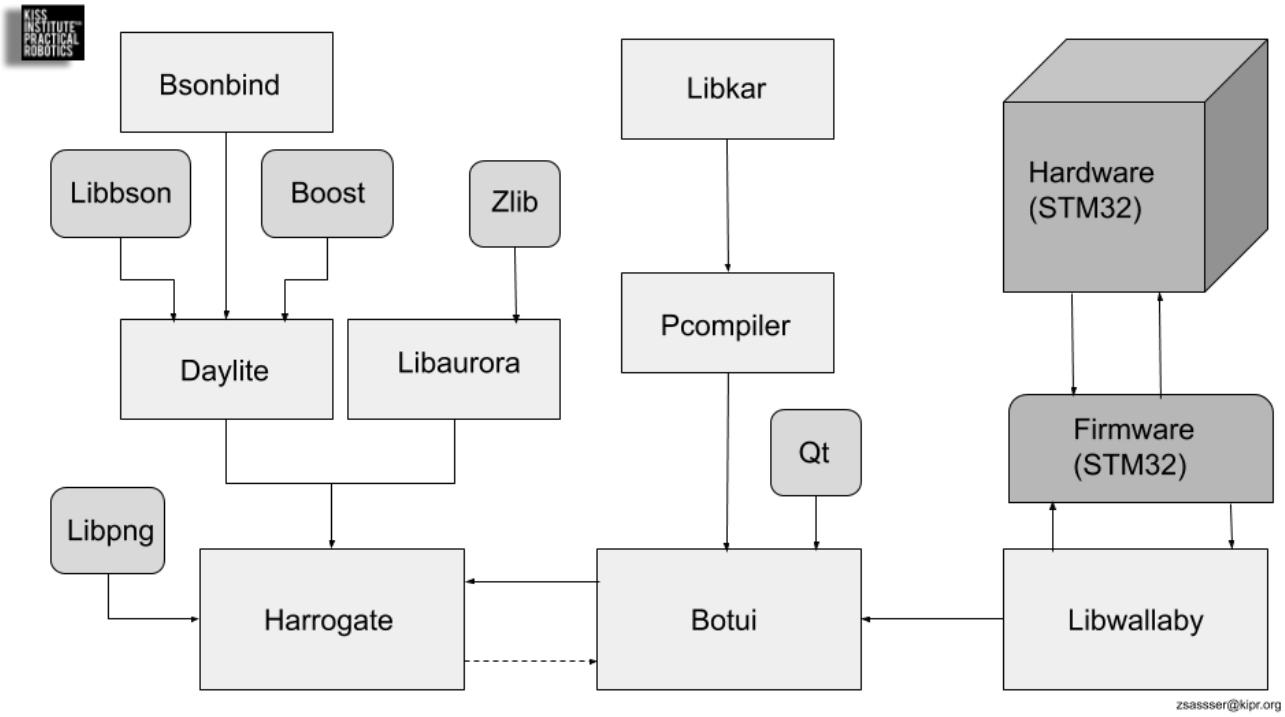
KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Author(s): Zachary Sasser

Overview of KIPR-Suite



Program	Description
Libwallaby	Library for interfacing with the controller hardware.
Botui	UI for Interfacing with the controller
Harrogate	Node.js webserver for KISS-IDE
Pcompiler	Used to compile KISS-IDE projects
Libkar	Archiving tool used by Pcompiler
Daylite	Networking Backbone for Harrogate
Libaurora	Graphics Library that interfaces with Daylite
Bsonbind	Utility that generates C++ structs for descriptions of BSON

Note: These program descriptions are over-simplified, visit their respective github pages/documentation for more information

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Operating System Installation:

Linux/MacOS/Unix:

