University of Southern Denmark

MSc in Engineering - Electronics
Individual Study Activity

Developing the Swarm Bot

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1 Introduction

A platform for research of flocking behaviour in swarms of robots was developed throughout the bachelor's thesis, "Investigating Bio-inspired Object Avoidance in a Swarm of Mobile Robots" by Niels A. Hvid and Rasmus K. Stagsted. Throughout that project an analysis was carried out in order to determine the requirements of the system. This project aims to replace the Raspberry Pi with an FPGA platform, namely a Zynq platform. Using an FPGA/ARM combination is believed to better enable the use of swarm algorithms. Additionally, since the completion of the bachelor's thesis, a new type of microphone has been procured. This type is digital, as opposed to the previous analogue microphones. Much of the electronics developed for that project is developed so as to work around the shortcomings of the Raspberry Pi, as well as the amplifier circuits required for the microphones. This project will redesign the electronics where necessary in order to accommodate the changes on the platform.

2 Analysis

This analysis will seek to expand on the analysis carried out in the aforementioned thesis. Some of the conclusions reached are no longer valid due to the new platform. It is necessary to determine which parts will need redesign and possibly, what new features will need to be added altogether.

2.1 Mechanical Platform

The chassis, battery and motors, including their encoders remain unchanged and as such will not be discussed further in this context.

2.2 Microphones

As mentioned, a new set of digital microphones has been procured for use with this robot. The previous electronic circuits developed include an amplifier section for the analogue microphones. This is no longer necessary. The analysis did find, however, that the multilateration algorithm is more robust when the microphones are further apart, therefore the new microphones should be placed towards the corners, as was done with the previous microphones.

2.3 Click Generator

Previously, it was attempted to generate a click using a piezo transducer. The attempt did not manage to produce a sufficiently loud click. A piezo transducer deforms when a voltage is applied to it. A higher voltage increases the deformation. By repeatedly pulsing the transducer with a sufficiently high voltage, it should be possible to generate a sound. Some type of circuit will have to be used to generate the necessary voltage spike.

The sound of a Piezo transducer is amplified when placed in a plastic housing with a small hole to let the soundwaves out. This housing and the size of the hole should be designed to amplify the specific piezo transducer's resonant freqency. Designing such a housing is infeasable, considering how cheaply a finished product can be procured. A piezo element is generally designed to generate sound with a specific frequency. This can be seen by inspection of the frequency response curve of a piezo transducer. A depiction of a typical response curve can be seen in figure 2.1

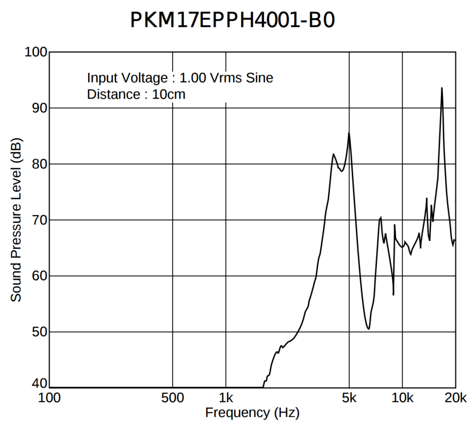


Figure 2.1: Typical frequency response of a piezo electric transducer. This particular model is most effective at approximately 5kHz and 18kHz.

Generally there are a range of frequencies around the resonant frequency that are at a much higher sound level than the rest of the frequencies. Frequencies not in close range of the resonant frequencies are often attenuated by decades of dB. This makes a normal piezo unfit for generating a click sound as this is approximated by a short frequency sweep. Another option is the piezo speaker that is designed to have the same flat frequency response curve as an ordinary speaker. It is therefore more fit to produce a clicking sound by making a frequency sweep. An ordinary speaker can also be used, but generally they consume much more current to produce the same sound. It was choosen to order three different kinds of sound generators to experiment with sound loudness, clicking sounds and power consumption.

- Piezo element with plastic housing and internal drive circuit [10].
- Piezo speaker in plastic housing without drive circuit [11].
- Miniature speaker [12].

Piezo Element with Internal Drive Circuit

This element produces a sound with a constant frequency just by connecting it to a DC power supply. This is very simply and allows for a minimal interface, but the internal drive circuit makes it impossible to produce a frequency sweep.

Piezo Speaker

This Piezo speaker is designed to have a more flat frequency response and is therefore suitable for producing a frequency sweep. An external drive circuit needs to be developed to test the device as a drive circuit is not included with this product. The developed circuit can be seen in figure 2.2.

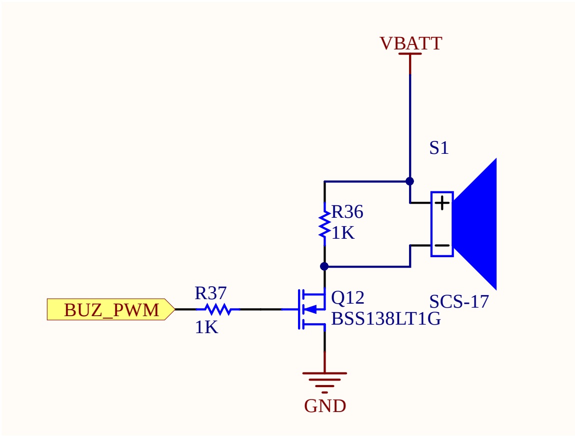


Figure 2.2: Schematic of drive circuit for piezo speaker.

A mosfet controlled by a `PWM` pin is toggling current from `VBATT` to `GND` and thereby controlling the sound generated by the piezo. By changing the dutycycle of the `PWM` signal the volume produced can be controlled. A 50%

dutycycle yields the highest volume. A resistor is placed in parallel with the piezo speaker as it is capacitive and needs to discharge when the mosfet goes off. The resistor in front of the mosfet is needed to limit the current from the `PWM` port.

In experiments with the circuit and the piezo speaker, the `PWM` port was connected to a frequency generator set up to do frequency sweeps. This produced loud and clear clicks.

Miniature speaker

The miniature speaker, as the piezo speaker, needs a drive circuit. The circuit from figure 2.2 was used again and the same frequency generator was used. In this setup the miniature speaker also produces clicks that was audible, but the sound produces was of significantly lower volume. Which was also expected.

Conclusion

It was chosen to use the Piezo speaker with the developed drive circuit as it has the capability of producing a click sound and it produced a significantly greater volume than the miniature speaker in the same setup. Besides that it produces no electro magnetic noise as the miniature speaker does.

