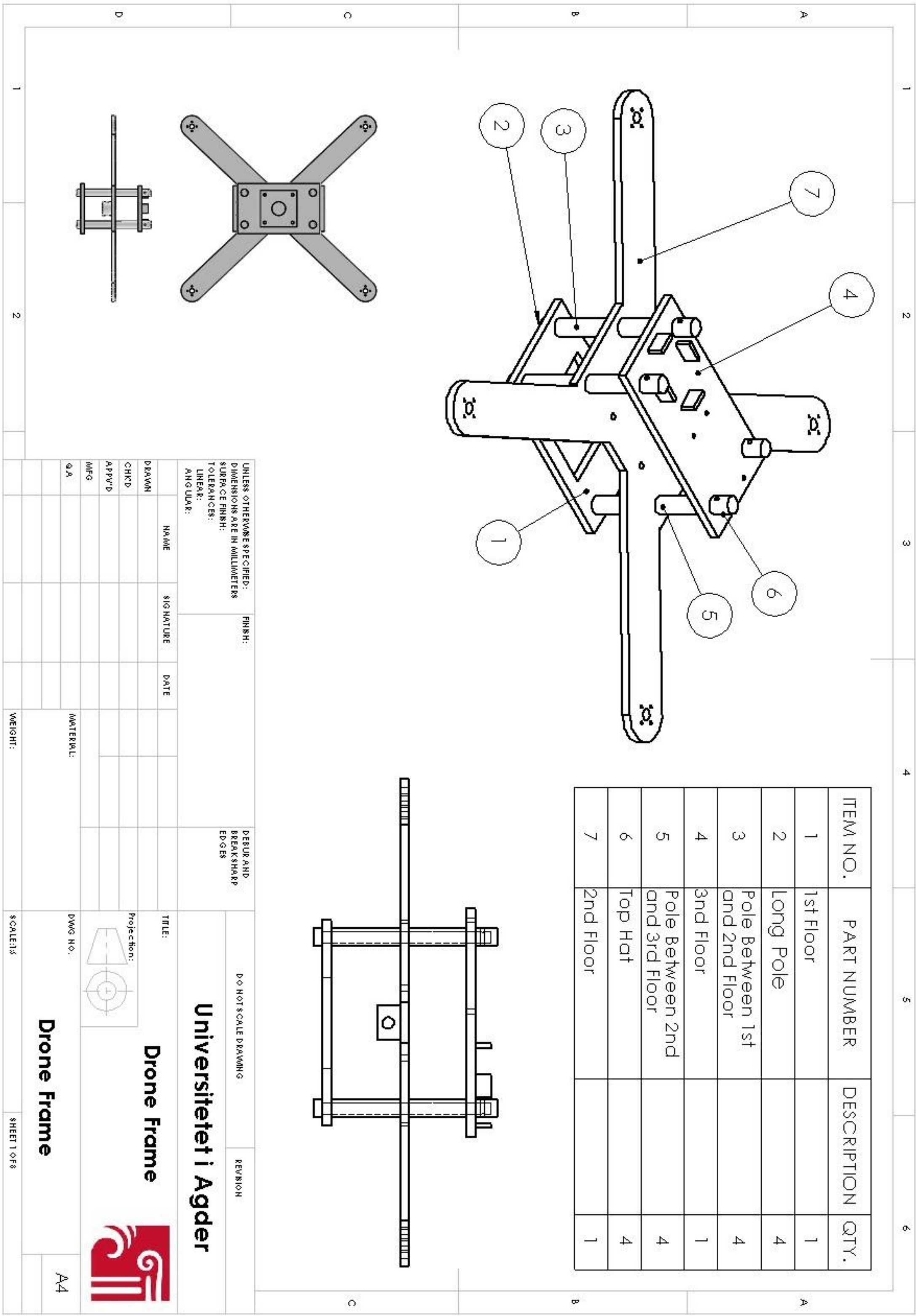
After entering parameter setting status, hold the throttle stick on the bottom position, you will be led to the repeat selection of that parameter setting status. Each sound likes 4 short sounds and one long sound (1 long sound=5short sounds), and by that analogy. After some sound, pull the throttle stick to the top position in 2 seconds, after you hear a tune "♪3 2 1 ♪3 2 1", which means the correspondent value has been chosen and saved. Hold the stick on the top position, return to the second step and continue programming.

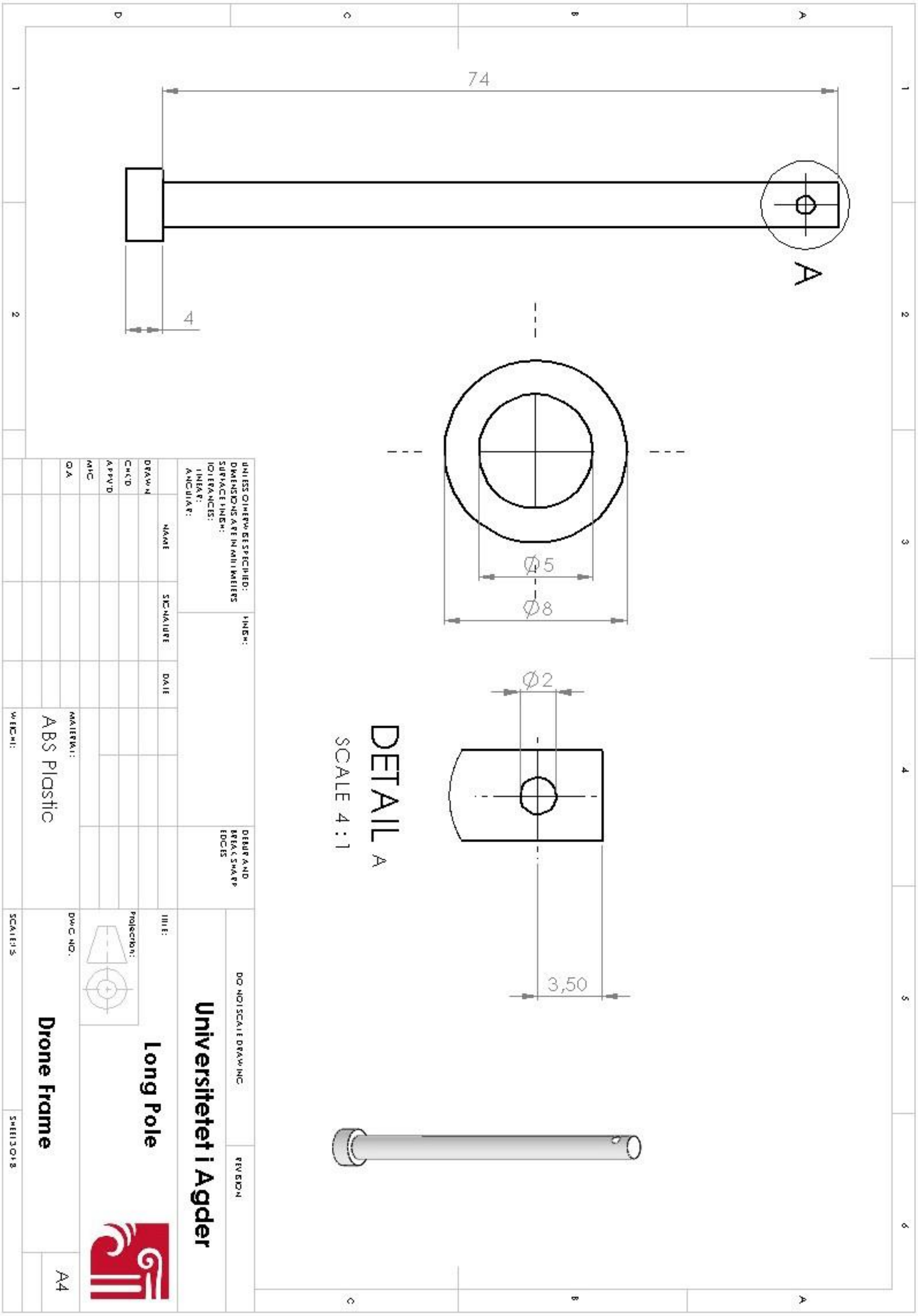
Step 4: Exit program

Pull the throttle stick to the bottom position within 2 seconds and hold on after saving parameters, until you hear a tune "beep—— beep- beep- beep- ♪ 1 2 3". Set the Min. Throttle at this moment and exit program and operate as normal.(beep——means Loading parameter. beep- beep- beep-means numbers of cells and ♪1 2 3 means ready.)

(1)
1: Scan of ESC user instruction that came in the package.

Frame SolidWorks Drawings

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Universitetet i Agder
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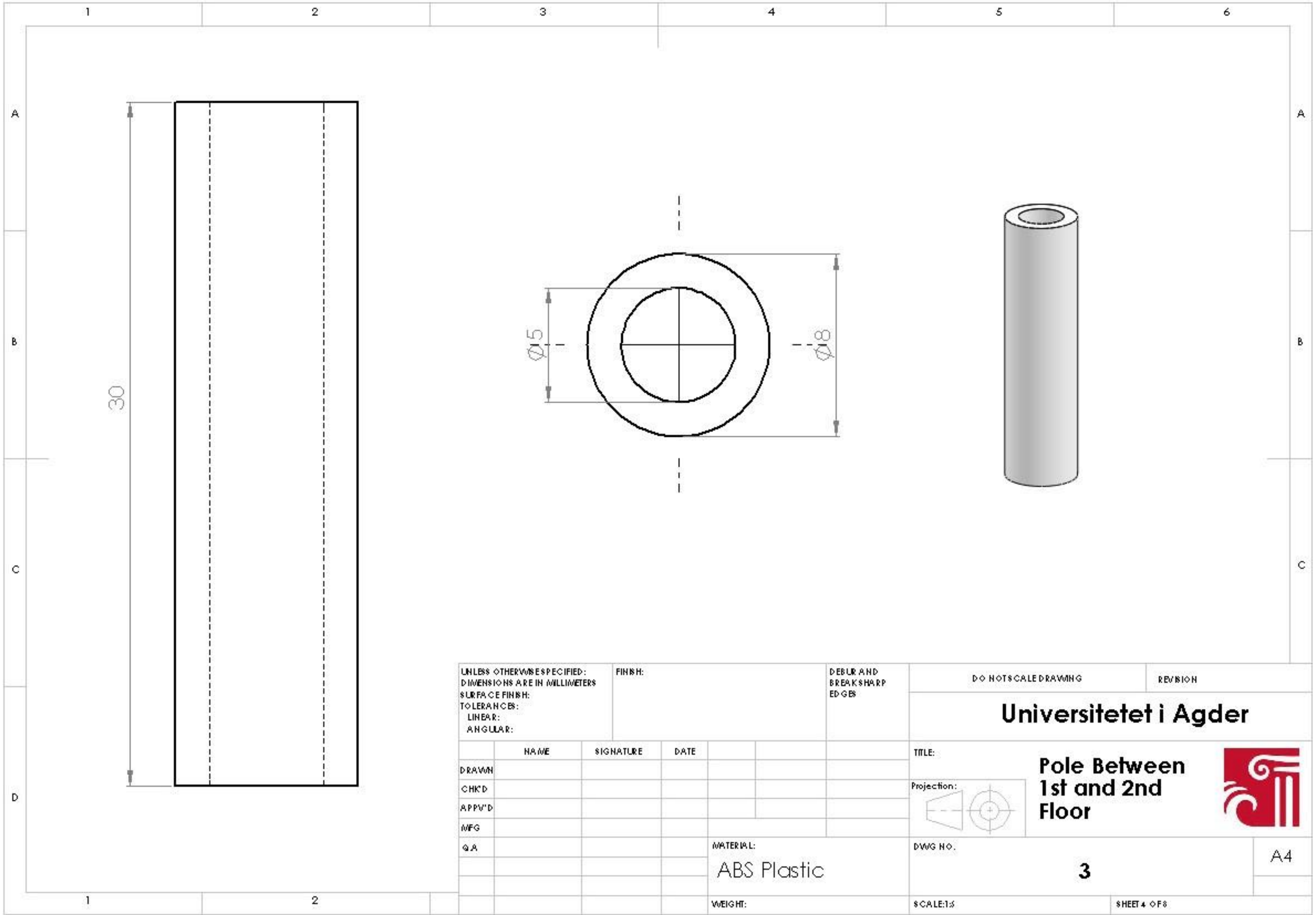
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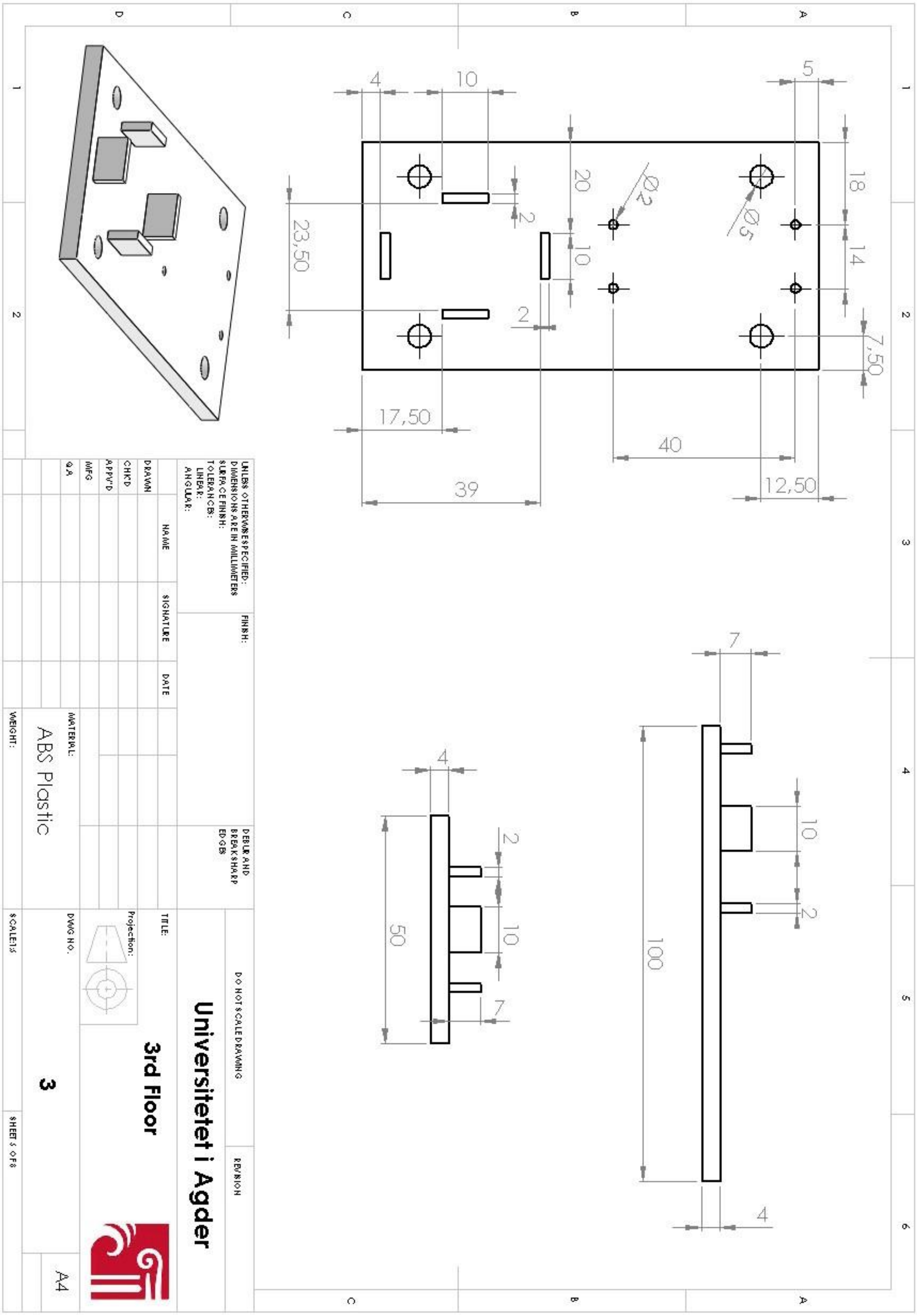