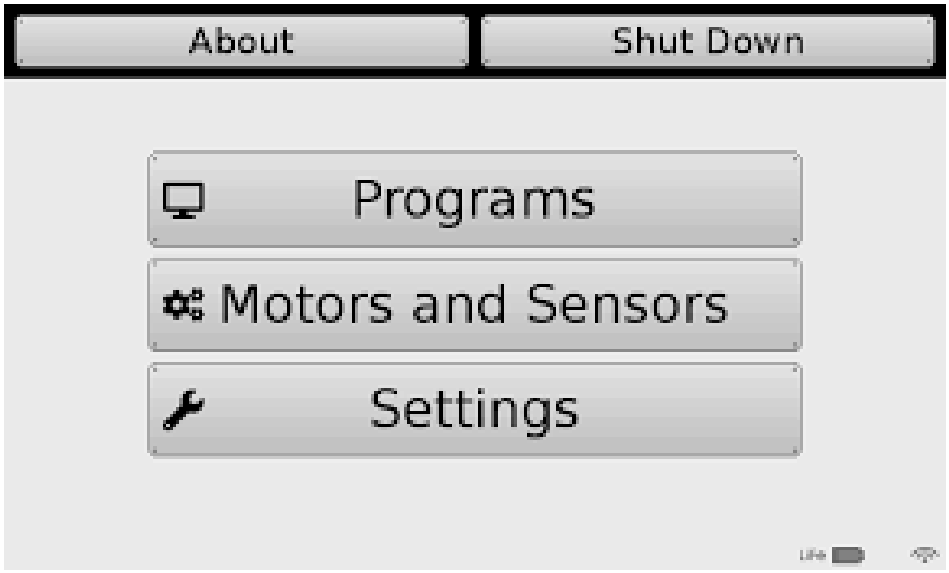
1. Download the latest KIPR-OS image: Click Here (Dropbox)
2. Most Linux Distros come with dd installed, but if not run the following:
    a. “sudo apt-get install gdebi”
3. Insert an SD card and find which pseudo-directory it is.
    a. “sudo fdisk -l“
    *b. Alternate: “*sudo df”
4. If your drive is /dev/sdb (/dev/sdb1 is a partition of sdb), then you would type
    a. “sudo dd if=”Wombat.img” of=/dev/sdb bs=4M status=progress

Windows (or Linux/MacOS):

1. Download Balena Etcher and install it to your PC: https://www.balena.io/etcher/
2. Download the latest KIPR-OS image: Click Here (Dropbox)
3. Open Balena Etcher and follow the simple prompts, choose your Wombat image and your SD card

On Startup:

The first time you boot up your pi, it will run fsck which is similar to CHKDSK in MS-DOS. Then it will reboot and boot into this screen; this is Botui. To get to the desktop, go to “*Settings⟶Hide UI”* or hit “*WIN+D”*.



KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Flashing the STM32:

When the Wombat is first assembled or the STM32 gets out of sync (DMA Desynchronized), you have to write the firmware binary to the STM32 processor (the device that handles the hardware). To flash the processor, navigate to /home/pi and then type “sudo ./wallaby_flash”, The output should look like this:

```
Wombat:~ $ sudo ./wallaby_flash
/sys/class/gpio/gpio17 - initializing gpio pins
echo 1 > /sys/class/gpio/gpio17/value
resetting co processor...
stm32flash -v -S 0x08000000 -w /home/pi/wallaby_v8.bin /dev/ttyAMA0
stm32flash 0.4

http://stm32flash.googlecode.com/

Using Parser : Raw BINARY
Interface serial_posix: 57600 8E1
Version      : 0x31
Option 1     : 0x00
Option 2     : 0x00
Device ID    : 0x0419 (STM32F427/37)
- RAM        : 192KiB  (8192b reserved by bootloader)
- Flash      : 1024KiB (sector size: 4x16384)
- Option RAM : 16b
- System RAM : 29KiB
Write to memory
Erasing memory
Wrote and verified address 0x080030f4 (100.00%) Done.

echo 0 > /sys/class/gpio/gpio17/value
resetting co processor...
```

If you are getting the “/sys/class/gpio/export: Permission denied” error:

- Try “sudo chmod +x wallaby_*” or “sudo chmod 777 wallaby_flash”
    - (Security doesn’t really matter for this)
- You are in the wrong terminal (use root not tty#)
- The GPIO cannot connect to the STM32 (usually because of a race condition)
- There is something blocking the output of the GPIO pins

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Botui Project Structure:

Folder	Function
src ("source")	This is for all the C++ files that handles any specific page's backend. The files are organized by the title of the page. The title in the src file should match the accompanying UI and include files (or anything really)
include/botui	This file is just a collection of header files. Qt objects have their function definitions here.
ui	This is for storing the XML/HTML-like .ui files that Qt uses for it's display. You can edit these files using software called Qt Creator. It is also possible to do it by hand with a text editor if you are used to dealing with markup languages.
rc ("Resource Collection")	RC is a file that is used for Qt icons, fonts, and other things like that. It allows us to use the Qt icon database for things like buttons, and technically also handles the font.
ts ("Translation Strings")	The ts files stores all the translations for text. Whenever we get a translator for a language, they will go and edit this file to replace it with the target language.
devices	These are header files that allow other parts of the project to access certain things on the controller. This is things from battery level to the serial number (stored on I2C registers). This is not how the program handles physical I/O like motors and digital ports. Libwallaby is responsible for handling the interaction with the STM32 directly.
dbus ("Desktop Bus")	Dbus is a software bus that allows you to communicate directly between processes. Botui (as of writing this) only uses it to access the network manager. This handles the access point that is broadcast by the Wombat.
debian	This is for building the project into a package

```
#Installing dependencies:
sudo apt-get install libzbar-dev libopencv-dev libjpeg-dev python-dev doxygen swig

# Create a build directory (inside botui) and change directory to it
mkdir build
cd build

# Initialize CMake
cmake ..

# Build
make

# Install
sudo make install
```