2.4 PWM Generation

The Raspberry Pi previously used has support only for one PWM channel. In order to fully control the robot, four channels are required. For this reason it was chosen to use an external PWM generator which can be communicated with through I2C. Moving to an FPGA based platform, this is no longer necessary, as it is possible to add as many PWM channels as required in VHDL.

2.5 Motor Driver

The BD6222HFP was chosen as the motor driver in the previous project. This is a full-bridge capable of continuously supplying sufficient power to drive the motors on the robot. This driver chip is maintained in the new design.

2.6 Current Limitations

A number of fuses were added to limit the current to the motors as well as the current draw from the battery. The battery however, includes a "safety board" which limits the maximum possible current draw, making this fuse irrelevant. The fuses on the motors can be excluded by instead running a check in software such that when a voltage is applied, the encoder signal must represent movement, or the voltage will be cut. Allowing overcurrent for a short period will not damage the motors and therefore this approach is acceptable.

2.7 Electronics Board

In order to accommodate the new electronics a new board will have to be designed. The board must support a number of components and circuits, listed below.

- **Motor controller:** The BD6222HFP, a full-bridge motor controller, is used to generate the drive signals for the motors.
- **Piezo:** Generating a click is done using a piezo transducer. A transducer with an external drive circuit will be used.
- **5V DC/DC Converter:** A DC/DC converter will be used to generate the 5V rail necessary to drive the embedded platform.
- **Connections:** A number of connections has to be present on the board. Passthrough for the microphone add-in board. Passthrough for the motor encoders. Connection for battery.
- **Debug LEDs:** Support for four LEDs for debugging is required. The necessary drive circuitry must be added.
- **Microphone board:** A microphone board has been developed at SDU, supporting up to four SPH0641LU4H-1 digital microphones. The board must allow for interfacing with this microphone board.

2.8 Power Calculations

In the previous project it was chosen to use linear regulators to supply the 5 and 3.3V rails. This project will analyse whether the added cost of using switch-mode converters is worthwile considering the possible extra battery life. It will be analyzed how much power is drawn from the 5V- and battery voltage-rails and what the expected additional battery life will be when using a switch-mode converter. It has been found that the DC/DC converter, `PTH08080WAH`, is suitable for this project and this component's specifications will be used for calculations.

5V Rail (VCC)

The following are powered by VCC:

- Microphones including circuitry, 11mA
- Zynqbased embedded platform, 500mA
- Two motorcontrollers, 5mA
- Six LEDs, 120mA

The current estimation of the microphones, motorcontrollers and LEDs are based upon datasheet values. Whereas the current estimation for the Zynqbased platform is based upon current measurements from a previous project. The current drawn of the Zynq is obviously dependent on the program running, the amount of logic in use, the number of GPIO in use and so on. All of these are unknown at time of writing. 500mA is by no means the maximum current draw that can be expected from a Zynqbased platform, as the MicroZed draws 1.7A at 85% utilization [4].

These estimates bring the total current draw of the VCC rail to 636mA

Battery Voltage Rail (VBATT)

The motors will be running directly from VBATT. To measure the current drawn by the motors and motorcontrollers a small test was conducted. Three different voltages were applied to the motors using a laboratory power supply. Voltage and current measurements were made with the robot driving. The results are shown in table 2.1.

Table 2.1: Voltage, current and power of motors and motorcontrollers measured at different velocities.

Velocity	Voltage, [V]	Current, [mA]	Power, [W]
Low	1	220	0.2
Medium	5	305	1.5
High	8	350	2.8

The piezo speaker is powered by VBATT as well, but it produces sound only for a few milliseconds at a time and in addition, with a very power. For this reason, this current draw is neglected throughout the remainder of the discussion.

Power Dissipation

When using a linear voltage regulator the power dissipated in the component can be calculated using:

$$P_{LR} = (V_{in} - V_{out}) \cdot I_{load}$$

The power dissipation in the linear regulalator can be found using the current estimation at 5V and the fact that the battery has a nominal voltage of 7.4V:

$$P_{LR} = (7.4[V] - 5.0[V]) \cdot 0.636[A] = 1.5[W]$$

If a switching regulator is used the voltage conversion will have a significantly higher efficiency. The `pth08080w` has a typical efficiency of 93.5% at 5V [6]. The power dissipated in the DC/DC converter would be:

$$P_{SW} = V_{in} \cdot I_{load} \cdot (1 - \eta)$$

$$P_{SW} = 7.4[V] \cdot 0.636[A] \cdot 0.065 = 0.3[W]$$

The total power drawn at the 5V rail is:

$$P_{5V} = 0.636[A] \cdot 5[V] = 3.2[W]$$

Based on the measurements of voltages and currents of the motors and motorcontrollers, the power dissipated were calculated to be as in table 2.1. The total power usage can be calculated as the sum of the combined powers.

$$P_T = P_{reg} + P_{motor} + P_{5V}$$

Calculating the total power usage at low velocity and using a linear regulator yields:

$$P_{T,LR} = 1.5 + 0.2 + 3.2 = 4.9[W]$$

The total power at the three velocities is calculated using a linear regulator or a DC/DC converter and is shown in table 2.2.

Drive Time

The amount of energy the battery can store should be calculated in order to calculate the drive time of the robot. The batteries have a rated capacity of 2600mAH [9]. Converted to Joule:

$$E_{bat} = 2.6[AH] \cdot 7.4[V] \cdot 3600 = 69.3[kJ]$$

The drive time can then be calculated:

$$T = \frac{E_{bat}}{P_T}$$

Specifically for low velocity and using a linear regulator:

$$T_{LR} = \frac{E_{bat}}{P_{T,LR}} = \frac{69.3[kJ]}{4.9[W]} = 14143[s]$$

Which corresponds to 3.9h. The calculation is done for all scenarios and the results are shown in table 2.2. Finally the extra drive time obtained by using a switching regulator rather than a linear regulator is calculated and shown in percent in table 2.2.

Table 2.2: Total power and drive times using linear regulator or switching regulator. The obtained extra drive time by using a switching regulator is given in percent.

Velocity	$P_{T,LR}$ [W]	$P_{T,SW}$ [W]	T_{LR} [h]	T_{SW} [h]	% **more** T
Low	4.9	3.7	3.9	5.2	33
Medium	6.2	5	3.1	3.8	23
High	7.5	6.3	2.6	3.1	19

Using a switching regulator yields a minimum of 19% more drive time compared to using a linear regulator. On the basis of the results it is concluded that using a switching regulator is worth the additional cost.

Note that these results are very conservative estimates. The more power is being drawn from VCC, the more the benefits if the switch-mode converter would show.