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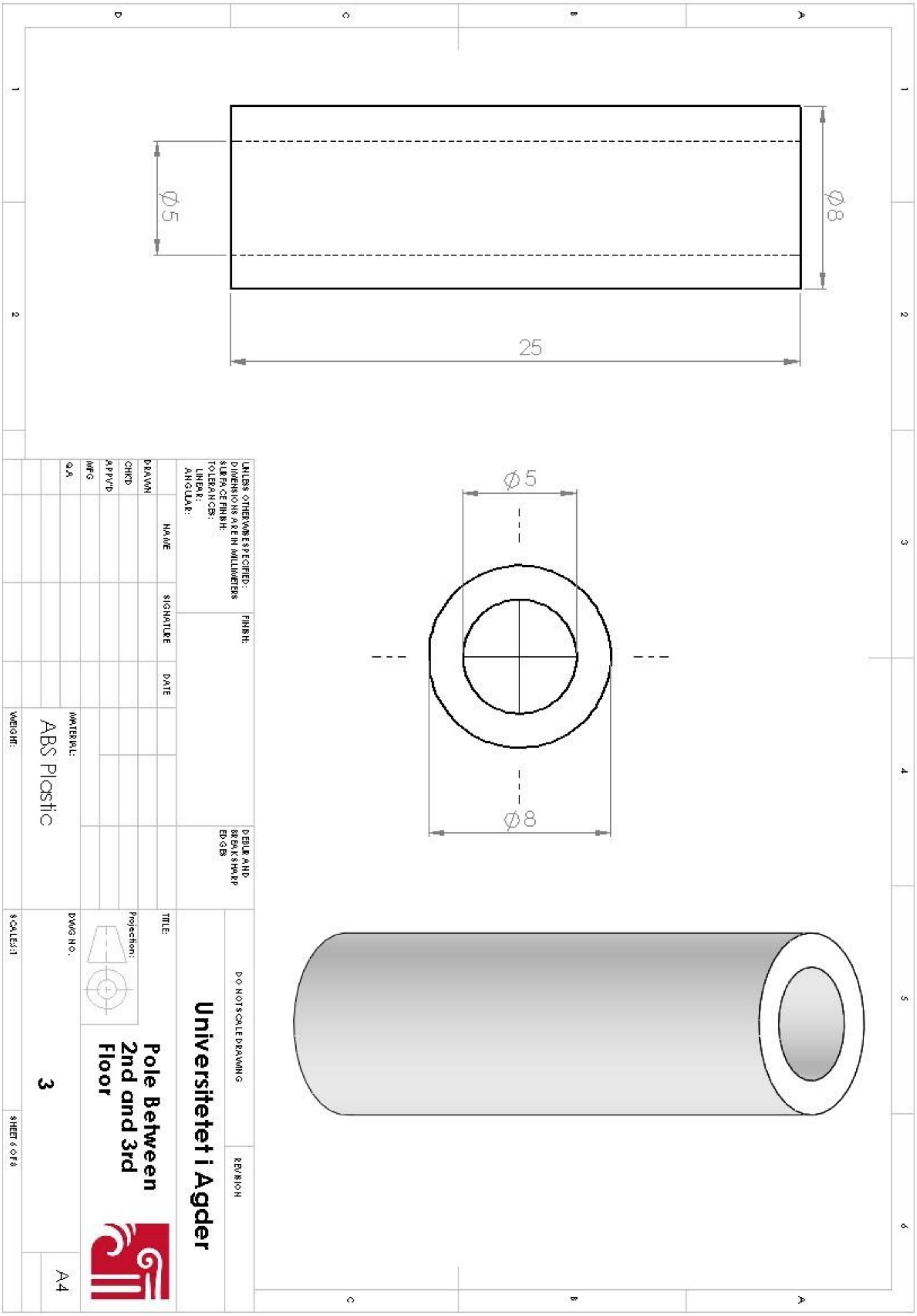

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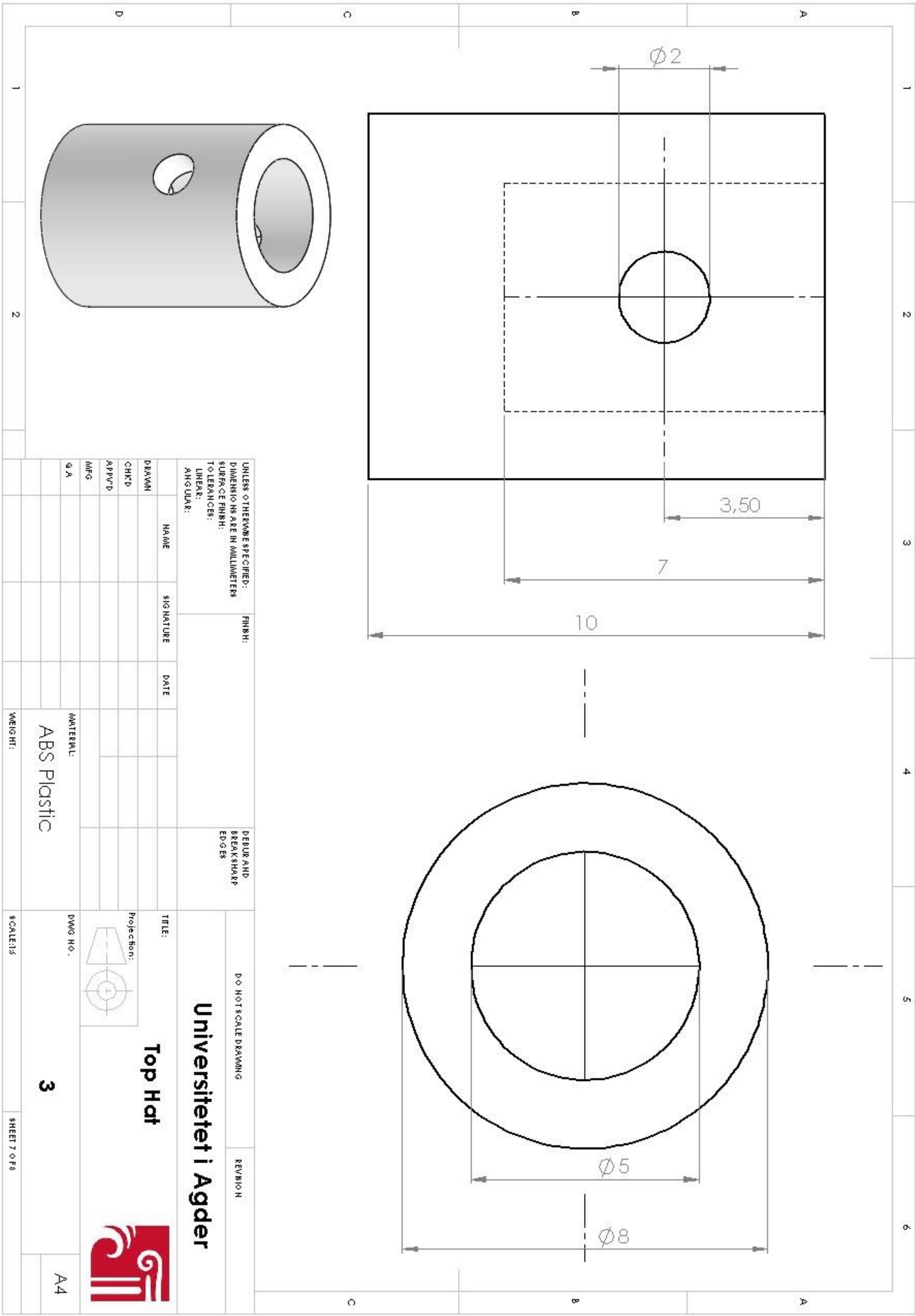
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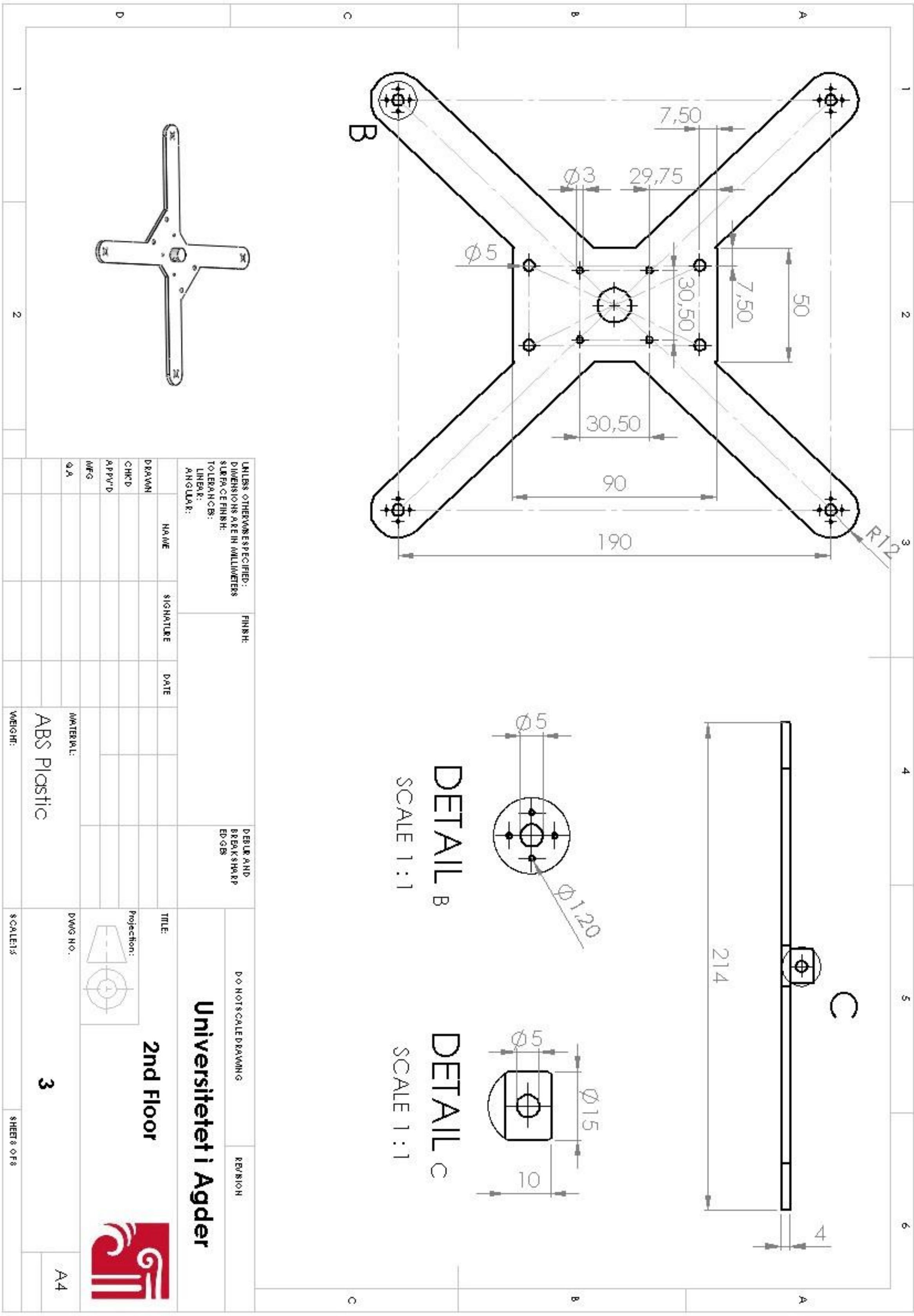
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DETAIL C
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Universitetet i Agder
2nd Floor
Projection:
DWG NO.
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SCALE:1:5
SHEET 8 OF 8

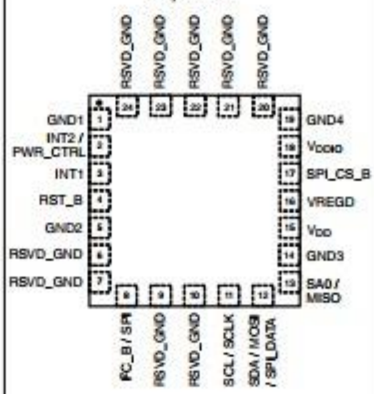
Gyroscope

3-Axis Digital Angular Rate Gyroscope

FXAS21002C

24 QFN
4 mm x 4 mm x 1 mm
Case 2209-01

Top View



Pin Connections

FXAS21002C is a small, low-power, yaw, pitch, and roll angular rate gyroscope with 16 bit ADC resolution. The full-scale range is adjustable from ±250°/s to ±2000°/s. It features both I^2C and SPI interfaces.

FXAS21002C is capable of measuring angular rates up to ±2000°/s, with output data rates (ODR) from 12.5 to 800 Hz. An integrated Low-Pass Filter (LPF) allows the host application to limit the digital signal bandwidth. The device may be configured to generate an interrupt when a user-programmable angular rate threshold is crossed on any one of the enabled axes.

FXAS21002C is available in a plastic, 24-lead QFN package; the device is guaranteed to operate over the extended temperature range of –40 °C to +85 °C.

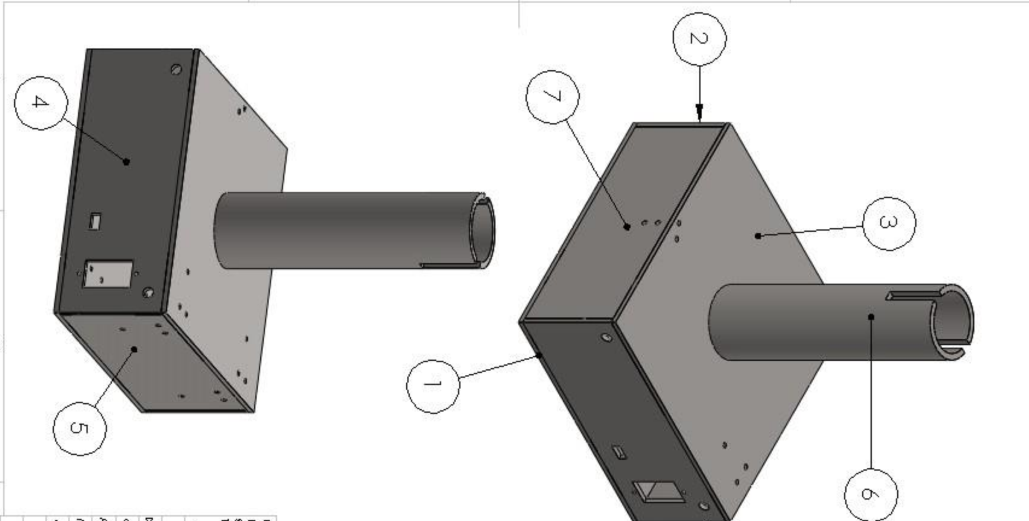
Features

- Supply voltage (V_{DD}) from 1.95 V to 3.6 V
- Interface Supply voltage (V_{DDIO}) from 1.62 V to V_{DD} + 0.3 V
- 16-bit digital output resolution
- ±250/500/1000/2000°/s configurable full-scale dynamic ranges
- Full-Scale Range boost function enables FSR's up to ±4000 dps
- Angular rate sensitivity of 0.0625°/s in ±2000°/s FSR mode
- Noise spectral density of 25 mdps/√Hz at 64 Hz bandwidth (200 Hz ODR)
- Current consumption in Active mode is 2.7 mA
- Fast transition from Standby to Active mode (60 ms)
- Supported digital interfaces include:
  - I^2C Standard and Fast Mode (100/400 kHz)
  - SPI Interface (3- and 4-wire modes, up to 2 MHz)
- FIFO buffer is 192 bytes (32 X/Y/Z samples) with stop and circular operating modes
- Output Data Rates (ODR) from 12.5 to 800 Hz; programmable low-pass filter to further limit digital output data bandwidth
- Low power standby mode
- Power mode transition control via external pin for accelerometer-based power management (motion interrupt)
- Rate Threshold interrupt function
- Integrated self-test function
- 8-bit temperature sensor

freescale

https://cdn.sparkfun.com/datasheets/Dev/Teensy/fxas21002.pdf

Platform SolidWorks Drawings



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2	Longest side plate	Aluminium	1
3	Lock plate	Aluminium	1
4	Side plate with USB and power inlet	Aluminium	1
5	Side plate with hinges	Aluminium	1
6	Cylinder	Aluminium	1
7	Short side plate	Aluminium	1

The four sideplates are welded together to each other and to the fundation plate.