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Libwallaby Project Structure:

Folder	Function
src (“source”)	This is for all the C++ files that handle the direct interaction with the STM32, translating the simplified functions in the library to the complexity of hardware.
include	The include folder is split into KIPR and Wallaby. KIPR is the modern version for the Wombat and potential future controllers. Wallaby is the elder used by the Wallaby.
bindings	The way that python is ran on the controller, is by “compiling” it down to C using SWIG. The bindings file contains SWIG related files that are used for this process.
Doxygen	Doxygen is used to generate the help page documentation. When you add comments to a function added to the library, it automatically generates the item on the help page. Here is a link to the version that KIPR hosts (old): https://www.kipr.org/doc/index.html
debian	This is for building the project into a package
cmake	Stores extra cmake files when needed.
tests	These are unit testing programs.

Note: Harrogate is not included as it is mostly self explanatory in respect to Nodejs.

```
#Installing dependencies:
sudo apt-get install libzbar-dev libopencv-dev libjpeg-dev python-dev doxygen swig

# Create a build directory (inside libwallaby) and change directory to it
mkdir build
cd build

# Initialize CMake
cmake ..

# Build
make

# Install
sudo make install
```

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

How to build a Project

```
cd <Project Folder>
mkdir build
cd build
cmake ..
make -j4
sudo make install <project name>
```

<Project Folder>: The folder downloaded from github, the main folder for the project.
make -j4: Adding -j4 to make allows the compiler to use 4 threads, you can adjust this number.

How to convert to a (.deb)

```
tar -zcvf <project>.tar.gz <project folder>
cp <project>.tar.gz <project folder>
cd <project>
dpkg-buildpackage -b -rfakeroot -us -uc
```

Creating a (.img) of your OS State

1. Take the SD card out of the Wombat (from the Pi, can be accessed at the bottom of the case)
2. Plug the SD card into a Linux PC and navigate to terminal
3. Find the correct drive with “sudo fdisk -l” (l for “list”)
4. Use the command below to save to output to a (.img) or a (.bin)
5. *(optional)* Install PiShrink.sh and run “sudo pishrink.sh Wombat.img”

```
sudo dd if=/dev/sdb of=”Wombat.img” bs=4M status=progress
```

if ⟶“input file”

of ⟶ “output file”