2.9 Embedded Platform

Previously a Raspberry Pi was used to power the platform. As mentioned, it has been requested that the system is ported to a Zynq platform. Currently available to the authors are the Zybo, MicroZed and Zynqberry platforms. All three are based around the Zynq-7010 chip. A number of GPIO ports are required; seven pins for PWM for the motors, four pins for encoders, four pins for microphones, one for a piezo transducer and six for two RGB LEDs. This amounts to a minimum of 22 pins required. Below is an overview of the pros and cons of the two platforms.

- **Zynqberry:** As the name implies, this platform is made to conform with the physical layout of the Raspberry Pi. Using this platform would allow the reuse of the mounting solution developed for the Raspberry Pi. At 26 total GPIO pins, the Zynqberry can supply the required GPIO, but has nearly no pins if extra sensors or hardware is needed in the future. When searching for information on this platform it was found that there is not a lot of documentation made by neither the manufacturers or the community.

- **Zybo:** This platform is significantly larger than the Zynqberry. The different form factor requires that a new mounting solution is devised. Additionally, the increased size means that the board will have to be mounted above the tracks to avoid interference. While this is an inconvenience, it should not pose an issue in collisions as the edges of the board are still within the bounds of the robot. At 48 total GPIO pins, the Zybo can supply the required GPIO.

- **MicroZed:** This platform is within the confines of the robot platform, but has a different formfactor than the Raspberry Pi and therefore the mounting solution would need a re-design. It can be used as a stand-alone evaluation board, but needs to be combined with a carrier card if the PLs I/O pins are to be used. This is because the I/O banks on the Zynq chip need external powering, supplied by the carrier card. The 100 I/O pins on the MicroZed are accessed through two micro headers. The company behind the MicroZed also ship different carrier boards that can be used. If a custom carrier board is needed, circuitry for control signals and power needs to be developed. The online documentation for the MicroZed and carrier card is thorough and plentyfull including user guides, hardware guides, schematics and bill of materials.

The MicroZed is found to be the best choice for this project. Mainly because it is within the confines of the robot platform, gives access to 100 I/O pins and has solid documentation.

MicroZed Carrier Card

It was decided to design a custom carrier card for the MicroZed. A number of the requirements, which are outlined in this section, would result in additional boards having to be connected to the Avnet carrier cards anyways and so it was decided to combine all of the functionality on one board. As mentioned, this section will define the requirements for the MicroZed carrier card to be designed. Avnet provides a carrier card design guide [1] that describes some of the requirements. It describes how to utilize the Zynq chip on the MicroZed board. In this project, only a number of general I/Os are needed. Two ADCs are added for the possibility of utilising them at a later stage. This carrier card however, is expected to be used across a number of other, yet undefined projects. For this reason the card is designed in a more general fashion, rather than specifically for the swarmbot. Below is a list of the features the carrier card is designed to support.

- ADC, not used on the swarmbot.
- Motor Drivers capable of driving the swarmbot.
- Support for the digital microphone board, developed at SDU.
- Support for click generator.
- Passthrough of MicroZed GPIO.
- Debug LEDs.

These points are the features that the user will be presented with when using the board. In addition to these, a number of requirements are set in the afforementioned design guide:

- Anti-aliasing filters for ADC inputs.
- Power for MicroZed board and Zynq I/O banks 34 and 35.
- Correct power sequencing on boot/shutdown.
- Microheader connection to MicroZed.

The following sections will outline how each of these points are addressed in the design of the carrier card.

3 Design and Implementation

Avnet supplies a MicroZed breakout carrier card as a reference design for designing carrier cards. All of the schematics and layout documents are made publicly available and will, in conjunction with the carrier card design guide [1] form the basis for the design of the swarmbot carrier card.

3.1 Power Requirements

A carrier card needs to provide the following voltages for the MicroZed:

- $V_{in} = 5V$
- $V_{ccio,13}$ (Voltage logic level for I/O bank 13)
- $V_{ccio,34}$ (Voltage logic level for I/O bank 34)
- $V_{ccio,35}$ (Voltage logic level for I/O bank 35)

The different I/0 banks can be operated at different voltage levels. According to [2], the possible logic levels are 1.2V, 1.5V, 1.8V, 2.5V, and 3.3V.

It was chosen to supply all I/O banks with a voltage level of 3.3V as the vast majority of hardware used is available at this voltage. Additionally, it simplifies both the circuitry, as well as the use of the board.

$$V_{ccio} = V_{ccio,13} = V_{ccio,34} = V_{ccio,35} = 3.3V$$

The schematic and components used for the generation of the 3.3V rail is available in [3] and [13] and will not be discussed further as this is not the design of the authors. Since the swarmbot is designed to be powered from a 7.4V LiPo battery, the 5V rail has to be generated from this rail. As the voltage of a battery is not static, the converter will have to be able to supply the required voltage throughout the entire discharge cycle. In order to determine the maximum and minimum voltages of the battery, a discharge curve was created. More detail on the test done to create the curve can be found in section 4.3, but the result is repeated in figure 3.1 for convenience. Here it can be seen that the maximum voltage once fully charged is 8.4V while the minimum voltage when discharged fully is approximately 5.5V, as per the documentation of the battery [9]. Attempting to procure a DC/DC converter capable of maintaining a stable 5V output with an input voltage of just 0.5V higher may prove to be an expensive endeavour. The curve reveals that the voltage remains above 6V for ≈85% of the discharge cycle, even when discharging at 4A, far above what the carrier card will be capable

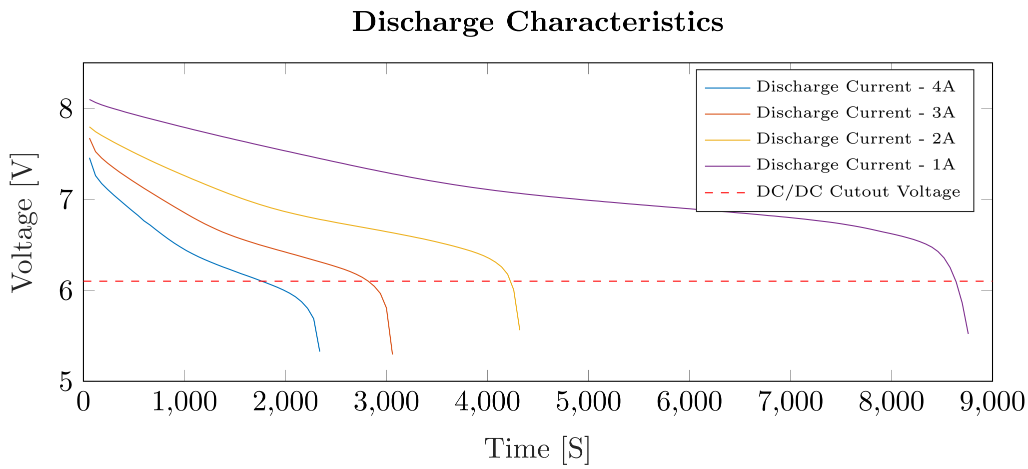


Figure 3.1: Discharge curve of the Ansmann 18650 2S1P Li-Ion battery used to power the swarmbot.