The cylinder is welded onto the lock plate.

The lock plate will be attached to the four plates with hinges (only holes for the hinges is shown on these drawings).

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:

FINISH: DEBUR AND BREAK SHARP EDGES DO NOT SCALE DRAWING REVISION

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APPV'D			
MFG			
Q.A			

MATERIAL: WEIGHT:

Universitetet i Agder

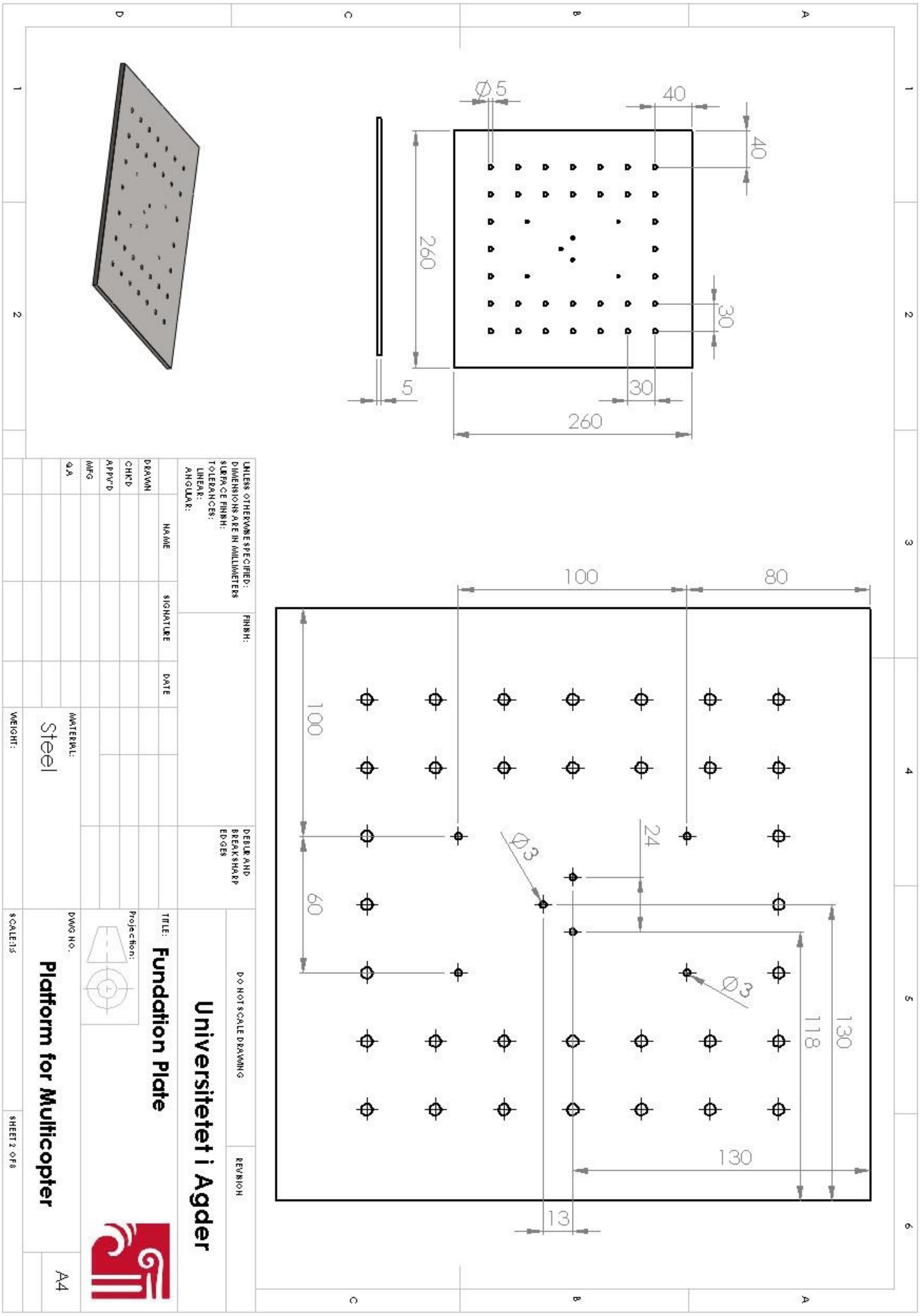
TITLE: Platform for Multicopter

Projection:

DWG NO. Platform for Multicopter

A4

SCALE:1:5 SHEET 1 OF 8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Universitetet i Agder
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Platform for Multicopter
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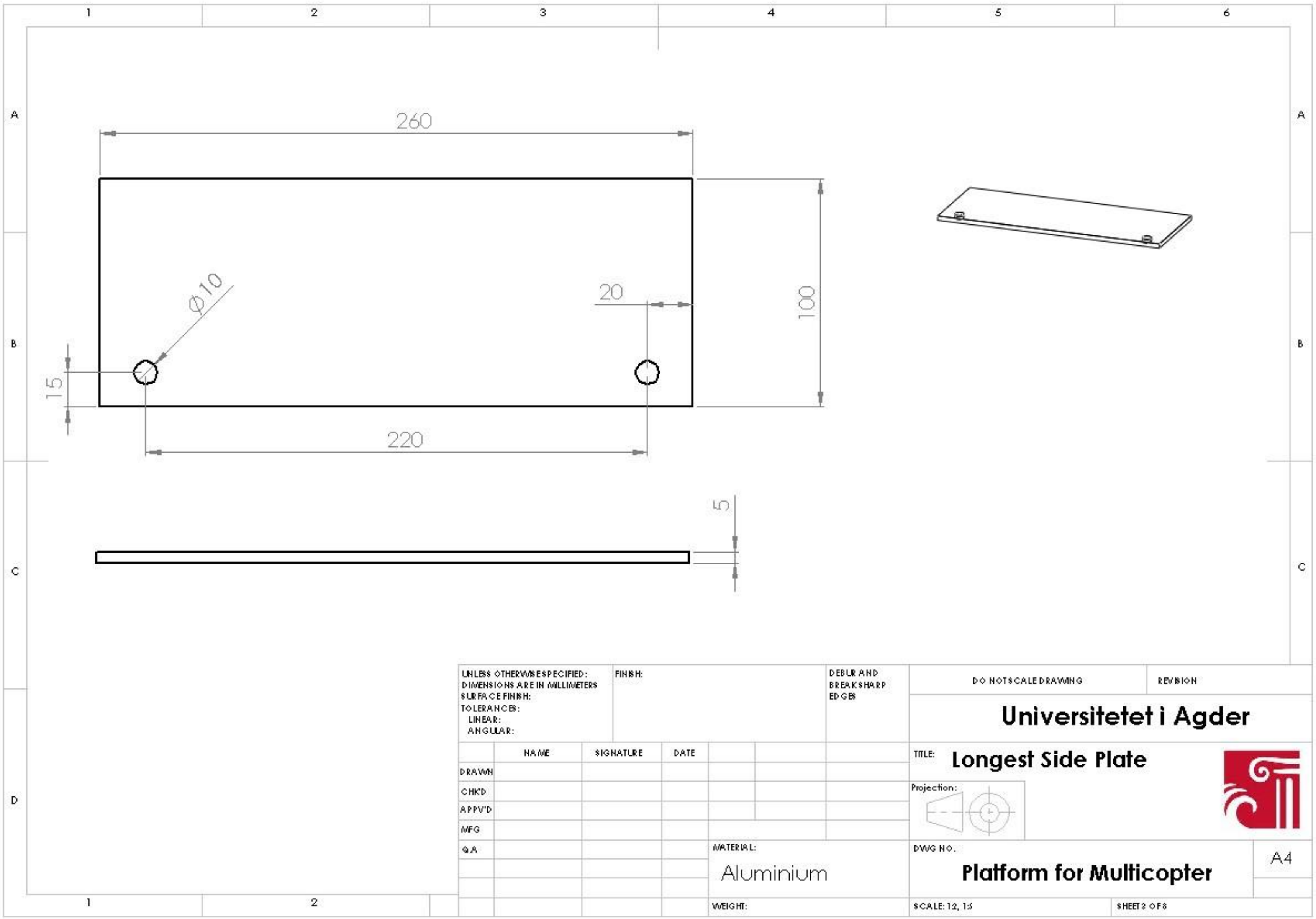
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APPV'D
MFG
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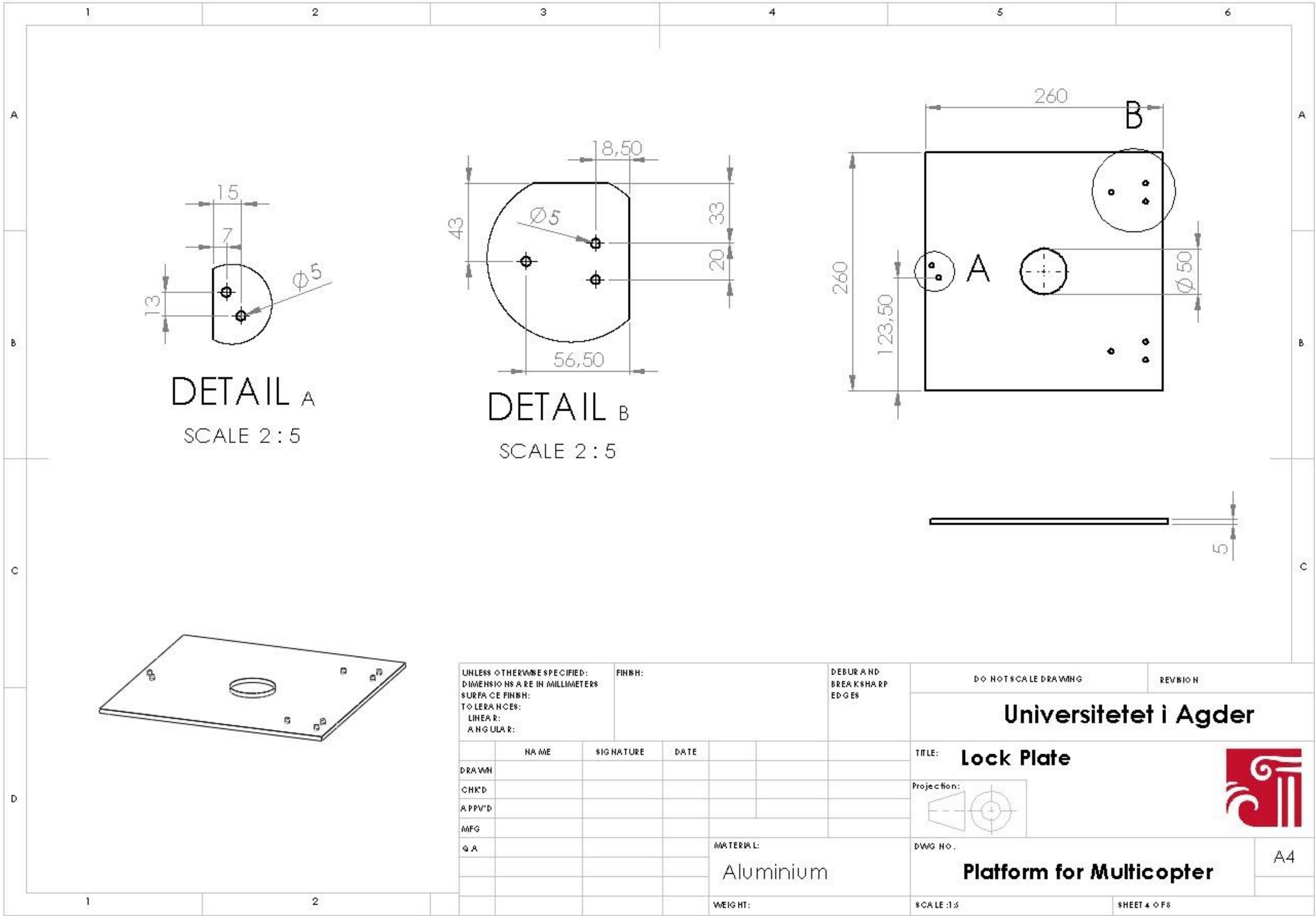
SHEET 3 OF 8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DETAIL B
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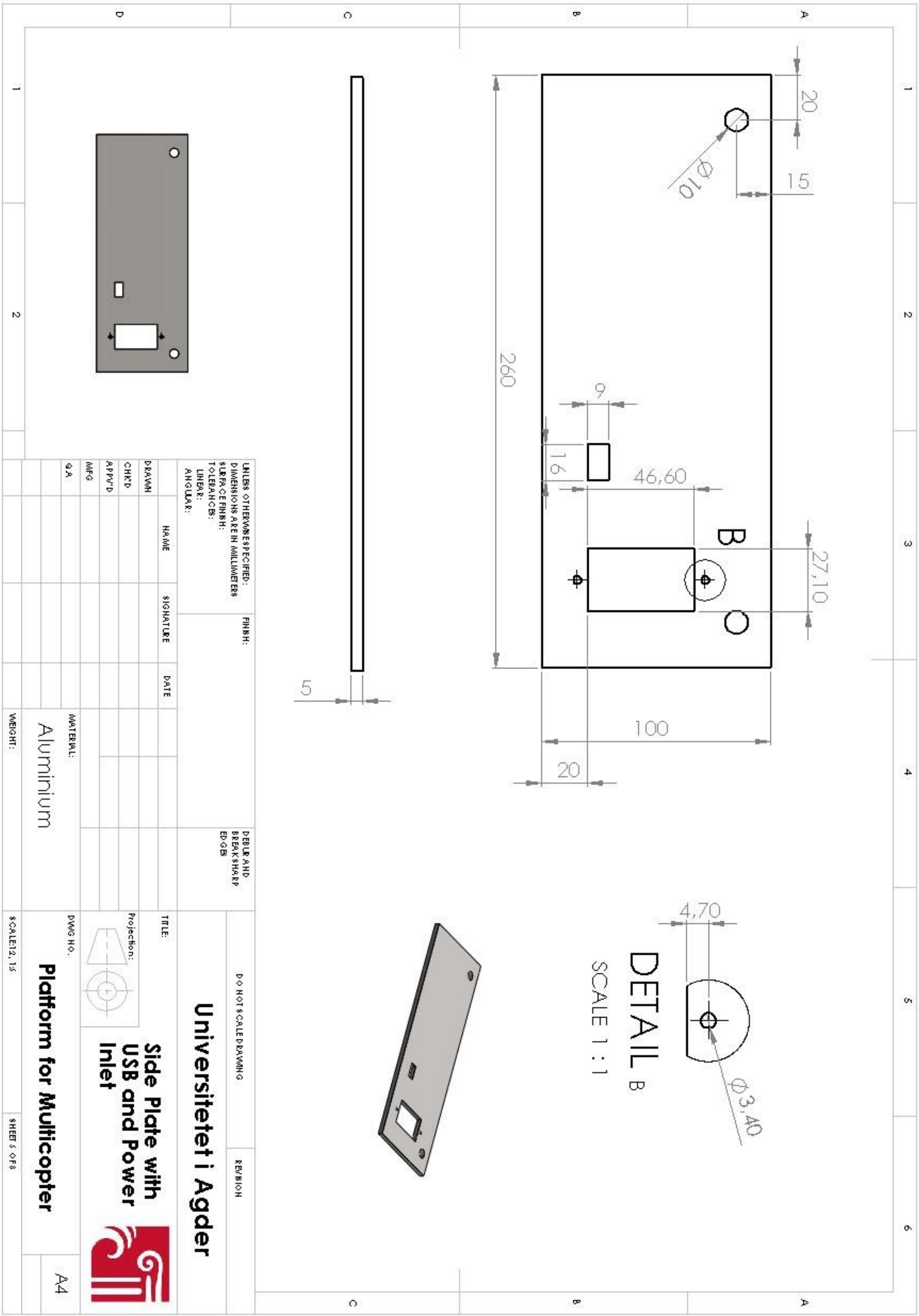