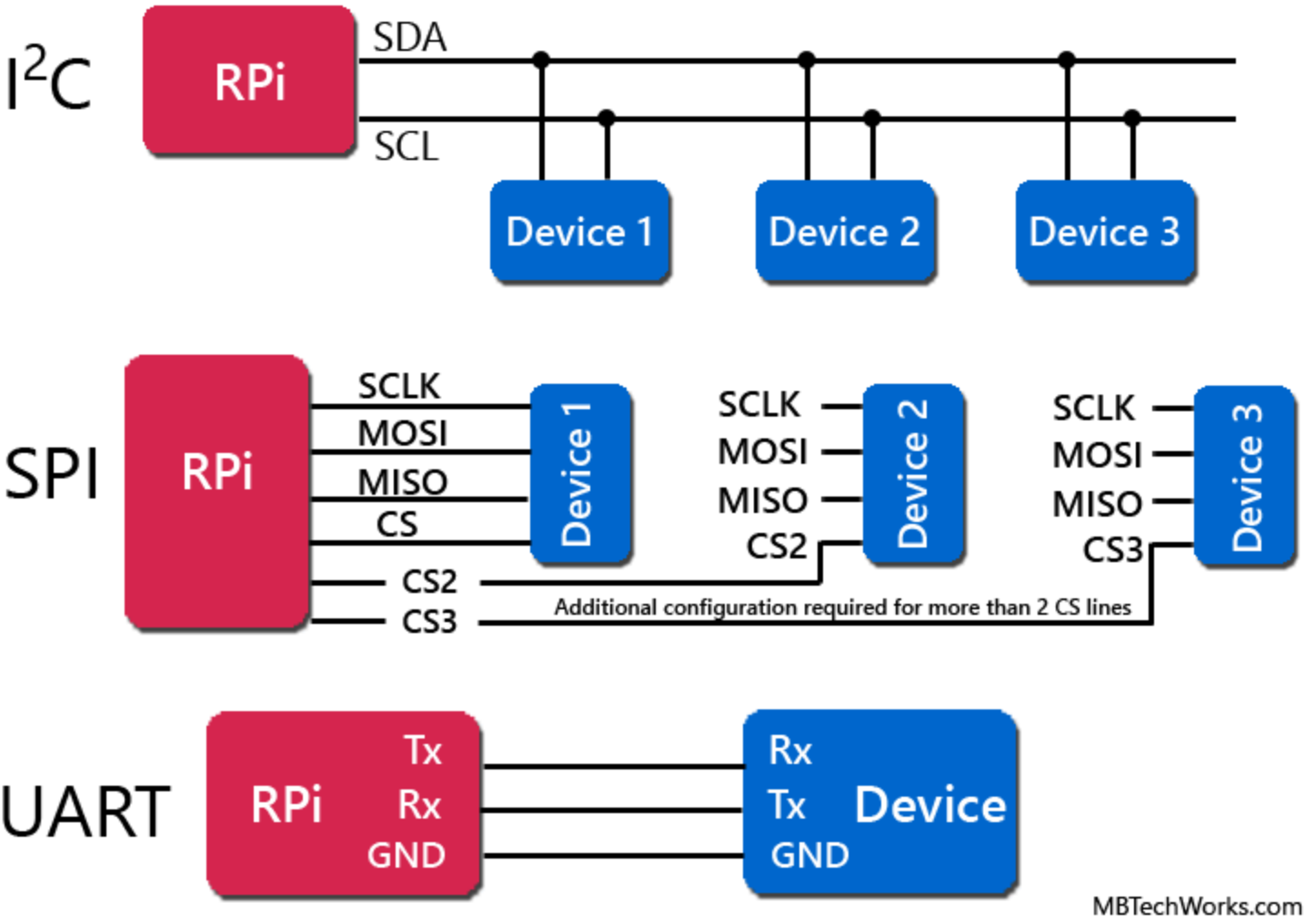
bs ⟶ “block size”

status=progress⟶ Show a progress bar/numbers

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Communication Protocols



The Wombat uses multiple communication protocols to access the STM32 as well as other devices. For example, the I2C lines are used to access the Touchscreen controller.

This is a good source for more information on these technologies:
https://www.seeedstudio.com/blog/2019/09/25/uart-vs-i2c-vs-spi-communication-protocols-and-uses/

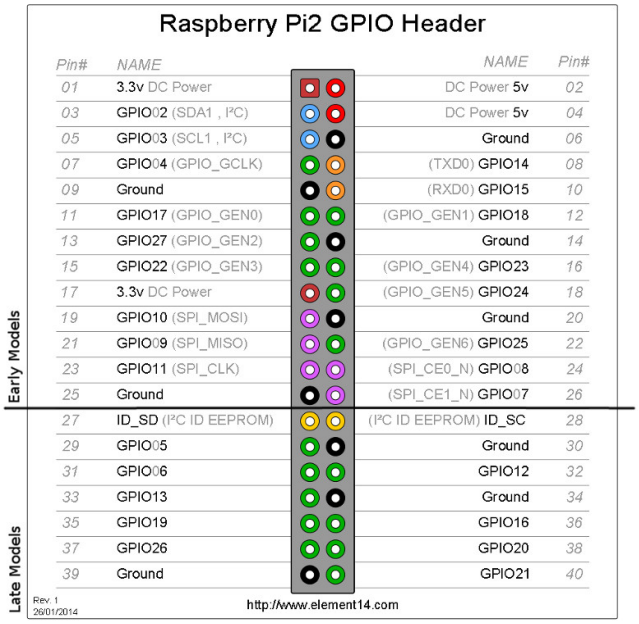
Note: The diagram creator made a mistake naming the CS lines. It is general practice to start naming at 0, ie CS0, CS1,etc.