of handling. For this reason, this will be the target minimum input voltage of the DC/DC converter. According to [4] the estimated maximum power draw of the MicroZed is 1.7A at 5V. This is assuming 85% utilisation of PL and a conservative 80% efficiency of the converters. The estimate made by Avnet is made with the Zynq-7010 in the Xilinx Power Estimator (XPE) [5]. The MicroZed used for the swarmbot project, however, is equipped with the Zynq-7020, a slightly larger chip. Running the same scenario, 85% utilisation, in XPE reveals that the 7020 draws 2.3W, just 0.1W more than the 7010, a marginal difference in the total power budget. In addition to the MicroZed, also the debug LEDs and the microphone board are powered from this rail, adding an estimated ≈150mA extra current draw. In summary, these are the requirements for the DC/DC converter used for generating the 5V rail:

- Must function across the entire voltage range of the battery, 6V to 8.4V.
- Should be able to supply at least 1.85A at 5V.

Below is a discussion of the various choices made in the design of the circuitry of the 5V supply.

Designing the 5V Rail

The PTH08080WAH [6] closely meets these requirements at a maximum power delivery of 2A/10W/5V. The device is designed to have a wide input range, accepting `Vin`=`Vo`+1.1V to 18V. At the required 5V this translates to an input range of 6.1V to 18V. This is of course slightly higher than the desired 6V, but even at the maximum discharge rate, estimated at 2.2A-2.3A, with the MicroZed drawing its maximum current and the motors running at full speed, there would still be approximately 70 minutes of operation per charge. `Vo` is determined via an external resistor `Rset`. A formulae is provided to calculate the exact `Rset` needed for a given voltage, however a large table of common values is already calculated. According to this table, `Rset`=353Ω results in 5V. 353Ω is not a standard value, choosing 348Ω instead yields 5.01V, which is fine for this application.

The circuit appertaining to this component can be seen in figure 3.2. This is the standard application circuit as shown in the datasheet (figure 10 [6]). According to the datasheet, the minimum recommended input capacitance is 100μF. Of the capacitors on the list of recommended capacitors, also given in the datasheet, the 20SVP150M was chosen. It is rated for 20V, sufficient for this application, and has a capacitance of 150μF.

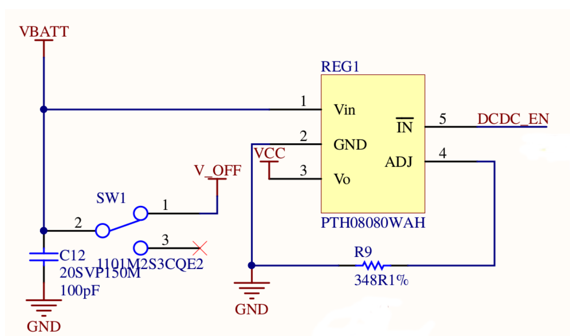


Figure 3.2: Circuit for generating `VCC`, the 5V rail.

3.2 Power Up Sequence

According the carrier card design guide, [1], a carrier card needs to adhere to a specific power up sequence in order for the MicroZed to turn on correctly. On power up, MicroZeds `PWR_EN` signals need to be pulled high on the carrier card, to enable power to the MicroZed. This is done with a pull-up resistor as shown in figure 3.3.

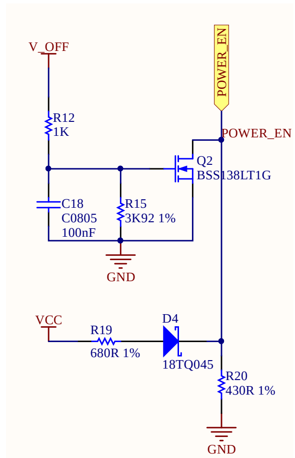


Figure 3.3: Circuit for proper power sequencing on MicroZeds PWR_EN.

When the MicroZed has powered up its internal DC/DC converters and is ready to receive voltage on its I/O banks `VCCIO_EN` will go high. `VCCIO_EN` has a logic level of 1.8V and the signal is therefore fed to a comparator that outputs a 5V signal to a DC/DC converter when `VCCIO_EN` is high. The DC/DC converter is configured to produce a voltage level of 3.3V that is connected to `VCCIO`. This circuitry can be seen in figure 3.4.

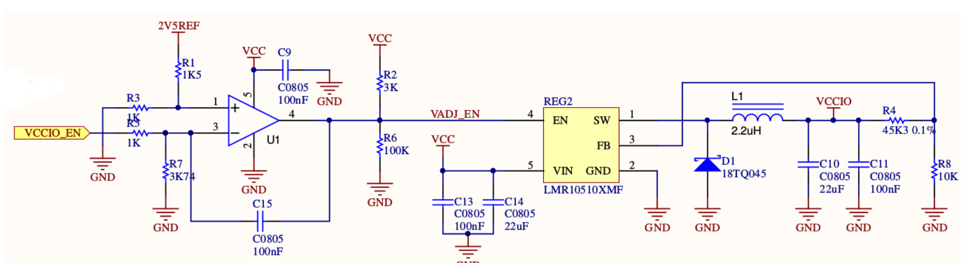


Figure 3.4: Circuit for proper power sequencing on I/O banks.

3.3 Power Down Sequence

A power down sequence is also described in [1], that needs to be followed to ensure signal integrity while powering down. The signals `VCCIO_EN`, `DCDC_EN` and `PWR_EN` should be pulled down in that order when powering off. The signals are pulled down by mosfets controlled by the `V_OFF` signal. When the power switch on the carrier card is in off mode, the battery voltage is connected to the `V_OFF` rail thereby turning the mosfets on and pulling the signals down. The correct sequence is maintained by charging capacitors on the gate side of the mosfets thereby creating a delay. Such a mosfet circuit is shown in figure 3.3.