Universitetet i Agder
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Side Plate with USB and Power Inlet
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Platform for Multicopter
A4
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Aluminium
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SCALE:1:2, 1:5
SHEET 5 OF 8
DO NOT SCALE DRAWING
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MFG
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Projection:
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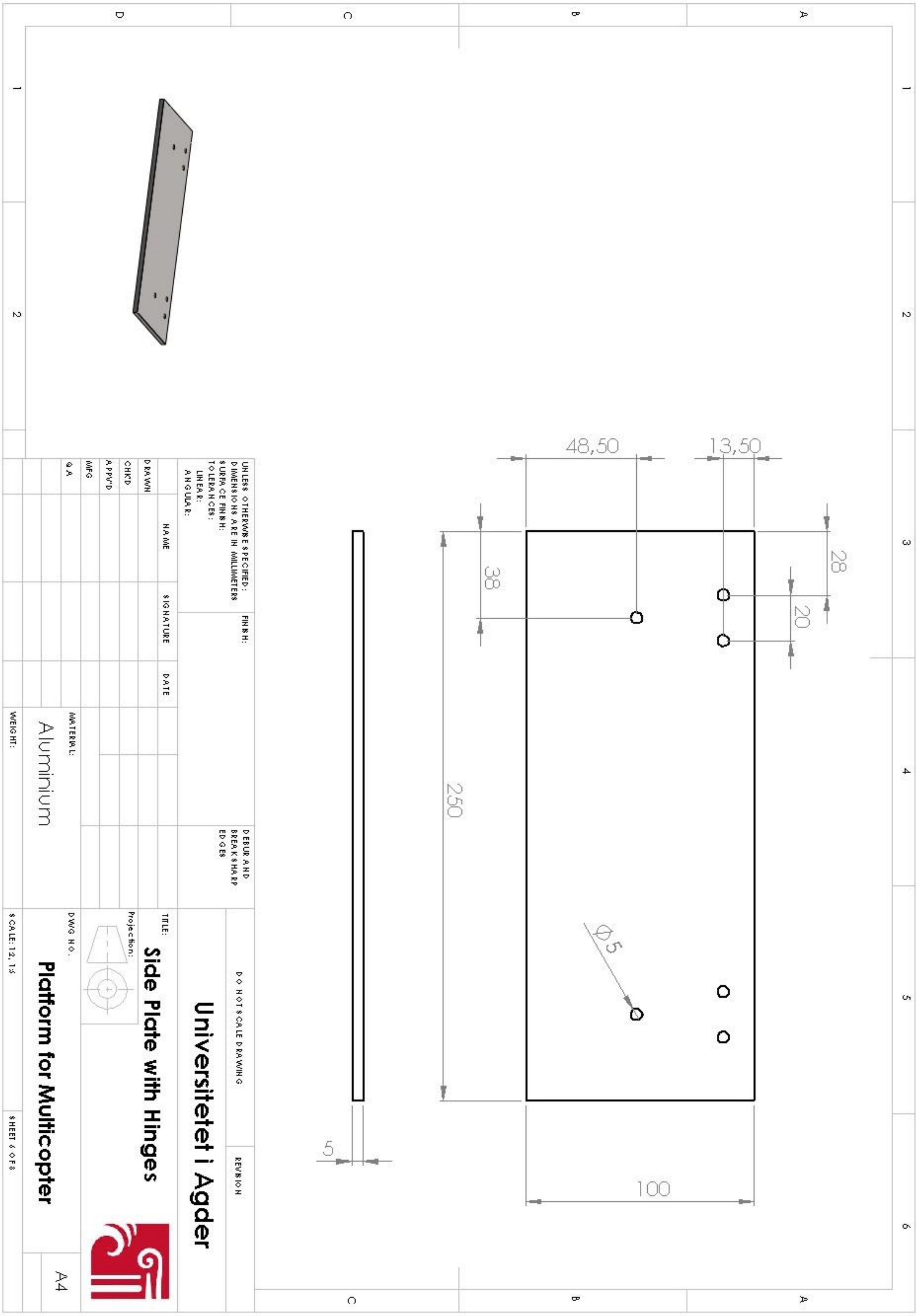

Universitetet i Agder
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Side Plate with Hinges
DWG NO.
Platform for Multicopter
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Aluminium
A4
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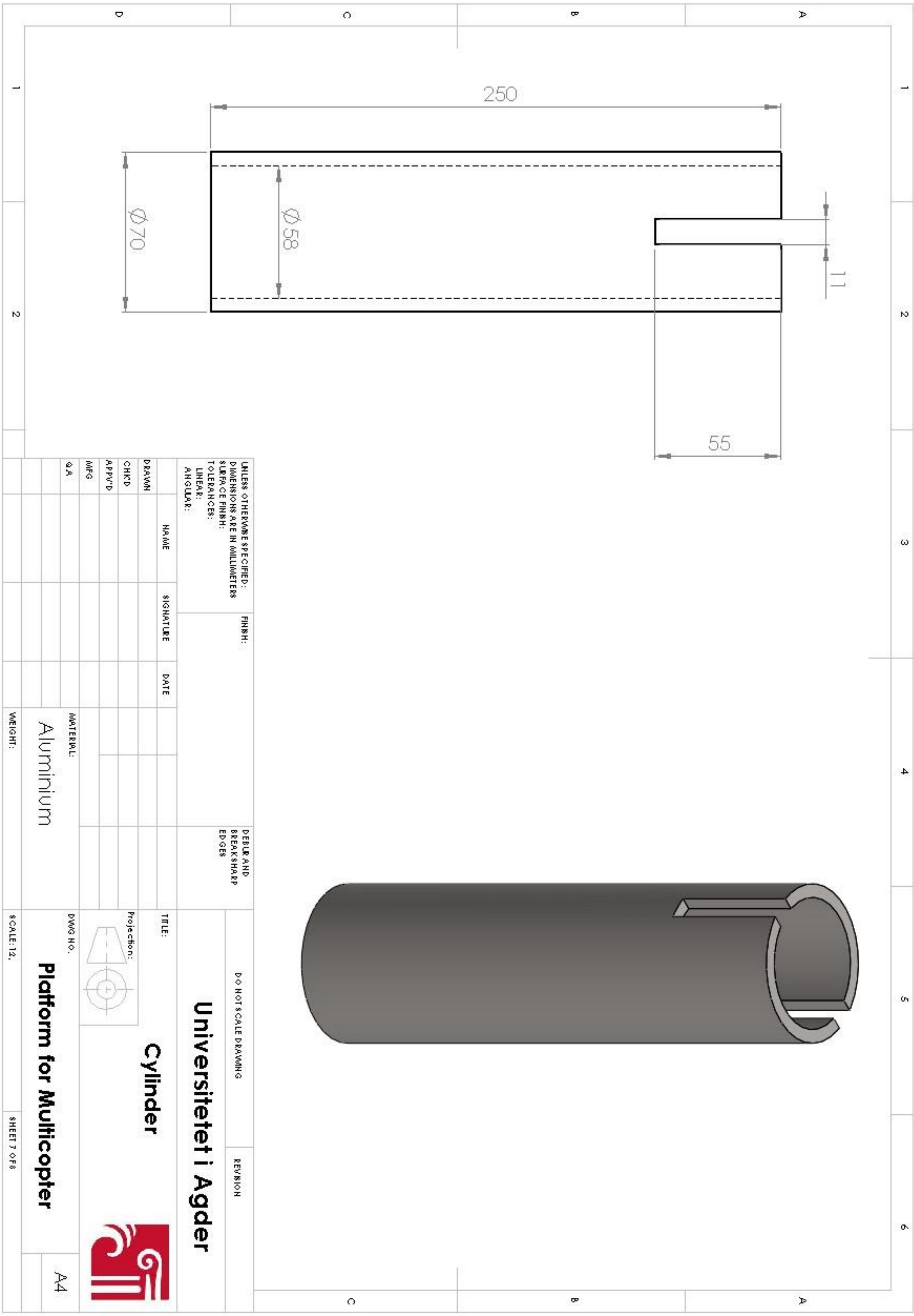
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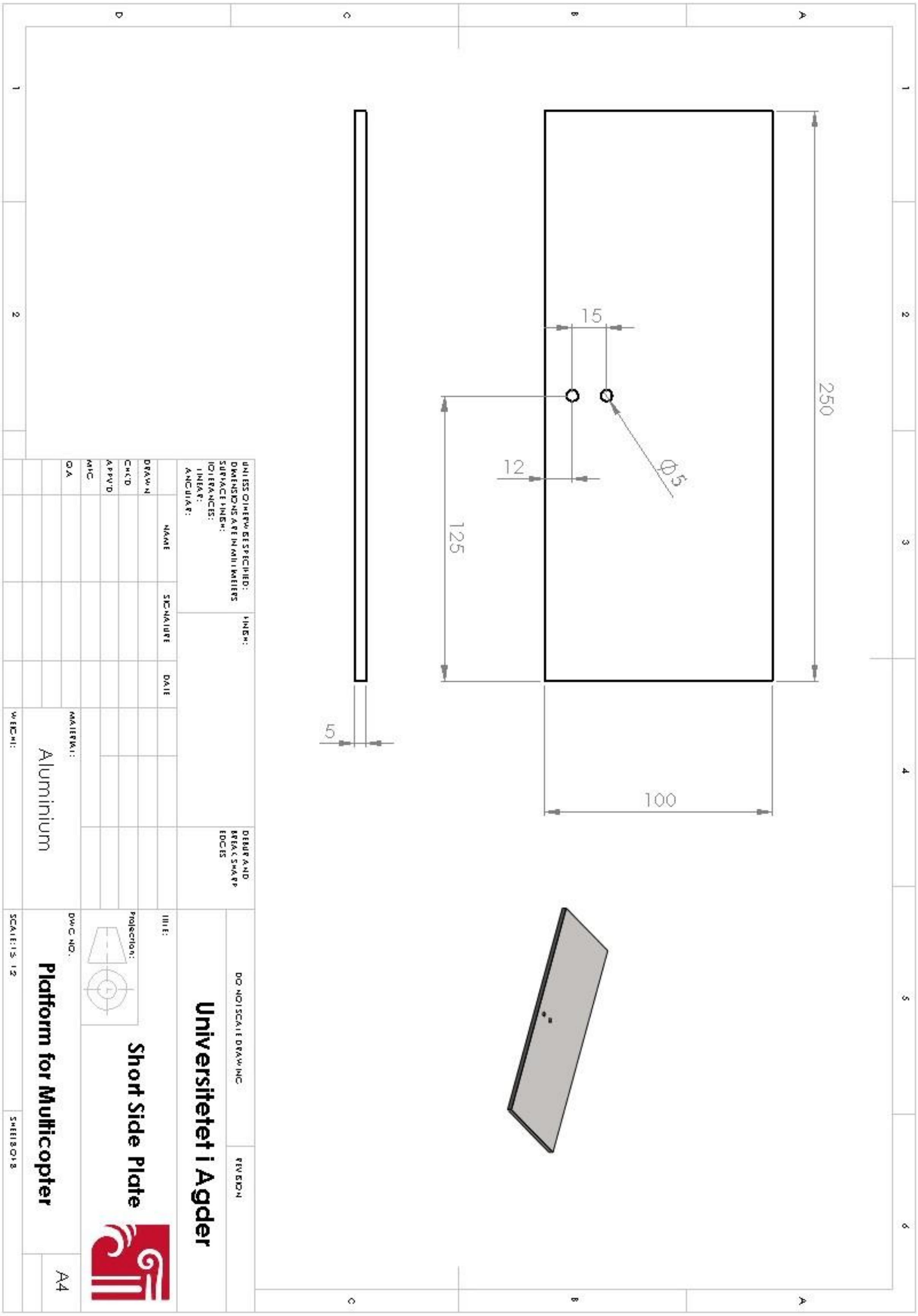
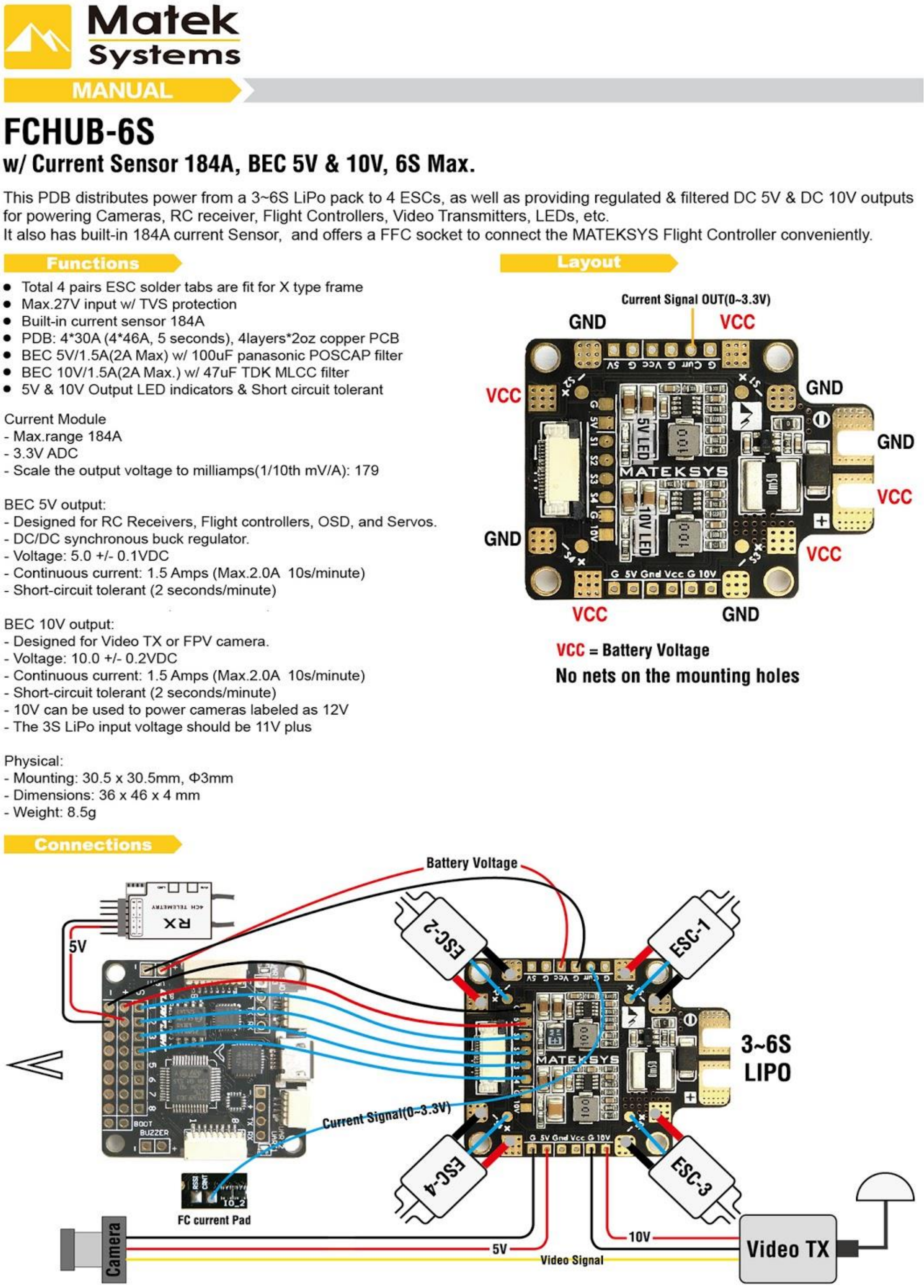
WEIGHT:
TITLE:
Universitetet i Agder
Cylinder
Projection:
DWG NO.
Platform for Multicopter
A4
SCALE:1:2
SHEET 7 OF 8



15
12
125
250
Ø5
5
100
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Aluminium
WEIGHT:
TITLE:
Universitetet i Agder
Short Side Plate
DWG NO.
Platform for Multicopter
A4

Power Distribution Board



Matek Systems

MANUAL

FCHUB-6S

w/ Current Sensor 184A, BEC 5V & 10V, 6S Max.