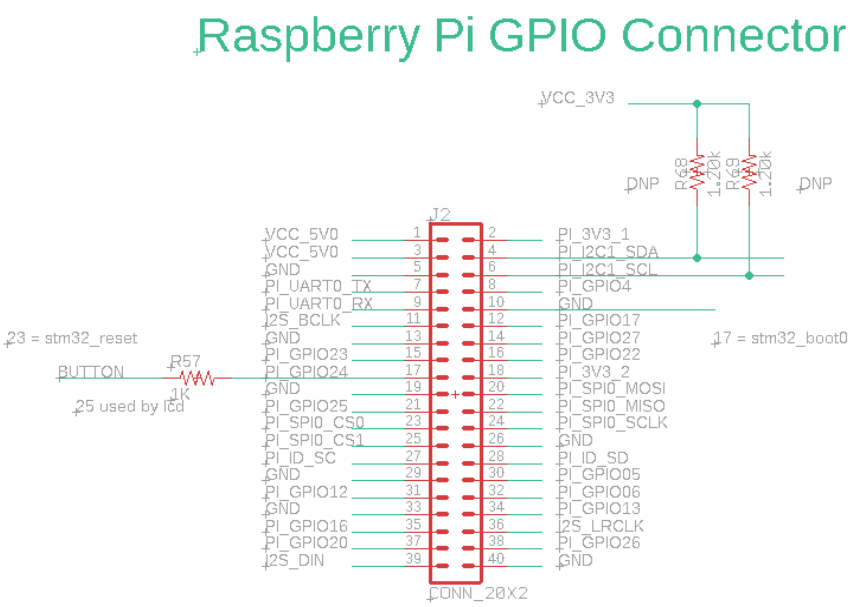
KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Hardware Overview

Pinout Table for Wombat J2 (Pi)





Keep In Mind: The GPIO number does not necessarily match the J2 Pin Numbering (some aren't GPIO), also the left diagram numbers are flipped.

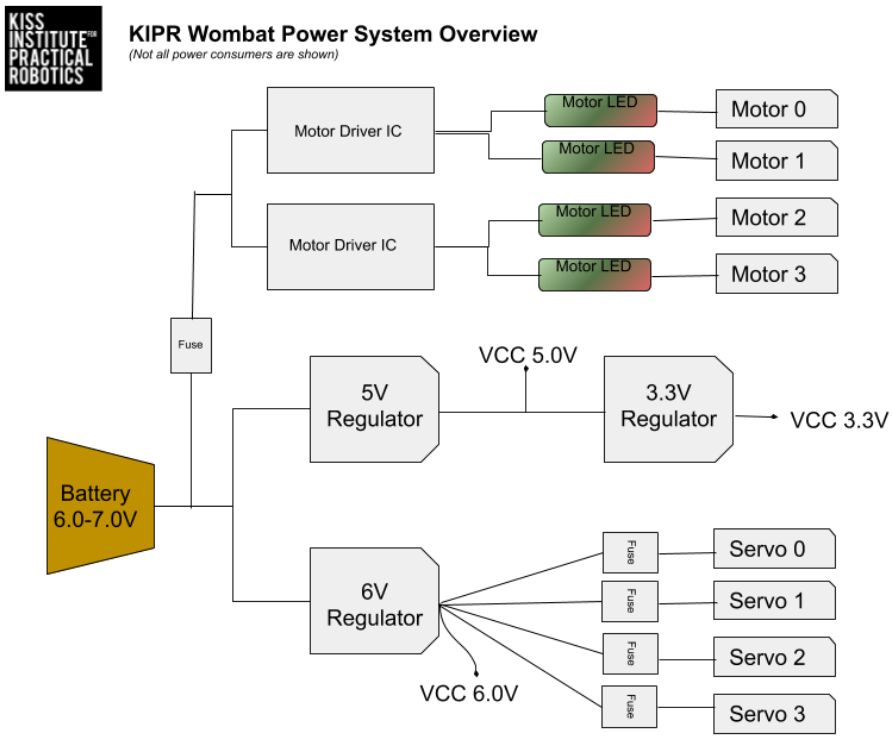
Pin	Description
1,3	Sourced by the 5V Regulator; Powers the Raspberry Pi (indirectly from the battery)
2,8,14 ,16,18 ,26-35 ,37,38	Not Actually Connected to Anything; These are potential for new features or modifications
4,6	Serial EEProm (Serial Number for Wombat); Touch Screen Controller; Real Time Clock (DNP);
7,9	STM32 UART Communication; https://github.com/kipr/Wombat-Firmware for more information.
11	I2S line for audio circuit (DNP)
12	Controls the boot setting of STM32 (2 bit, Boot0 and Boot1 which is pulled low),setting the mode "Boot from User Flash"
15	STM_RESET, This will reset the STM32; For specifics on what that means, see datasheet U37
17	Takes the physical button input (GPIO set to input mode), The button is also connected to Pin 35 of the STM32.
20,22, 23,24,	SPI Communication with the STM32. Despite having two select lines only the STM32 is connected, so it is possible to add more SPI devices in the future.
25	Receives touch detection from the touchscreen controller (U$8). This was intended as the CS1 Line for the SPI communication, but as there is only one device (and CS0 can handle 2), it is not needed.
36,39	Intended for speaker circuit LRCLK and I2S_DIN but was removed during development (DNP)