3.4 Analog to Digital Converter

The Zynq 7-series FPGA's are equipped with a dual, 12 bit ADC, yet has only one dedicated analog differential pair, `VP_0` and `VN_0`. See figure 3.5 for an overview of the XADC architechture If more ADC channels are needed, any of the 16 auxiliary analog inputs (AAI) can be used. These are placed on I/O bank 35 which, as the rest of the I/O on the swarmbot carrier card, is supplied with `VCCIO`=3.3V. Once selected, a multiplexer applies each signal to the ADC's in turn. For this reason any signal on the AAI can never go above `VCCIO` to avoid damaging the inputs. On the swarmbot carrier card the dedicated analog pins, as well as three AAI pairs are routed to the ADC header (`CON4`). The signals `VAUX_P0` and `VAUX_N0` on `JX1` are the dedicated analog inputs and can be used on its own. The remaining three pairs are AAI and must be multiplexed if the user wishes to use them. It should be noted that due to the anti-aliasing filters, these pairs cannot be used as digital I/O on the swarmbot carrier card. These anti-aliasing filters are required in order to filter out high frequency noise in the differential pairs and should be placed as closely to the Zynq as possible, in this case, that is next to the connectors `JX1` and `JX2`, the main connectors to the MicroZed. Figure 3.6 from [?] illustrates a simple measurement setup and the anti-aliasing filter. `R1` and `R2` form a voltage divider, creating a 1V signal. `R5` is matched to the parallel impedance of `R1||R2`. Resistors `R3`, `R4` and the capacitor `C1` can be adjusted to change the settling time of the circuit. [7] gives equation 3.1 which can be used to calculate the settling time and by that determine the maximum sampling frequency.

$$T_s = \ln 2^{resolution+1} \cdot \left(\frac{R1 \cdot R2}{R1 + R2} + R3 + R4 + R5 \right) \cdot C_1 = 4.9 \cdot 10^{-6} [\mathrm{S}] \quad (3.1)$$

3.5 Buzzer Solution

As described in section 2.3 it was found that the best solution for creating a clicking noise on the platform was to use a piezo speaker with a drive circuit

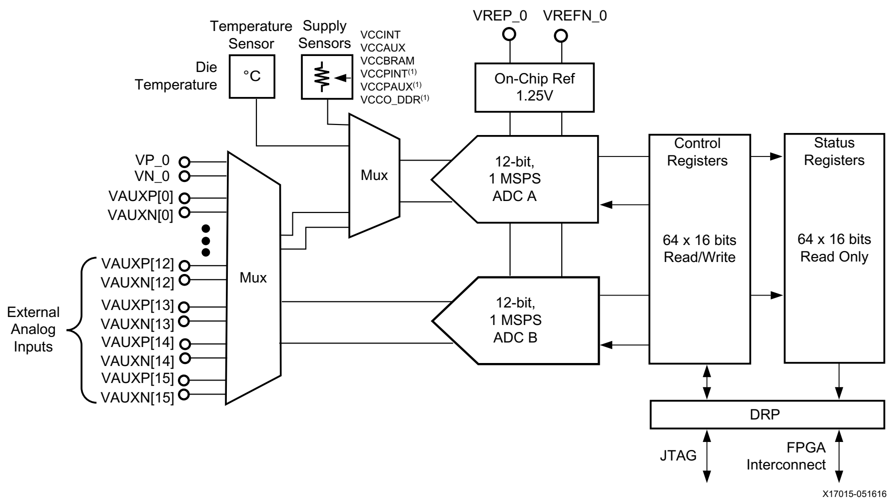


Figure 3.5: XADC Block Diagram from Xilinx ADC userguide [7].

and a `PWM` signal. But because there has been made no further investigation into what sound level is needed and what the frequency spectrum of the generated click is, it was decided to leave the circuitry out of the carrier card. Furthermore the sound source should be placed in the center of the robot to ease localization of the robot, but the design of the carrier card did not allow this. Therefore it was decided to include a header providing access to two IO ports, ground and `VBATT`. The header is shown in figure 3.7. Two IO ports are needed if differential drive of the piezo is wanted. Two holes were added to the carrier card to allow for fixture of the external piezo and drive circuit.

3.6 Pinout

The complete pinout can be found at [15] but a few cases are mentioned here for completeness. Some pins on the GPIO headers, (`CON5, CON6`) are routed to multiple locations, this increases the amount of available IO, but also introduces some possible traps for the user. Below is a list outlining the pins in question.

- `MIC_*:` All of the ports related to the microphone board are routed both to the microphone header, `CON3`, and one of the GPIO headers, `CON5`. These ports should not be used as IO if the microphone board is connected.

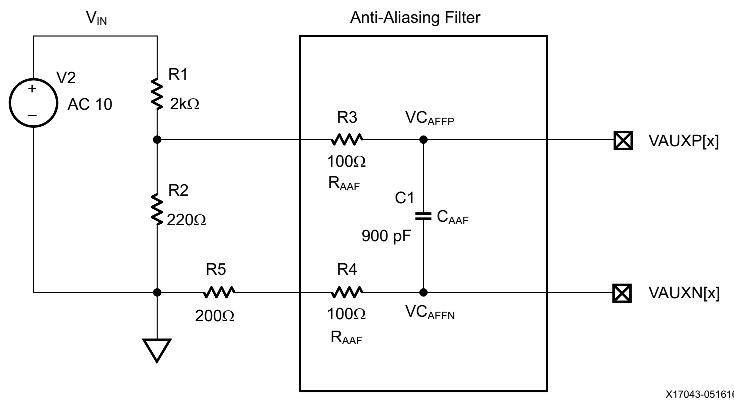


Figure 3.6: Anti-Aliasing diagram from Xilinx ADC userguide [7].

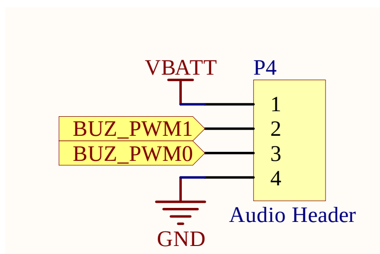


Figure 3.7: Audio header on the carrier card.

- `ENCxy`: These ports are wired to both the `CON1` or `CON2` for channel 0 and 1 respectively, and `CON6`. The connection to the GPIO header is for measurement only.
- `Mx_PWMy`: These ports are wired directly to the motor controller and should not be used as IO. The connection to the GPIO header, `CON6` is for measurement only.
- `BUZ_PWMx`: These signals are wired to the audio header, `P4`, and to one of the GPIO headers, `CON6`. These ports should not be used as IO if a buzzer is connected.

In addition to these signals it should be noted that the four signals marked `JXx_TPyy` are meant as test signals. They are GPIO ports but are placed on a seperate header to allow for easier access with measurement equipment.

3.7 Choice of Components

As mentioned, the choice of components is largely based upon the Avnet carrier card. Generally the same components were chosen but due pricing, availability or minimum order size, some components were changed to similar ones. Table A.1 and A.2 in appendix A explains what components were chosen and why.