This PDB distributes power from a 3~6S LiPo pack to 4 ESCs, as well as providing regulated & filtered DC 5V & DC 10V outputs for powering Cameras, RC receiver, Flight Controllers, Video Transmitters, LEDs, etc.
It also has built-in 184A current Sensor, and offers a FFC socket to connect the MATEKSYS Flight Controller conveniently.

Functions

- Total 4 pairs ESC solder tabs are fit for X type frame
- Max.27V input w/ TVS protection
- Built-in current sensor 184A
- PDB: 4*30A (4*46A, 5 seconds), 4layers*2oz copper PCB
- BEC 5V/1.5A(2A Max) w/ 100uF panasonic POSCAP filter
- BEC 10V/1.5A(2A Max.) w/ 47uF TDK MLCC filter
- 5V & 10V Output LED indicators & Short circuit tolerant

Current Module
- Max.range 184A
- 3.3V ADC
- Scale the output voltage to milliamps(1/10th mV/A): 179

BEC 5V output:
- Designed for RC Receivers, Flight controllers, OSD, and Servos.
- DC/DC synchronous buck regulator.
- Voltage: 5.0 +/- 0.1VDC
- Continuous current: 1.5 Amps (Max.2.0A 10s/minute)
- Short-circuit tolerant (2 seconds/minute)

BEC 10V output:
- Designed for Video TX or FPV camera.
- Voltage: 10.0 +/- 0.2VDC
- Continuous current: 1.5 Amps (Max.2.0A 10s/minute)
- Short-circuit tolerant (2 seconds/minute)
- 10V can be used to power cameras labeled as 12V
- The 3S LiPo input voltage should be 11V plus

Physical:
- Mounting: 30.5 x 30.5mm, Φ3mm
- Dimensions: 36 x 46 x 4 mm
- Weight: 8.5g

Layout

Connections

(1)1: http://www.mateksys.com/?portfolio=fchub-6s#tab-id-2

AR610 User Guide

The AR610 features DSM2/DSMX technology and is compatible with all Spektrum™ and JR® aircraft radios that support DSM2/DSMX technology.

NOTICE: The AR610 receiver is not compatible with the DX6 parkflyer radio system.

Features

- Full Range
- QuickConnect with Brownout Detection (Brownout Detection only in DSM2 mode)
- Resolution: 2048
- Flight Log and Telemetry Compatible

Specifications

Type: Full Range Sport Receiver
Channels: 6
Modulation: DSM2/DSMX
Dimension (LxWxH): 36.6mm x 26.7mm x 12.7mm (1.44 in x 1.05 in x 0.50 in)
Weight: 9 g
Input Voltage Range: 3.5–9.6V
Resolution: 2048
Compatibility: All DSM2/DSMX Aircraft Transmitters and Module Systems

Receiver Installation

For optimum RF link performance, mount the antennas for best possible signal reception for the aircraft in all possible attitudes and positions. Orient the antennas perpendicular to each other—one vertical and one horizontal Mount the long antenna at least 2 inches away from and perpendicular to the short antenna using tape.

Do not use amplified Y-harnesses or servo extensions with Spektrum equipment. Use only standard, non-amplified Y-harnesses or servo extensions. When converting an existing model to Spektrum, replace all amplfied Y-harnesses and/or servo extensions with conventional non-amplified versions.

https://www.spektrumrc.com/ProdInfo/Files/SPMAR610_Manual_EN.pdf

SNU11 series USB slip ring

1channel USB1.0/USB2.0+1~20circuits power/signal

SNU11 series USB slip ring with through hole 12.7mm & OD56mm, could transmit one channel USB combined with power and signal, with advantages of reliable transmitting,no packet loss,no string code,low return loss, low insertion loss. Contact materials:precious metal +gold plating which ensures low BER(bit-error rate)and high noise-signal ratio

SNU11 - 0610 - 12S

12S —12 Circuits Signal , 2A each

0610 — 6 Circuits Power , 10A each

For example :

SNU11-0610-12Smeans : through hole 12.7mm,OD 56mm,slip ring,one channel USB USB1.0/USB2.0+ 6circuit , 10A each+ 12circuits,2A each (signal)

Ethernet Technical Data

Ethernet	USB1.0 /USB 2.0	Connectors	USB male/female
BER(bit-error rate)	1.00E-10	insertion loss	2db

Power/signal Technical Data

Circuits No.	2~20(Pls refer to above table)	Current	signal(2A),10A/ circuit
Voltage	250 VDC/VAC	Max speed	600RPM
Housing material	AL alloy	Torque	0.1N.m;+0.03N.m/6 circuits
Working life	>120millions revolutions(depends on working speed)	Contact material	Precious metal:gold-gold
Electrical Noise	<10 MΩ	Contact Resistance	<20 MΩ(AWG16#,300mm)
Dielectric Strength	800VDC@50Hz	Lead wire Spec	UL Teflon@Awg22,Awg16
Insulation Resistance	1000MΩ@600VDC	Lead wire length	300mm
Work Temperature	-40°C to 80°C	IP grade	IP51
Mechanical vibration	MIL-SID-810E	Work Humidity	10% to 85% RH
Material	RoHS compliant	CE certificate	YES

Remarks:

1)Working life depends on working speed,temperature and humidity

2)Lead wire Spec.: 2A/ signal -> AWG26, 5A -> AWG22, 10A -> Awg16, 15A -> Awg14, different color wires

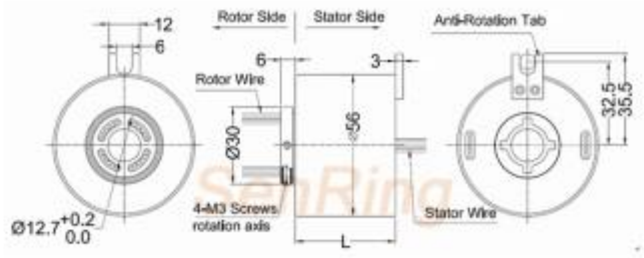
3)Electrical noise depends on working speed,current and voltage

Model no

Model no	Signal/2A	10A	20A	Ethernet Channels number	OD*Length(mm)
SNU11-02S	2	--	--	1	56*37
SNU11-0210	--	2	--	1	56*37
SNU11-08S	8	--	--	1	56*54
SNU11-0810	--	8	--	1	56*54
SNU11-0210-06S	6	2	--	1	56*54
SNU11-0410-04S	4	4	--	1	56*54
SNU11-14S	14	--	--	1	56*70.5
SNU11-1410	--	14	--	1	56*70.5
SNU11-0410-10S	10	4	--	1	56*70.5
SNU11-0810-06S	6	8	--	1	56*70.5
SNU11-20S	20	--	--	1	56*87.5

Tel:+86-755-29717812 Fax:+86-755-33250183 Email:Info@senring.com Website : www.senring.com

Drawing



Lead Wire Color Code					
Ring no.#	Color	Ring no.#	Color	Ring no.#	Color
1	black	5	yellow	9	grey
2	brown	6	green	10	white
3	red	7	blue	11	pink
4	orange	8	purple	12	light blue

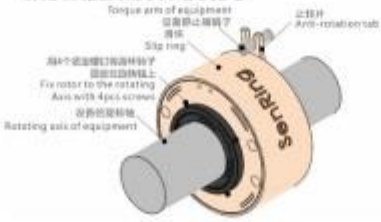
12 colors wires as a group,repeat from 13...24 , each group wire marked with No. tube (1,2,3,4...)

Options

- ▲Connectors and heat shrink tube
- ▲Lead wire length
- ▲Shield wire
- ▲500 MHz transmitting speed
- ▲Transmit combined high speed data (Ethernet ,USB,Profibus)
- ▲Combined with signal wires,coaxial wire and power wire
- ▲Combined with thermocouple and signal
- ▲Customize for high temperature,shockproof environment
- ▲Combined with pneumatic,hydraulic
- ▲Customize high temperature 250℃ slip ring
- ▲Customize high voltage,large current slip ring
- ▲Military level

Installation

INSTALLATION GUIDE



Instructions :
Since it is difficult to keep the rotor and stator concentric, suggest to fix the slip ring on the rotating shaft with four screws and insert the torque arm into the anti-rotation tab, do not force to fix anti-rotation tab which may cause damage and shorten working life

Caution :
- Do not let slip ring to carry loads as well as lead wires
- Protect lead wire to avoid any damages of insulation when intallation
- As a precise component, slip ring should be operated in a dry, less dust environment. Pls take protect measurements if bad conditions

Customization

Customize based on this model

As one of domectic forthgoers in developing and manufacturing of slip rings,Senring has rich experiences in customizating slip rings for many industries, we have more than 10000 solutions and data sheets

for example:
if to order SNU11,support 3circuits*15A+12circuits*signals,,model no. is SNU11-0315-12S.
if to order SNU11,support 2circuits*15A+6circuits*signalsA+2circuits*50A,model no. is SNU11-0250-0215-06S

Tel:+86-755-29717812 Fax:+86-755-33250183 Email:Info@senring.com Website : www.senring.com

http://www.senring.com/data/upload/pdf/SNU/snu11.pdf

TRACO® POWER

Metal Case Power Supplies

TXH Series, 120–480 Watt

Features

- Compact U-bracket and enclosed power supplies
- Screw terminal block
- Very high efficiency up to 93 %
- No internal fan for 120 W & 240 W models.
- Universal input 90 – 264 VAC
- Adjustable output voltage
- EMI/EMC compliance with EN 61000-6-3 and EN 61000-6-1
- Compliance to EN 61000-3-2 (PFC)
- Short circuit and overvoltage protection
- 3-year product warranty

The TXH series is a family of power supplies in metal enclosure, designed for a wide range of cost critical applications. The very high efficiency of up to 93% admits of a compact design with free air convection coouling for the 120 and 240 Watt models. The units are equiped with screw terminal blocks and are easy to install in any equipment.
These power supplies have universal input and comply with European EMC standards and the Low Voltage Directive (LVD).

Models with Single Output

Order code	Output power max.	Output Voltage [VDC] nominal *	Output Voltage [VDC] adjustable	Output current max.	Efficiency typ. at 230 VAC
TXH 120-112	120 Watt	12	11.4 – 13.2	10 A	90 %
TXH 120-124		24	22.8 – 26.4	5.0 A	91 %
TXH 120-148		48	45.6 – 52.0	2.5 A	92 %
TXH 240-112	240 Watt	12	11.4 – 12.6	20 A	90 %
TXH 240-124		24	22.8 – 25.2	10 A	92 %
TXH 240-148		48	45.6 – 50.4	5.0 A	93 %
TXH 360-112	360 Watt	12	10.8 – 13.2	30 A	89 %
TXH 360-124		24	21.6 – 26.4	15 A	91 %
TXH 360-148		48	44.0 – 51.0	7.5 A	93 %
TXH 480-112	480 Watt	12	10.8 – 13.2	40 A	88 %
TXH 480-124		24	21.6 – 26.4	20 A	90 %
TXH 480-148		48	43.2 – 50.4	10 A	91 %

* 36 VDC output voltage models on request.

Input Specifications

Input voltage	– nominal – AC range (universal input) – DC range		100 – 240 VAC 90 – 264 VAC 120 – 370 VDC
Input frequency			47 – 63 Hz
Earth leakage current (240 VAC / 63 Hz)		360 W models: other models:	300 µA max. 500 µA max.
Input current at full load	– at 115 VAC / 230 VAC	120 W models: 240 W models: 360 W models: 480 W models:	1.2 A typ. / 0.6 A typ. 2.3 A typ. / 1.1 A typ. 3.6 A typ. / 1.8 A typ. 5.1 A typ. / 2.5 A typ.
Recommended circuit breaker (characteristic C) or slow blow fuse		120 W models: 240 W models: 360 W models: 480 W models:	3.15 A 5 A 6.3 A 10 A

Output Specifications

Voltage set accuracy			±2 % max.
Output voltage adjustment range			details see table page 1
Regulation	– Input variation – Load variation (0–100%)		1 % max. 1 % max.
Minimum load			not required
Ripple and noise (20 MHz bandwidth) [mVp-p] max.		(see table below)	
Hold-up time			10 ms min.
Current limitation			130 - 150 % foldback, auto recovery
Short circuit protection		 360 & 480 W models: 120 & 240 W models:	indefinite, auto recovery no auto recovery (power disconnect required)
Overvoltage protection by Zener diode		 360 & 480 W models: 120 & 240 W models:	120 % of Vout typ. auto recovery no auto recovery (power disconnect required)
Overtemperature protection			for 360 & 480 W models only, auto recovery
Capacitive load, (µF) max.		(see table below)	

Ripple and noise (20 MHz bandwidth) [mVp-p] max.:

Models:	12 VDC	24 VDC	48 VDC
120 W	120	240	480
240 W	120	200	200
360 W	150	200	200
480 W	100	200	300

Capacitive load, (µF) max.:

Models:	12 VDC	24 VDC	48 VDC
120 W	23'000	10'000	470
240 W	23'000	10'000	470
360 W	85'000	48'000	13'000
480 W	180'000	75'000	25'000

General Specifications

Temperature ranges	– Operating – Storage (non operating)	480/360/120 W models: other models:	–25°C to +70°C –10°C to +70°C –25°C to +85°C
Derating	– Ambient temperature – Low input voltage		2.5 %/K above +50°C low temperature derating for TXH480-112 model: 2%K below 5°C below 100 VAC: 1%/V
Temperature coefficient			0.03 %/K
Humidity (non condensing)			95 % rel max.

All specifications valid at nominal input voltage, full load and +25°C after warm-up time unless otherwise stated.