*DNP = Do Not Place, The component/circuit is **not** soldered on and the pads are empty in production*

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Power System Overview



VCC_5V0 (5 Volt Regulator Source)	Raw Battery
Raspberry PI (Via J2 Connector)	Battery Level Measuring Circuit (STM32)
3V3 Regulator (U7)	Power Switching Circuit
Servo Controller	No Fuse Battery
Speaker and Amplifier (DNP)	6V Regulator (U72)
HDMI Output (Pi's 5V source which comes from VCC_5V0)	5V Regulator (U73)
VCC_3V3 (3 Volt Regulator Source)	Fused Battery
LEDs (Red Power LED and Yellow Warning LED)	Motor Driver Circuits
Push Button (used for LOW signal)	VCC_6V0 (6 Volt Regulator Source)
Digital Ports (used for HIGH signal)	Servos (Fused)
Analog Ports (Used for HIGH signal)	
Real Time Clock and Coin Cell Charging (Not Used)	
Servo Controller	
Motor Back EMF Measurement	
I2C Registers	
Inertial Measurement Unit (IMU) (Accelerometer, Magnetometer, and Gyroscope)	

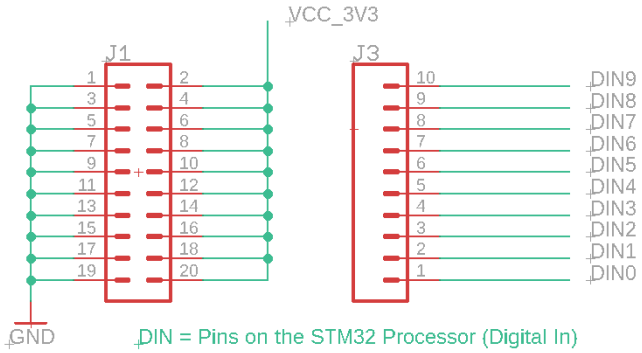
This document will not dive into the specifics of the schematic such as how the Regulator circuits work
For more information on hardware, email zsasser@kipr.org

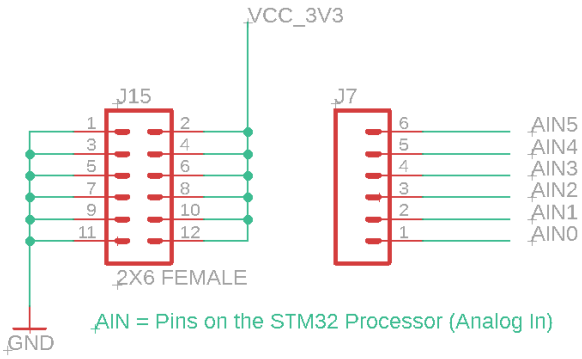
KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Sensors (Analog/Digital)

All botball sensors can be thought of as either a button (digital) or a potentiometer (analog). Digital sensors are fairly self explanatory, when it needs to output “1” it connects the measurement pin to the positive side, when it needs to send a “0” it connects it to the ground.





Analog Sensors take the voltage across the power pins and output some voltage between them. The power pins have GND (0V) and 3.3V attached, so the output will be between 0 and 3.3V. For example, if a light sensor wants to report half the maximum light level, it will send 1.65V out the measurement pin.