3.8 Swarmbot Carrier Card Layout

The layout of the swarmbot carrier card was done using Altium Designer. From an early stage it was decided to have the board manufactured by a professional outlet as this would both greatly ease the layout process and, hopefully, minimize the potential points of failure in debugging process. The former, a simpler layout process, is expected for a number of reasons outlined below:

- **Mutlilayer Board:** Due to the size constraints of the board it is desirable to minimize the number of traces that are required to be routed on the board. Creating a 4-layer board means that the two middle layers can be `GND` and `VCC`, allowing every connection to either of these plains to be done using a simple via.

- **Feature Size:** The manufacturing method used at SDU is not reliable at tracewidths below 20mil and all vias must be drilled by hand, resulting in signal traces being far wider than what is actually required. The manufacturer used to produce the swarmbot carrier card [8] allows traces as low as 8mil and vias at 12mil.

- **Plated Vias:** The vias created by the manufacturer are plated with copper, meaning that, when using throughhole components the trace can be routed on both the top and bottom layers, without the use of additional vias. This greatly reduces the number of vias required for the layout.

Finally, as was alluded to in the previous paragraphs, the manufacturing process at SDU is not particularly robust and often requires several attempts before the correct combination of incantations, candles and luck is found and a fully functional board is created.

The board has three trace widths: 40mil for `VBATT`, 20mil for `VCCIO` and 8mil for the remaining signal wires. Mostly, the size of the board is due to the number of connectors that are required. For this reason there is plenty of room for components and generally capacitors and resistors were chosen with a 0805 footprint. The anti-aliasing filters described in section 3.4 are required to be placed close to the Bergstak connectors (the connector for mounting the MicroZed), which has a 0.8mm pitch. Using 0805 components here is infeasible due to size and it was decided to use 0402 instead.

4 Verification

Throughout this section the verification of voltage-rails, desired power-up and power-down sequences are made in order to avoid damaging the MicroZed when first connecting it. After these steps, the correct functionality of the MicroZed while connected to the carrier card is verified. In addition, the functionality of the different IO ports on the carrier are verified to ensure that the carrier card functions as expected. This section will describe the work done to debug and verify the functionality of the carrier card.

4.1 Carrier Card Debugging

After soldering of all the components it was found by measurement that the board was not functioning correctly. The debugging of the board will be described in this section.

The carriercard is designed to allow for measurement of the voltage-rails on the powerheader, `P1`, without connecting the MicroZed. Specifically the `J1` jumper should be present to simulate the `VCCIO_EN` signal from the MicroZed. All voltages on the powerheader were measured with an oscilloscope whilst toggling the power switch. `VCC` should switch between 0V and 5V, which it was not, leading to the conclusion that the circuitry handling the enable signal, `DC/DC_EN`, to the `REG1` DC/DC converter could be faulty. By inspection, it was found that the footprint of the mosfets `Q1`,`Q2` and `Q3` was wrong. A temporary fix was done by rotating the components, soldering them in place using signal wires. The power switch now toggled both the `VCC` rail and the 2.5V rail on and off.

Measurements of `VCCIO` during powerup showed that it immediately went to approximately 3.3V, but then discharged slowly towards zero voltage. The enable signal, `VADJ_EN`, was low even though the input voltages were measured to be as expected. This lead to a thorough examination of the component and the schematic and it was found that the input signals should be switches. The input signals were switched, which fixed the issue and made the `VCCIO` voltage follow the position of the powerswitch.

Measuring the voltage level of VCCIO showed it to be 3.4V rather than the expected 3.3V. This was due to placing a 47kΩ resistor as R4 instead of a 45.3kΩ as specified in the schematics. Even though 3.4V is within spec, it was decided to parallel the 47kΩ resistor was with a 1.5MΩ resistor to yield a resistance of 45.6kΩ and a voltage of 3.33V.

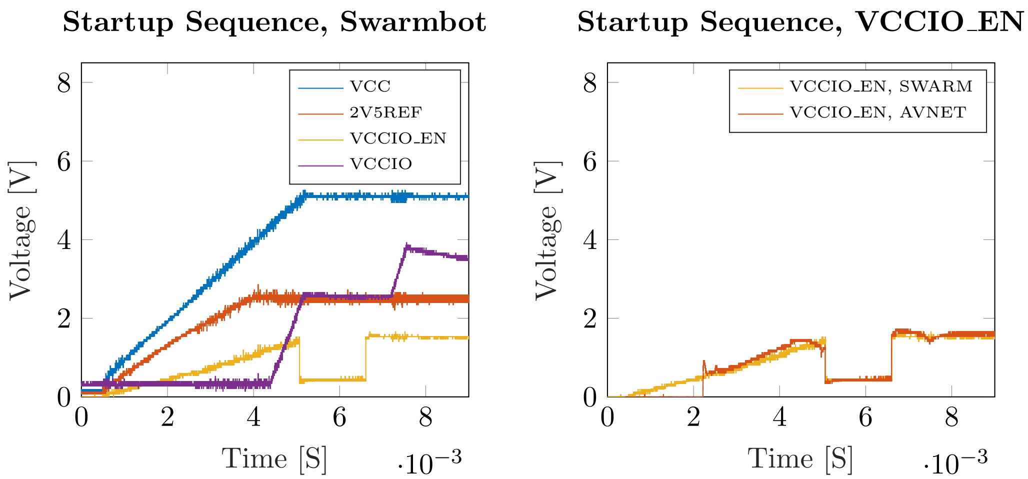
4.2 Carrier Card Power Sequencing

As described in sections 3.2 and 3.3 the carrier card is designed to provide a specific power sequence on startup and shutdown.

Startup

To verify the proper startup power sequence of the Swarmbot carrier card the signals VCC, 2V5REF, VCCIO_EN and VCCIO were measured and plotted in figure 4.1a. [1] dictates that POWER_EN signal must be pulled high on powerup, which was measured to be true. VCCIO_EN is produced by the MicroZed and is plotted in figure 4.1a. It can be seen that VCCIO_EN rises to its logical level, 1.8V, then goes low for a while and hereafter goes high, which is not the expected behavior. To determine if this behavior was caused by an issue on the Swarmbot carrier card the value of VCCIO_EN on the AVNET carrier was measured at startup when connecting the MicroZed to the AVNET carrier card. The two measurements of VCCIO_EN at startup is plotted in figure 4.1b. It can be seen that the two datasets are nearly identical concluding that the Swarm and AVNET carrier card yields the same behavior. As VCCIO_EN has the same behavior when connecting the MicroZed to the AVNET carrier it is believed to be non problematic.