TRACO POWER

Metal Case Power Supplies
TXH Series **120–480 Watt**

General Specifications

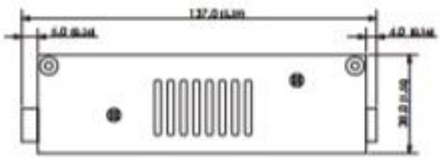
Switching frequency (pulse width modulation PWM)		120 & 240 W models: 360 W models: 480 W models:	100 kHz typ. 75 kHz typ. 62.5 kHz typ.
Isolation voltage (60 sec.)	– Input / Output	120 & 240 W models: 360 & 480 W models:	4'000 VAC 3'000 VAC
	– Input / Case	120 & 240 W models: 360 & 480 W models:	2'000 VAC 1'500 VAC
	– Output / Case		500 VAC
Reliability /calculated MTBF (MIL-HDBK-217F, at +25°C, ground benign)		120 & 360 W models: 240 W models: 480 W models:	>120'000 h >50'000 h >100'000 h
Electromagnetic compatibility (EMC), Emissions	– Conducted input RI suppression – Harmonic current emissions		EN 55022, class B, FCC part 15, level B IEC/EN 61000-3-2 class B
Electromagnetic compatibility (EMC), Immunity			EN 55024
Degree of protection			class I
Safety standards			UL 60950-1, IEC/EN 60950-1
Safety approvals	– UL/cUL 60950-1 – CB report according to IEC 60950-1		www.ul.com -> certifications -> File e188913 www.tracopower.com/products/txh-cb.pdf
Environment	– Vibration		3 axes, sine sweep, 10–500Hz, 2g, 0.1 oct/min
Environmental compliance	– Reach – RoHS		www.tracopower.com/products/txh-reach.pdf RoHS directive 2011/65/EU
Altitude during operation		120 / 240 & 360 W models: 480 W models:	up to 4'000 m (13'120 ft) approved up to 3'000 m (9'840 ft) approved

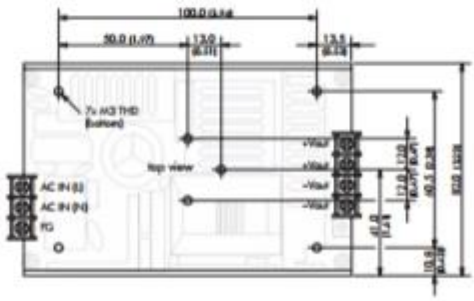
Outline Dimensions

TXH 120 models

Weight: 390 g (13.8 oz)

Optional Cover	
TXH 120–COV	Cover incl. screws for TXH 120 models





Max mounting screw penetration: 2.5 mm (0.1)

(1)

TRACO POWER

INSTALLATION INSTRUCTIONS

TXH 120, TXH 240, TXH 360 & TXH 480 Series — Switching Power Supply

Order Code	Nominal AC-Input Voltage Range	AC-Input Voltage Range	*Output Power max.	**DC-Output	Recommended Circuit breaker
TXH 120-112	100 – 240VAC 50/60Hz Universal Input	90 – 264VAC 47 – 63Hz 120 – 370VDC	120 Watt	12.0Vdc / 10.0A	5A (Characteristic C)
TXH 120-124			120 Watt	24.0Vdc / 5.0A	
TXH 120-148			120 Watt	48.0Vdc / 2.5A	
TXH 240-112			240 Watt	12.0Vdc / 20.0A	5A (Characteristic C)
TXH 240-124			240 Watt	24.0Vdc / 10.0A	
TXH 240-148			240 Watt	48.0Vdc / 5.0A	
TXH 360-112			360 Watt	12.0Vdc / 30.0A	10A (Characteristic C)
TXH 360-124			360 Watt	24.0Vdc / 15.0A	
TXH 360-148			360 Watt	48.0Vdc / 7.5A	
TXH 480-112			480 Watt	12.0Vdc / 40.0A	10A (Characteristic C)
TXH 480-124			480 Watt	24.0Vdc / 20.0A	
TXH 480-148			480 Watt	48.0Vdc / 10.0A	

*Total output power must not exceed specified max output power.

**Output adjustable by potentiometer with a screwdriver.

Input current:	@ V_{in} = 115VAC	@ V_{in} = 230VAC	Power Consumption	@ V_{in} = 115VAC	@ V_{in} = 230VAC
➢ TXH 120	1.2 A typ.	0.6 A typ.	➢ TXH 120	136 Watt typ.	133 Watt typ.
➢ TXH 240	2.3 A typ.	1.1 A typ.	➢ TXH 240	265 Watt typ.	255 Watt typ.
➢ TXH 360	3.6 A typ.	1.8 A typ.	➢ TXH 360	413 Watt typ.	398 Watt typ.
➢ TXH 480	5.1 A typ.	2.6 A typ.	➢ TXH 480	586 Watt typ.	567Watt typ.

Output Voltage Adjustment range:	±5% ±10% (TXH 480-1xx)
Operating temperature range: Natural Air Convection Cooling	-25°C – +75°C max ➔ (TXH 120-1xx) -13°F – +167°F max ➔ (TXH 120-1xx) -10°C – +70°C max ➔ (TXH 240-1xx & TXH 360-1xx) +14°F – +158°F max ➔ (TXH 240-1xx & TXH 360-1xx) -20°C – +70°C max ➔ (TXH 480-1xx) -4°F – +158°F max ➔ (TXH 480-1xx)
Output Power Derating above +50°C:	above +50°C ➔ 2.5 %/K above 122°F ➔ 2.5 %/K TXH 480: below +41°C ➔ 2.5 %/K and above +50°C ➔ 1.5 %/K TXH 480: below +41°F ➔ 2.5 %/K and above 122°F ➔ 1.5 %/K
Storage temperature range: Non operating	-25°C – +75°C max -13°F – +167°F max
Input Connections:	Screw type terminal COMBICON. Recommended tightening torque 0.5 to 0.7Nm (4.5 to 6.2lb.in.)
Output Connections:	Screw type terminal COMBICON. Recommended tightening torque 0.5 to 0.7Nm (4.5 to 6.2lb.in.)
Terminal for wiring:	Y or Ring shape recommended (max. inside diameter = 3.0mm / max. outside diameter = 5.0mm)
Case material:	Aluminium base
Mounting inserts:	7 x M3 (TXH 120-1xx & TXH 240-1xx on the bottom side) 9 x M3 (TXH 360-1xx; 5 x on the bottom side and 4 x on the side) 11 x M3.5 (TXH 480-1xx; 7 x on the bottom side and 4 x on the side)

TRACO POWER

Safety Instructions:

- Before installation read these instructions carefully and completely. This installation instruction cannot account for every possible condition of installation, operation or maintenance. Further information can be obtained from your local distributor's office or from the product data sheet, which can be downloaded, from the Internet at www.tracopower.com/products/txh.pdf.
- The power supplies are constructed in accordance with the safety requirements of IEC/EN60950-1, UL 60950-1 and CSA C22.2 No.60950-1. They fulfil the requirements for CE-compatibility and carries the CE mark. They are UL and cUL approved in accordance to UL60950-1 (recognised).
- Before any installation, maintenance or modification work ensure that the main switch is switched off and prevented from being switched on again. Non-observance, touching of any live components or improper handling of this power supply can result in death, severe personal injury or substantial property damage. Proper and safe operation is dependent on proper storage, handling, installation and operation.
- Compliance with the relevant national regulations (in the USA, Europe or other countries) must be ensured. Before operation is started the following conditions must be ensured:
  - Connection to mains supply in compliance with national regulations (VDE0100 and EN50178).
  - By use of stranded wires, all strands must be fastened in the terminal blocks. (Potential danger of contact with the case)
  - Power supply and mains cables must be sufficiently fused.
  - The non-fused protective earth connection must be connected to the FG terminal (Protection class I).
  - All output wires must be rated for the power supply output current and must be connected with the correct polarity.
  - Sufficient cooling must be ensured.
- ***Never work on the power supply if power is supplied!*** Risk of electric arcs and electrical shock, which can cause death, severe personal injury or substantial property damage.
- **Warning:** Hazardous voltages and components storing a very substantial amount of energy are present in this power supply during normal operating conditions. However, these are inaccessible. Improper handling may result in an electric shock or serious burns!

  Do not open the power supply until at least 5 minutes after it has been disconnected from the mains on all poles.
  - Only trained personnel may open the power supply.
  - Do not introduce any objects into the power supply. The output voltage adjustment potentiometer may only be actuated using an insulated screwdriver.
  - Keep away from fire and water

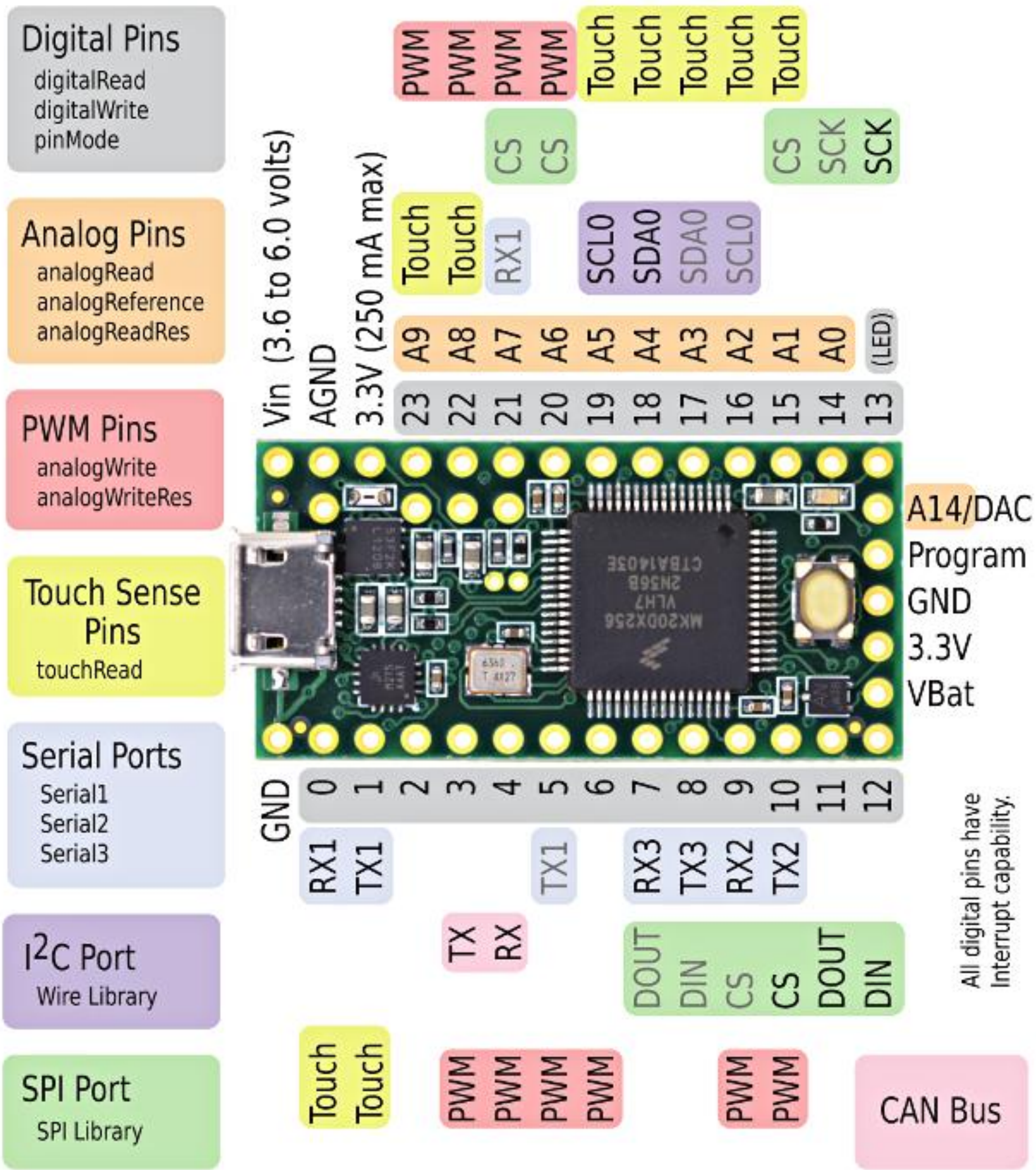
Installation Instructions:

- This power supply is designed for professional indoor systems. In operation the power supply must not be accessible. It may be installed and put into service by qualified personnel only.
- Do not operate without PE connection! To comply with EMC and safety standards (CE mark, approvals) the power supply must be operated only if PE terminal is connected to the non-fused earth conductor.
- The correct mounting position for optimal cooling performance must be observed. ***Do not cover any ventilation holes.*** Leave a fee space of minimum 50mm (2in.) above and on the sides of the power supply. Observe power derating. (see our TXH data sheet)
- The internal fuse is not accessible, as it may not be replaced by the user. If this internal fuse has blown, the power supply has an internal defect and, for safety reasons, must be shipped to the local distributor. In case this internal fuse has to be replaced in the field, replace only with same type and rating of fuse for continued protection against risk of fire.
- ***Recycling:*** The unit contains elements that are suitable for recycling, and components that need special disposal. You are therefore requested to make sure that the power supply will be recycled environment friendly at the end of its service life.

http://www.tracopower.com Rev: 18/12

(2)
1: https://www.tracopower.com/products/txh.pdf
2: installation instructions that came with the power supplier

Teensy 3.2 Pins



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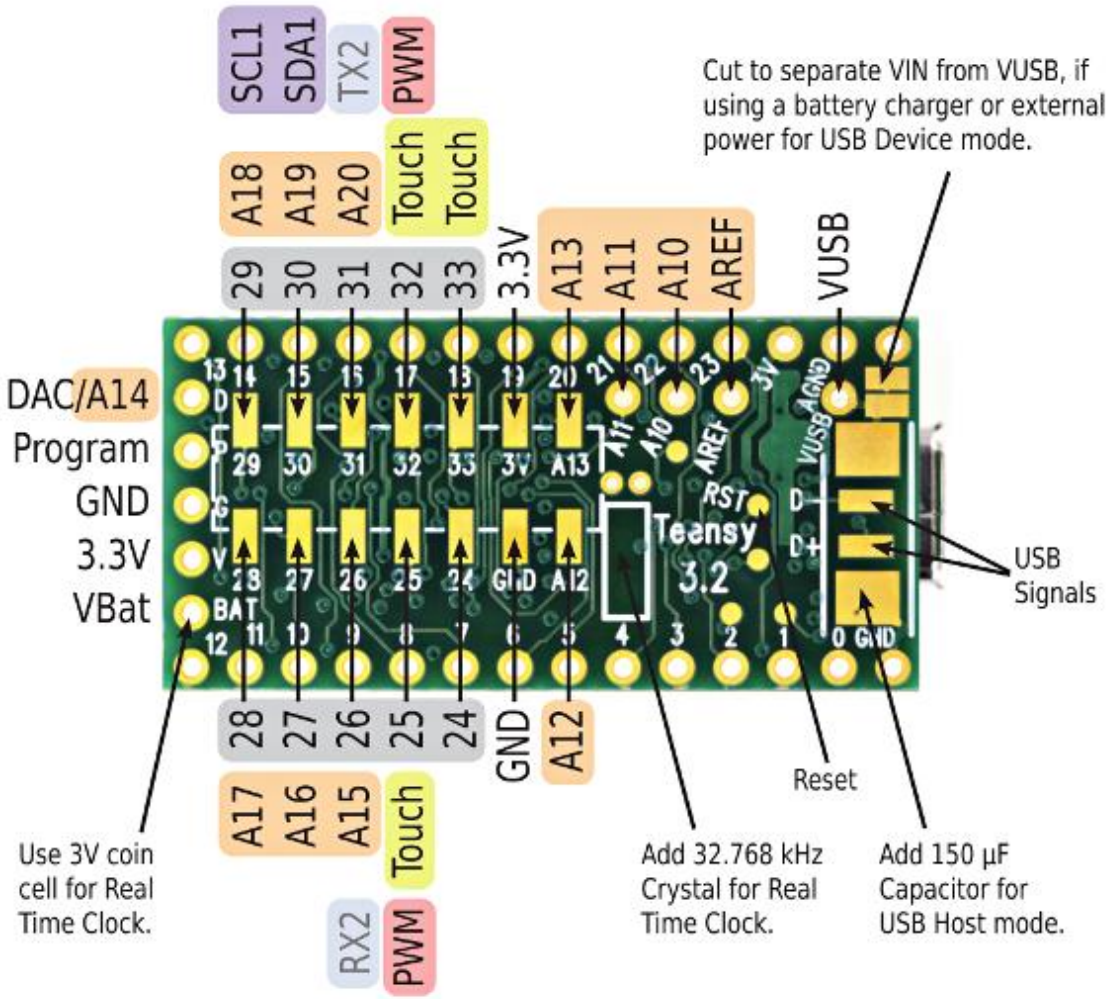
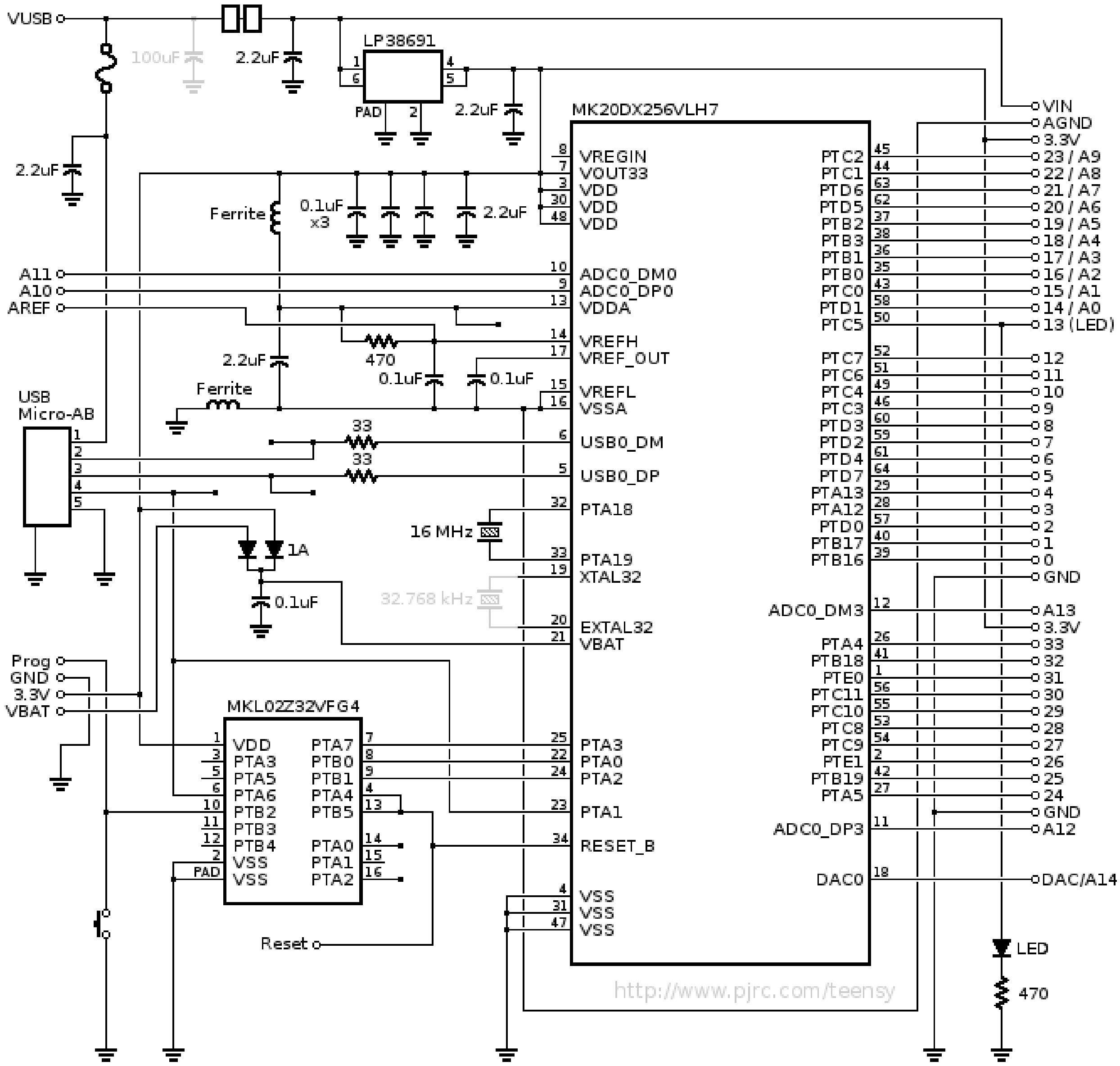

SCL1
SDA1
TX2
PWM
A18
A19
A20
Touch
Touch
29
30
31
32
33
3.3V
A13
A11
A10
AREF
VUSB
Cut to separate VIN from VUSB, if using a battery charger or external power for USB Device mode.
DAC/A14
Program
GND
3.3V
VBat
Teensy
3.2
USB
Signals
28
27
26
25
24
GND
A12
A17
A16
A15
Touch
RX2
PWM
Reset
Use 3V coin cell for Real Time Clock.
Add 32.768 kHz Crystal for Real Time Clock.
Add 150 µF Capacitor for USB Host mode.

(1)

Teensy 3.2 Schematic



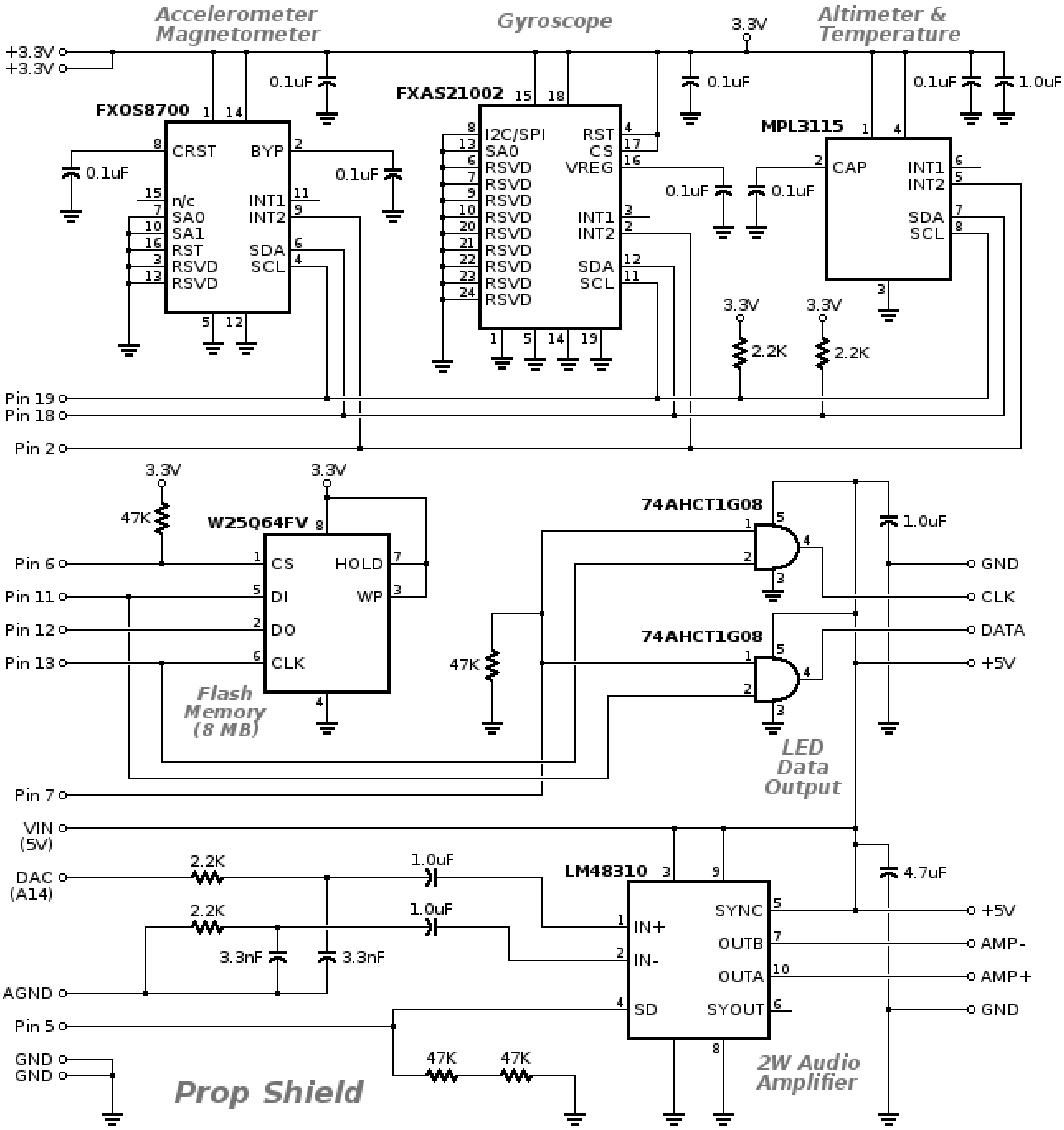
(2)

Complete datasheet: https://www.pjrc.com/teensy/K20P64M72SF1.pdf
Complete manual: https://www.pjrc.com/teensy/K20P64M72SF1RM.pdf

1: https://www.pjrc.com/teensy/pinout.html
2: https://www.pjrc.com/teensy/schematic.html

Teensy Prop Shield

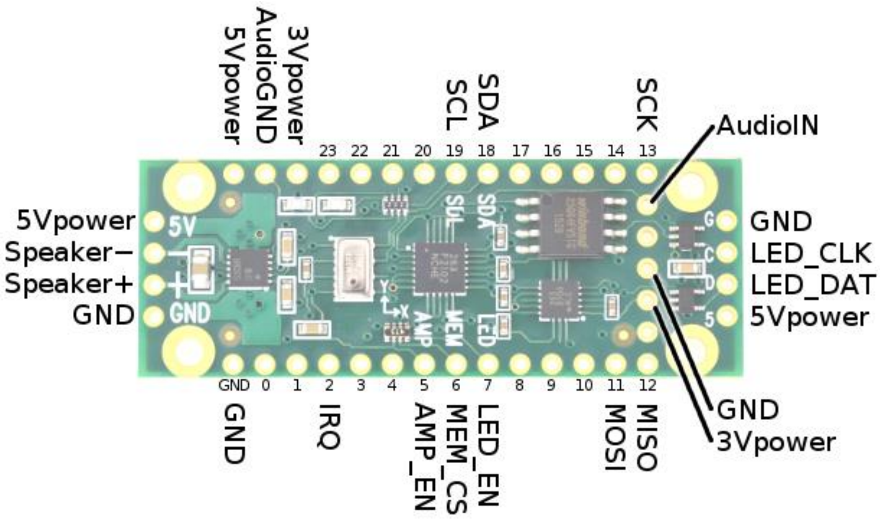
Teensy Prop Shield Schematic



(1)

Teensy Prop Shield Pins

Signal	Pin #	Used By:	Description
SDA	18	sensors	I2C Data for motion sensors
SCL	19	sensors	I2C Clock for motion sensors
IRQ	2	sensors	Interrupt from motion sensors
MOSI	11	memory,led	SPI Data
MISO	12	memory	SPI Data
SCK	13	memory,led	SPI Clock
MEM_CS	6	memory	Low to access memory
LED_EN	7	led	High to send LED data
LED_DAT	-	led	5v buffered LED Data output
LED_CLK	-	led	5v buffered LED Clock output
AMP_EN	5	amp	High to enable amplifier
AudioIN	DAC	amp	Audio signal
AudioGND	AGND	amp	Audio ground
Speaker+	-	amp	Connect a 4Ω or 8Ω speaker Twisted pair wire is recommended
Speaker-	-	amp	
5Vpower	VIN	amp,led	
3Vpower	3.3V	sensors,memory	
GND	GND	(all)	