The converter providing VCCIO should be enabled by VCCIO_EN. By inspecting figure 4.1a it is verified that when VCCIO_EN is high the converter providing VCCIO is enabled and VCCIO rises towards its final level of 3.3V. It is also verified that 2V5REF reaches its expected voltage level of 2.5V.



(a) Signals on the Swarm carrier card at startup.

(b) `VCCIO_EN` at startup on Swarm and AVNET carrier card. Data is shifted in time for clarity.

Figure 4.1: Measured signals at startup.

Shutdown

To verify the proper shutdown power sequence of the Swarm carrier the signals `POWER_EN`, `DCDC_EN`, `VCCIO_EN` and `V_OFF` were measured and plotted in figure 4.2. `V_OFF` switches from 0 [V] to the battery voltage, when setting the power switch in off mode. Then the signals `VCCIO_EN`, `POWER_EN` and `DCDC_EN` should be pulled low in that order. Figure 4.2 shows that to be true.

It should be noted that figure 4.2 only shows the first few microseconds after toggling the power switch. In figure 4.3 the first millisecond is shown and it can be seen that the switch creates quite a lot of bouncing on `V_OFF`. The bouncing could be removed by designing and inferring a low pass filter to the circuit, possibly with a Schmitt trigger circuit to generate a clean edge. This, however, adds additional cost and complexity to the board. Until deemed necessary, this will not be explored futher.

4.3 Discharge Curve of the Ansmann 2S1P

In an effort to quantify the possible runtime of the system, a discharge curve was made for the Ansmann 2S1P Li-Ion battery used in this project. Making the discharge curve was done by fully charging the battery using the

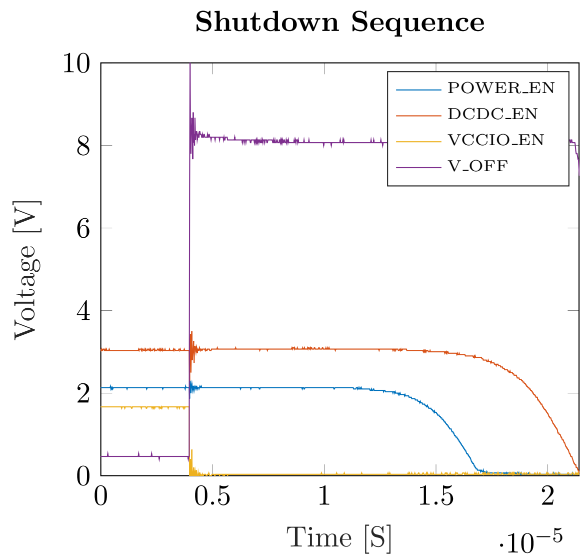


Figure 4.2: Measured signals on the Swarm carrier card at shutdown.

Swallow AC/DC 2 charger. This charger is capable of charging a variety of batteries, following the specific charge curve for each technology. As is expected from a 2-cell Li-Ion battery, the no-load voltage once fully charged is ≈8.4V. After charging, the battery is connected using a DC Electronic Load (model number: EA-EL 3160-60). The load is set at constant current mode and the current set. The battery is equipped with undervoltage protection that turns off the output once the voltage dips below 5-5.5V, in spite of this, it was decided to calculate the theoretical duration and run the test for that amount of time. At 2600mAh it will take 2600mAh/4000mA $= 0.65h$ or, in human terms, 39 minutes, to discharge the battery. For the sake of completion, the trial is repeated for 4, 3, 2 and 1A. The result can be seen in figure 4.4. As discussed in sections 2.8 and 3.1, the maximum current draw of the platform at the battery is approximately 2.2A. Although it should be noted that this is a theoretical maximum and that it is unlikely that this will actually be reached.

As with any battery, due to the internal resistance of the battery the voltage seen at the terminals depends heavily on the current being drawn. The platform will remain functional so long as the voltage remains above 6.1V, the minimum voltage required to maintain `VCC`, the rail supplying the MicroZed. The maximum speed of the motors will however decline as the battery dis-

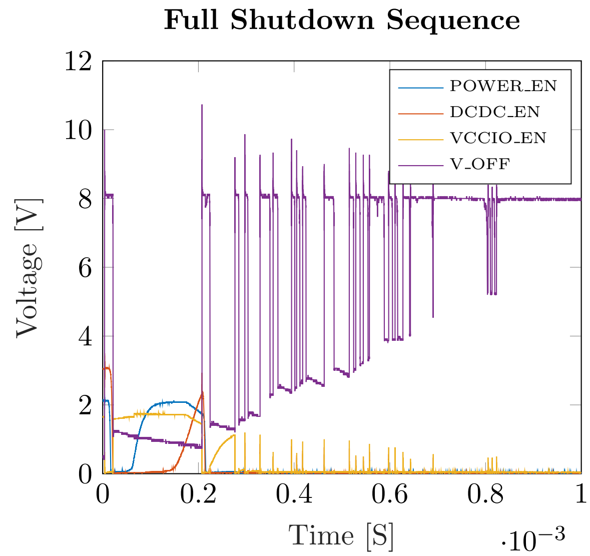


Figure 4.3: Measured signals on the Swarm carrier card at shutdown. Full sequence is shown.

charges. From table 4.1 it can be seen that discharging at 2A will give 4200 seconds or 70 minutes of use. Note that the graphs were acquired using two batteries in order to shorten the time required to finish the test. This may have a marginal impact on the results, but is assumed to be irrelevant.

Current [A]	4	3	2	1
Time [S]	1740	2820	4200	8640

Table 4.1: Table showing the discharge current and the time before the cutout voltage of the DC/DC converter is reached.

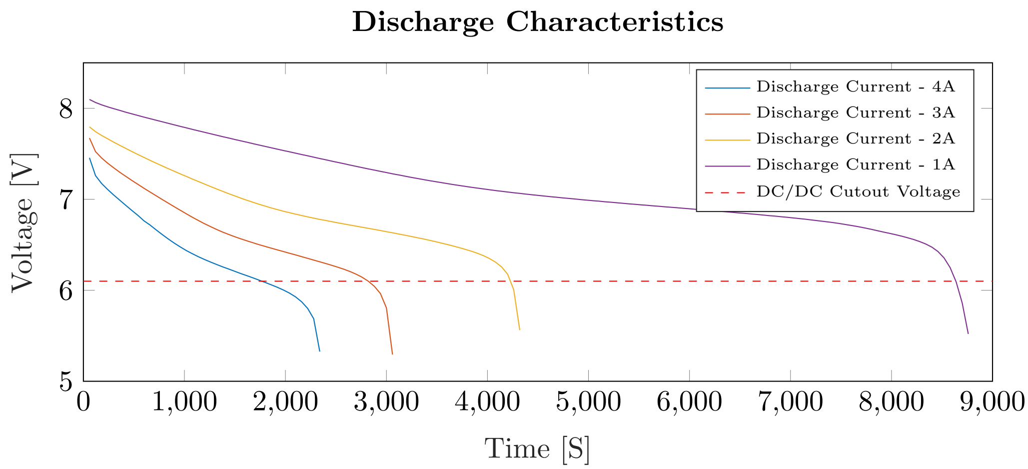


Figure 4.4: Discharge curve of the Ansmann 18650 2S1P Li-Ion battery used to power the swarmbot.