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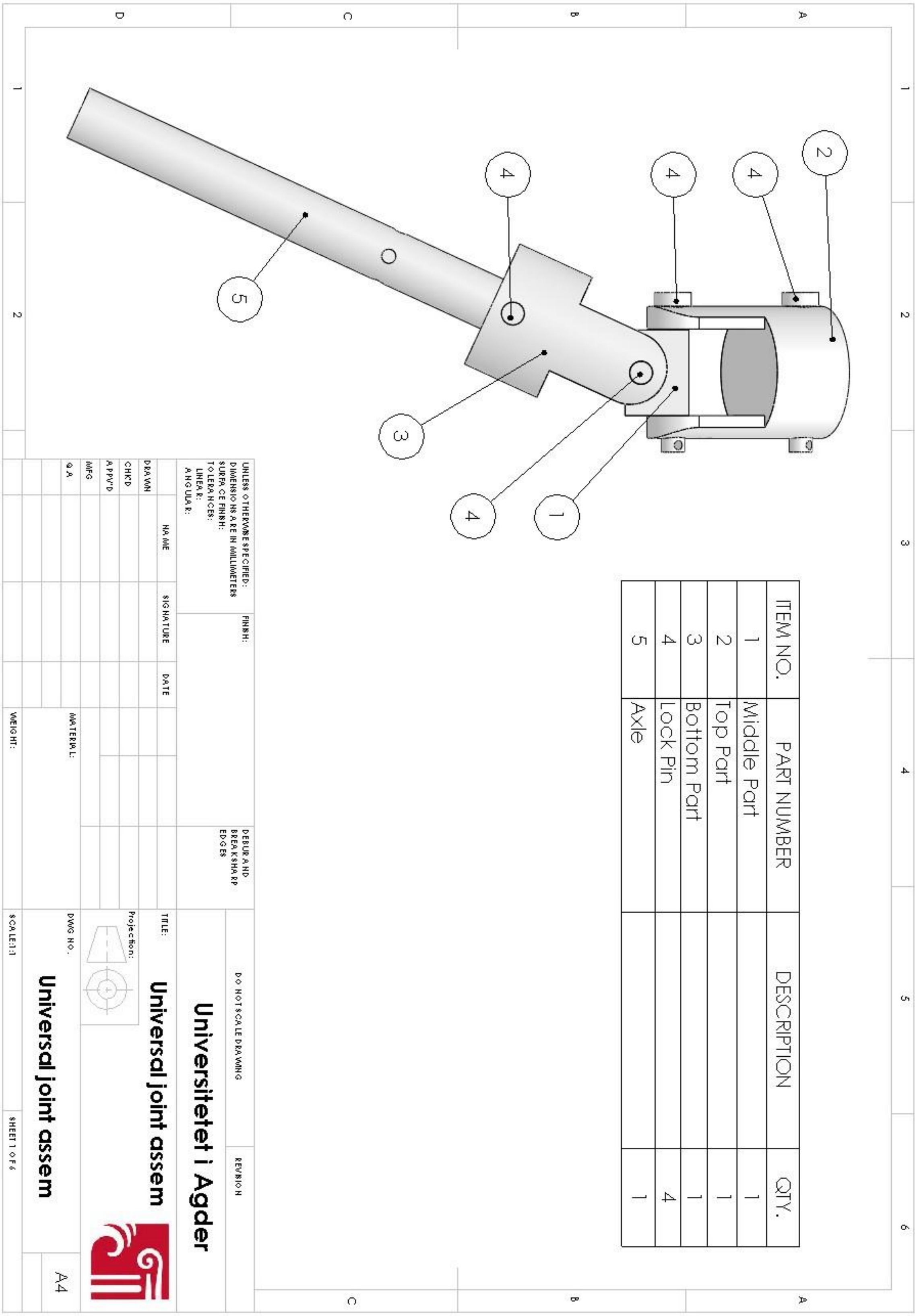
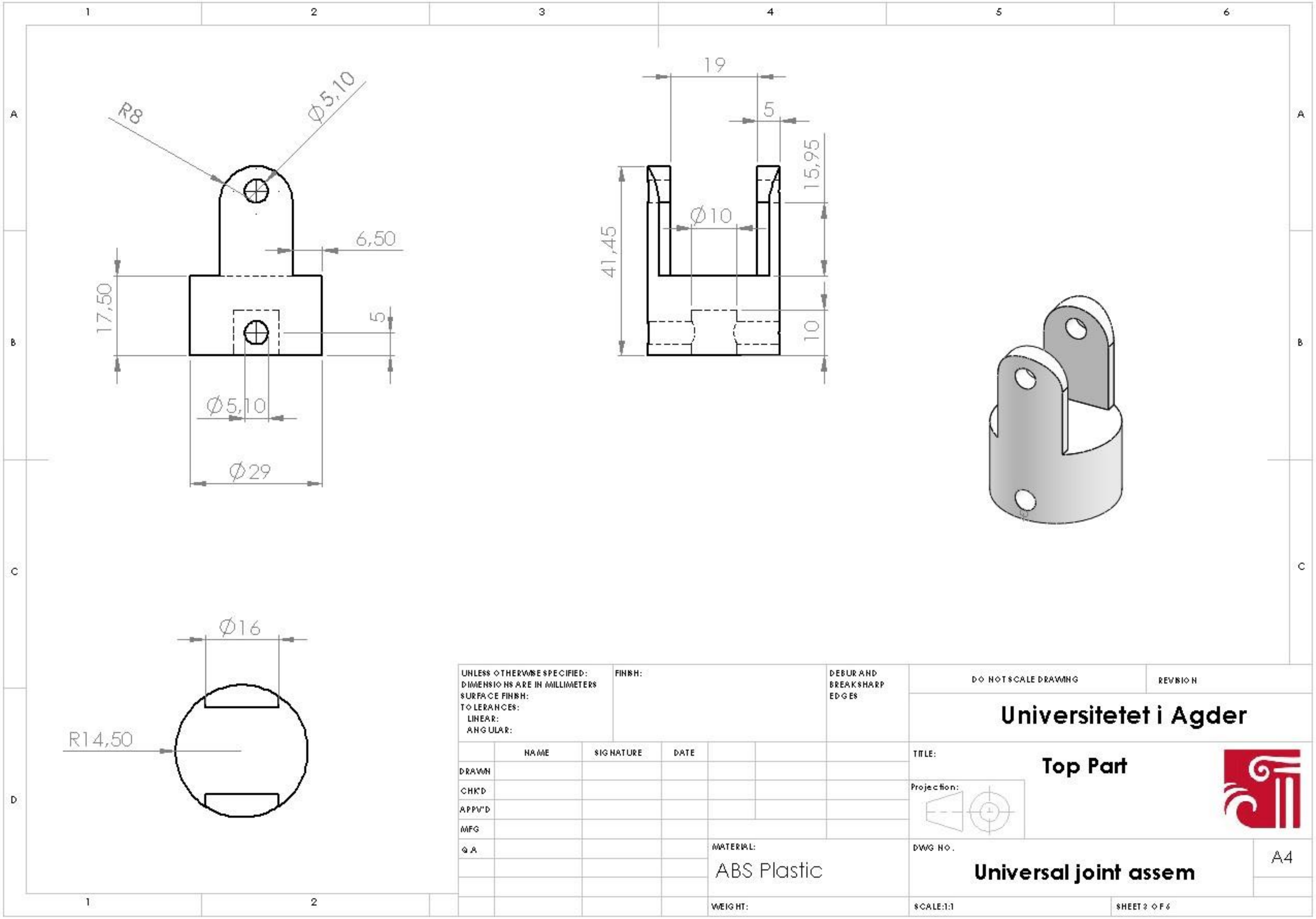
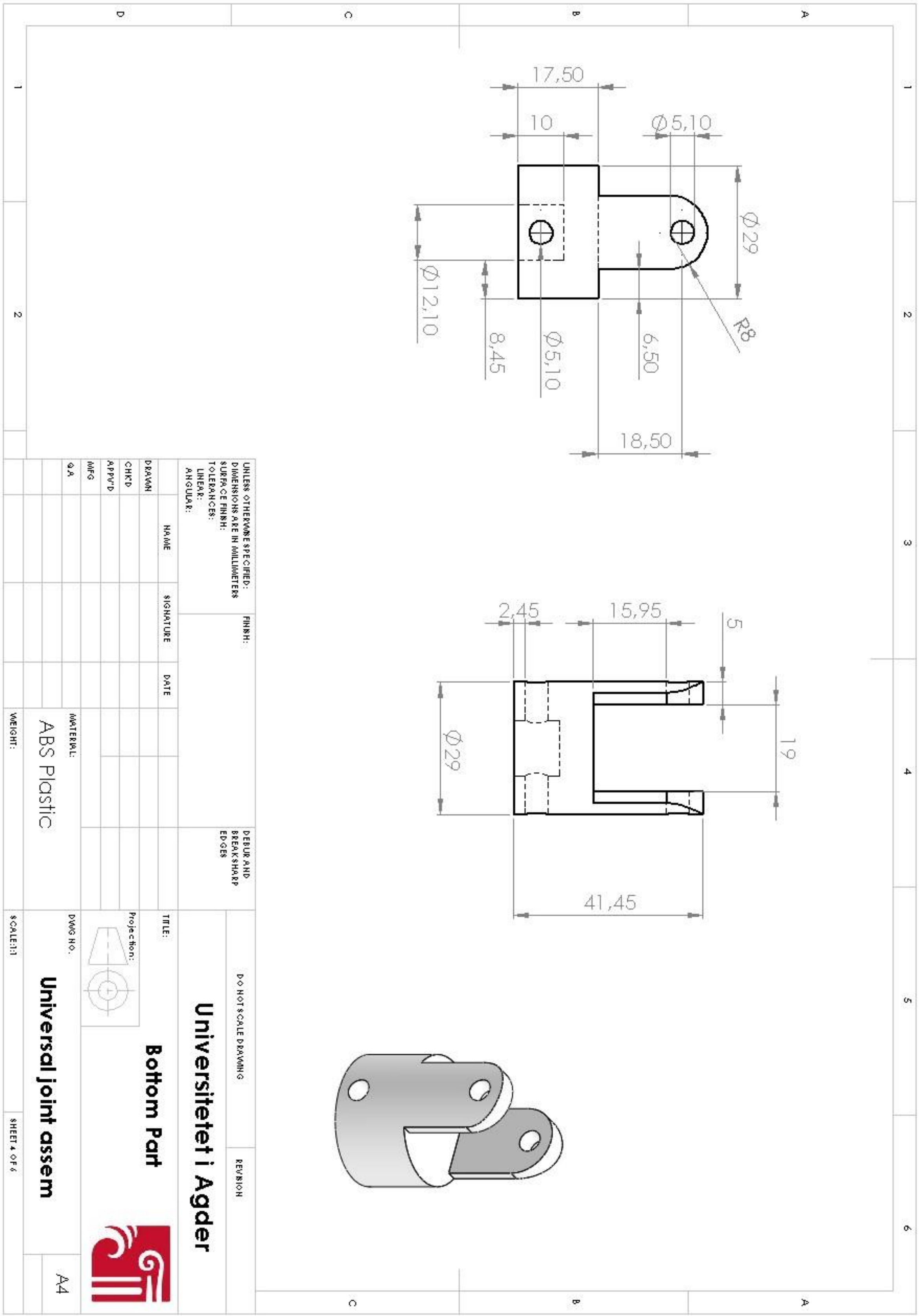
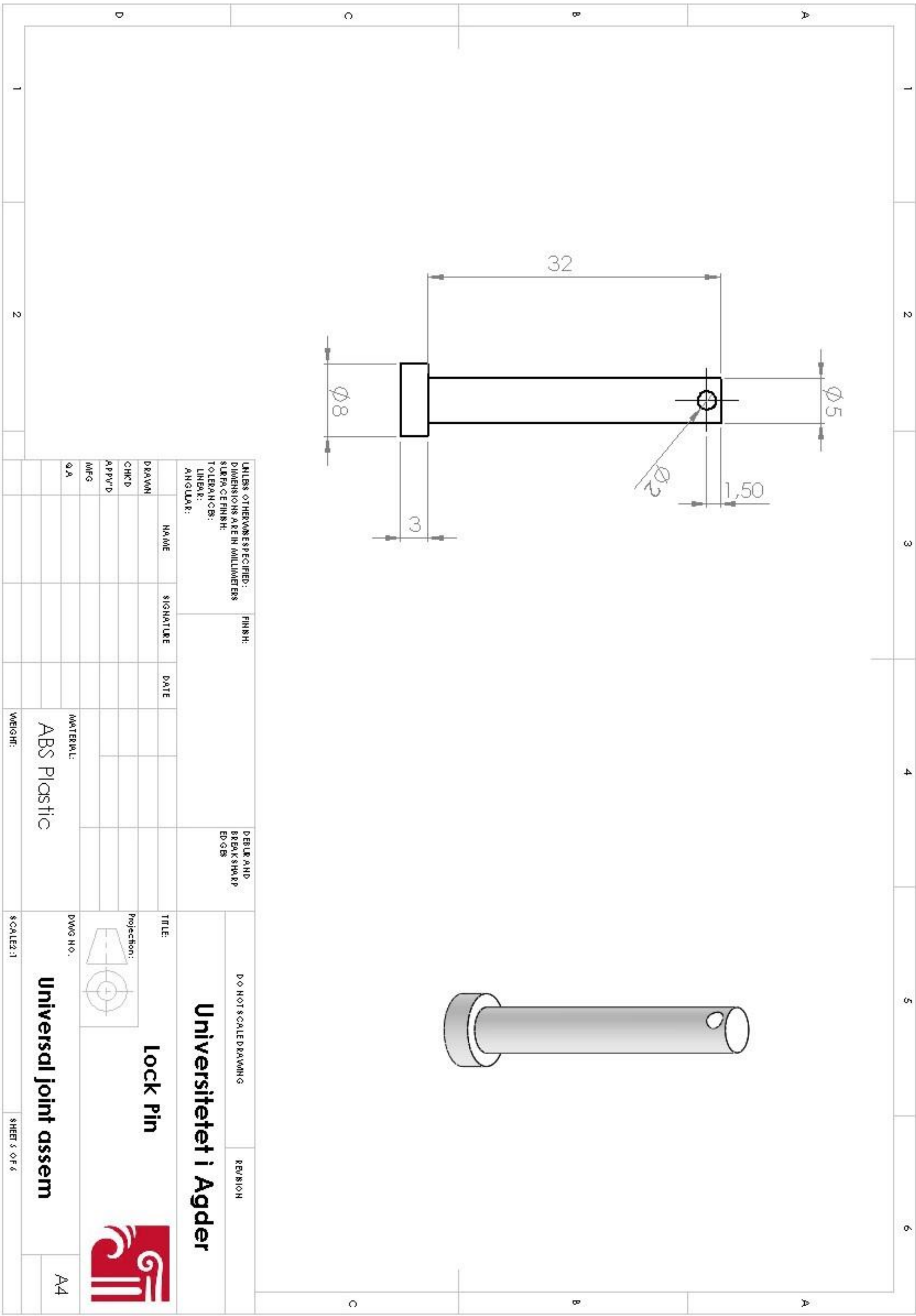
1: https://www.pjrc.com/store/prop_shield.html

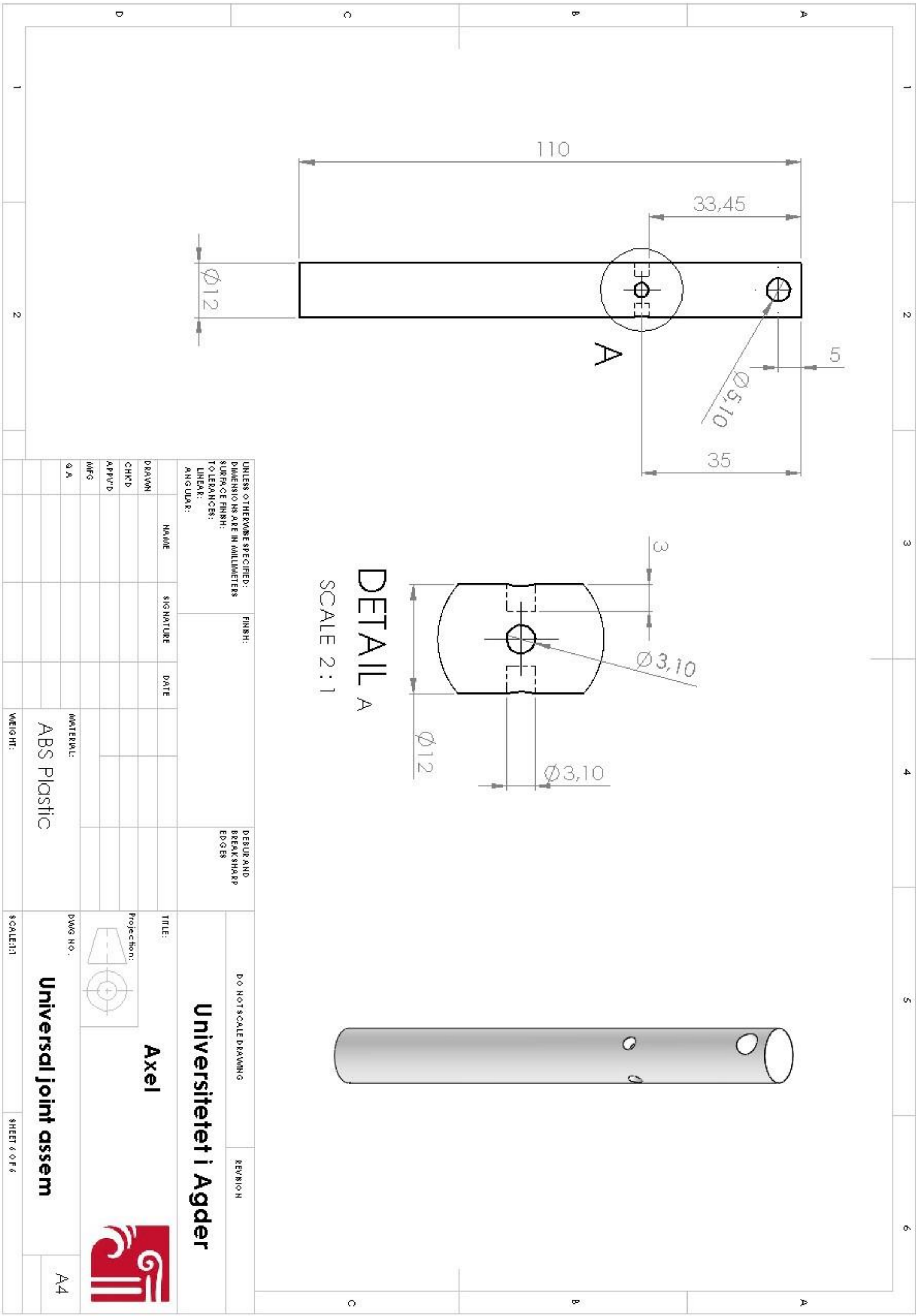
Universal Joint SolidWorks Drawings




R8
Ø5,10
6,50
17,50
5
Ø5,10
Ø29
19
5
15,95
Ø10
41,45
10
Ø16
R14,50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
ABS Plastic
WEIGHT:
Universitetet i Agder
TITLE:
Top Part
Projection:
DWG NO.
Universal joint assem
A4
SCALE:1:1
SHEET 2 OF 6


17,50
10
Ø5,10
Ø29
Ø12,10
8,45
Ø5,10
6,50
R8
18,50
2,45
15,95
5
19
Ø29
41,45
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
ABS Plastic
WEIGHT:
TITLE:
Universitetet i Agder
Bottom Part
Projection:
DWG NO.
Universal joint assem
A4
SCALE:1:1
SHEET 4 OF 6


32
Ø8
Ø5
Ø2
1,50
3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
ABS Plastic
WEIGHT:
Universitetet i Agder
TITLE:
Lock Pin
Projection:
DWG NO.
Universal joint assem
A4
SCALE:2:1
SHEET 5 OF 6


110
33,45
5
Ø5,10
35
Ø12
A
3
Ø3,10
Ø3,10
Ø12
DETAIL A
SCALE 2 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Universitetet i Agder
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Axel
Projection:
MATERIAL:
ABS Plastic
DWG NO.
Universal joint assem
A4
WEIGHT:
SCALE:1:1
SHEET 6 OF 6