IO ports

To ensure the functionality of the IO ports and the MicroZed in general two tests were performed. In the first test a VHDL program was written to turn on an LED connected to an IO port. The test was successful, which led to the conclusion that the PL part of the MicroZed and the IO port are in working order.

In the next test a C program was written to make an LED blink. This test also succeeded, which led to the conclusion that both the PS and PL part of the MicroZed are functioning properly.

Conclusion

The problems on the carrier card were found and fixed through systematic debugging. The carrier card has the wanted powerup and powerdown sequence which was measured using an oscilloscope. Bouncing was seen by the power switch on shutdown. A low pass filter and a schmitt trigger was suggested to alleviate this issue, but it was decided not to implement the solution. A small experiment was conducted in order to get some data on the discharge behaviour of the batteries. This experiment revealed that the platform is likely to see at least 70 minutes of use, possibly more. The PS, PL and IO functionalities of the MicroZed when connected to the carrier were verified through tests.

5 Conclusion

This project develops on the work done in the bachelor thesis “Investigating Bio-inspired Object Avoidance in a Swarm of Mobile Robots” with the main goal of replacing the Raspberry Pi with a Zynq based platform. It was decided to keep the mechanical platform, battery, motors, motor drivers. Fuses were excluded as the batteries include a ”safety boards” and software can be used to protect the motors. Tests were made to find the sound producer best suited for making a clicking noise on the platform. It was found that a piezo speaker is the best choice, but it was not included on the board to allow for further testing, before making the final decision. A switch-mode DC/DC converter is included as tests and calculations showed that a minimum of 19% extra drive time is gained when using this component instead of a linear voltage regulator. It was decided to use the MicroZed Zynq platform rather the Zynqberry or the Zybo. The MicroZed was chosen as it has plenty of I/O pins, has a solid documentation and it is within the confines of the robot platform. When using the MicroZed a carrier card is needed to power the I/O banks and give access to I/O pins.

It was decided to design such a carrier card and include all electronic for the project on it. The PTH08080WAH converter was chosen and test showed that at least 70 minutes of use can be expected from the robot. It was chosen to supply all I/O banks with 3.3V and circuits were designed to ensure correct power up and power down sequences. Four pairs of anti-aliasing filters were added to enable use of the on-chip ADCs. The carrier card layout was done using Altium Designer and it was decided to have the board manufactured by a professional outlet to allow for a multilayer board, small feature size and plated vias.

After receiving and soldering the designed carrier cards, it was found that the board was not functioning correctly. Thorough physical debugging and fixing of errors led to a correctly functioning board. Correct power up and power down sequences were verified by measuring voltages on the included power header. Verification of main features of the board, such as I/O pins, was made by performing small ”Hello World” style programs in `C` and `VHDL`.

In hindsight, it is clear to the authors that the decision to develop a MicroZed carrier card resulted in many hours being spent on this, rather than developing a robot, but it led to a very valuable exercise in the development of a professional layout of PCB and, hopefully the beginning of a platform that can be used by future students.

In addition to the work enclosed herein, documentation such as pinout, schematic and layout, including the entire Altium project, can all be found on the `SDU-Embedded:swarm_bot` github [14].

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A Components

Table A.1: Components on the MicroZed carrier card and on the SwarmBot carrier card.

#	Comment	Qty	MicroZed Carrier Card	SwarmBot Carrier Card	Comment
1	Capacitor	7	0805ZD226MAT2A	GRM21BR60J226ME39L	Found equivalent capacitor as the original comes in packages of 3000.
2	DNP				
3	Capacitor	8	06035C104KAT2A	GCM21BR71H104KA02L	Found equivalent capacitor with 0805 footprint
4	Capacitor	4	04023C104KAT2A	C0805C103K5RACTU	Original was out of stock. Found equivalent capacitor with 0805 footprint
5	Connector				Equivalent ones will be found at the component storage at SDU
6	MicroUSB	1	1981584-1	47589-0001	Original needs to be bought in packs of 10. Found a cheaper equivalent one that can be bought in packs of 5.
7	DNP				
8	Schottky Diode	1	MBR230LSFT1G	SBR2A40P1-7	Original only ships in packs of 50. Found a a similiar diode with. Has a a higher forward voltage drop, but rough calculations estimate that it will only decrease the efficiency with one percentage point.
9	Schottky Diode	2	BAT54LT1G	SBR2A40P1-7	The SBR2A40P1-7 diode is better in all aspects and 25 of them are already bought for #8

Table A.2: Components on the MicroZed carrier card and on the SwarmBot carrier card.

#	Comment	Qty	MicroZed Carrier Card	SwarmBot Carrier Card	Comment
10	Jumper		969102-0000-DA		Is not needed on the Swarm-Bot Carrier Card.
11	Connector		5-146257-3		Is not needed on the Swarm-Bot Carrier Card.
12	Bergstak connector	2	61083-104400LF	61083-104400LF	
13	Inductor	1	SRN5020-2R2Y	SRN5020-2R2Y	
14	DNP				
15	MOSFET	2	BSS138LT1G	BSS138LT1G	
16 - 32	Resistors				Equivalent ones will be found at the component storage at SDU
33	Converter	1	LMR10510XMFE/NOPB	LMR10510XMFE/NOPB	
34	Switch	1	1101-M2-S3-C-Q-E-2	1101M2S3CQE2	
35	DNP				
36	Compara-tor	1	AP331AWG-7	LMV331QDBVRQ1	Original ships in packs of 50. New comparator is compati-ble, faster and ships in packs of 5.
37	Pro-grammable reference	1	TL431AIDBZR	TL431AIDBZR	
n/a	Capacitor for anti-aliasing filter	4	n/a	08055C102KAT2A	Similar to the one used in the MicroZed I/O carrier card and with the 0805 footprint
n/a	Resistors for anti-aliasing fitler	8	n/a		SDUs storage