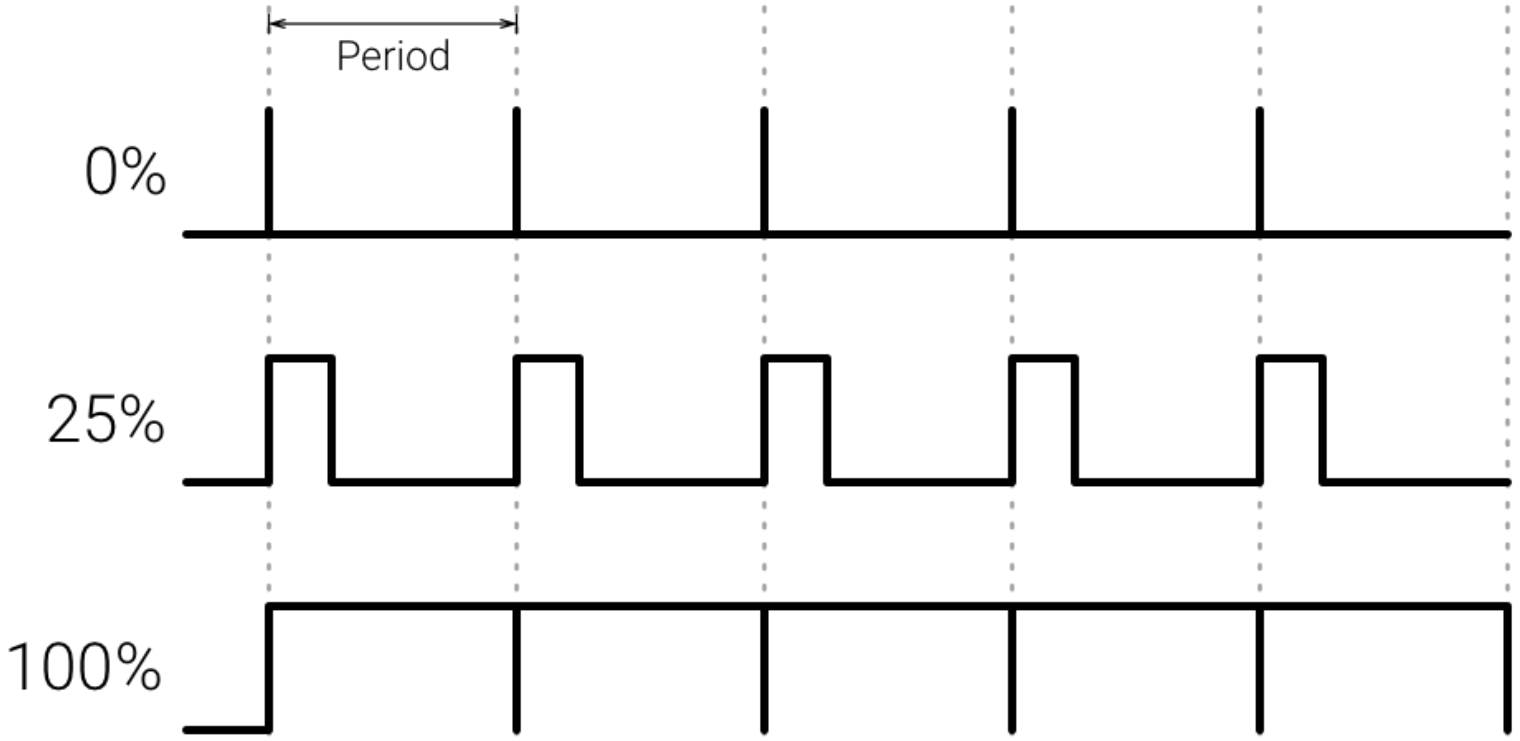
KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Motors

Pulse Width Modulation:
The motor speed is controlled using a type of signal called PWM (Pulse Width Modulation).

The way that most of the robotics/automation world does motor control is through a device called an encoder or a potentiometer. These components can be expensive or difficult to implement.



As you can see from the diagram, a motor value of 100% is "full on" and the motor driver adjusts the width between pulses to essentially turn the motor off and on fast enough that it doesn't run at full speed.
Hence, "Pulse Width Modulation".
(In practice, 100% does not actually keep the voltage always on)

There is a chip on the board that handles this automatically based on our input (Part #: TB6612NG)
This however only manages speed, and it's a speed relative to the maximum that the particular motor can do.
(which is why you see drift with motor commands)

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

How the STM32 Controls the Driver:

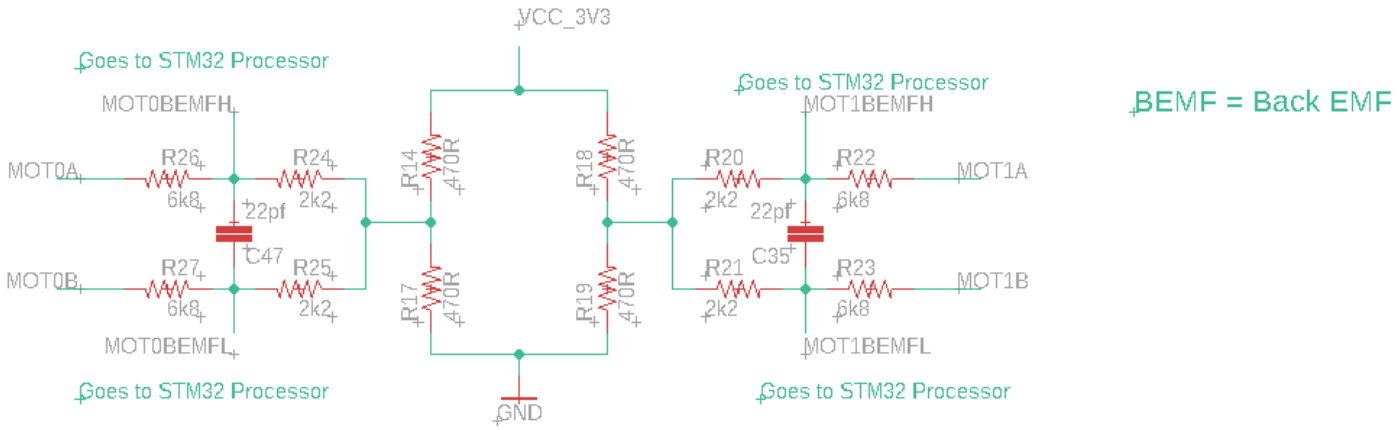
The processor actually has to send a PWM wave and two bits of information to the chip in order for it to do this. The two bits control which action the motor is doing "short brake", "stop", "Clockwise", and "Counter-clockwise"

Input				Output		
IN1	IN2	PWM	STBY	OUT1	OUT2	Mode
H	H	H/L	H	L	L	Short brake
L	H	H	H	L	H	CCW
		L	H	L	L	Short brake
H	L	H	H	H	L	CW
		L	H	L	L	Short brake
L	L	H	H	OFF (High impedance)		Stop
H/L	H/L	H/L	L	OFF (High impedance)		Standby

The STM32 Processor on the board receives input from the raspberry pi that you want the motor to go at 50% Clockwise, then the STM32 will send a 50% PWM, 1 on IN1 and a 0 on IN2. The "short brake" is basically the motor being cut power during the off cycle of the PWM. During that time the motor is just being carried by momentum.

Back EMF:

The position of the motors is tracked using a fancy physics phenomenon called "Back EMF".
Essentially, as the motor spins there is a backward voltage that happens every period or so (every rotation ideally).
This comes from the (magnetic) impulse that is invoked on the motor from the PWM signal.
There is a circuit in the Wallaby/Wombat that detects this subtle shift in voltage and counts them.
The assumption being that the irregularity will occur every rotation.



Here is that circuit, the “MOT0BEMFH” connections lead back to the processor so that it can count them.
When you use get_motor_position() and functions that are related, it is simply giving you the number that it counted.

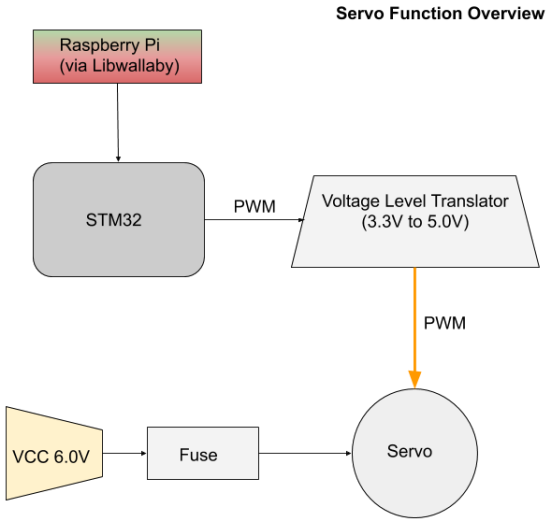
This is pretty inaccurate because of a lot of reasons, but it is a cheap and effective way to do it.

KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

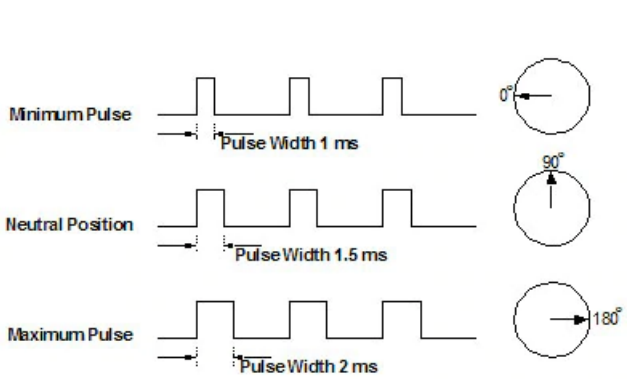
Servos

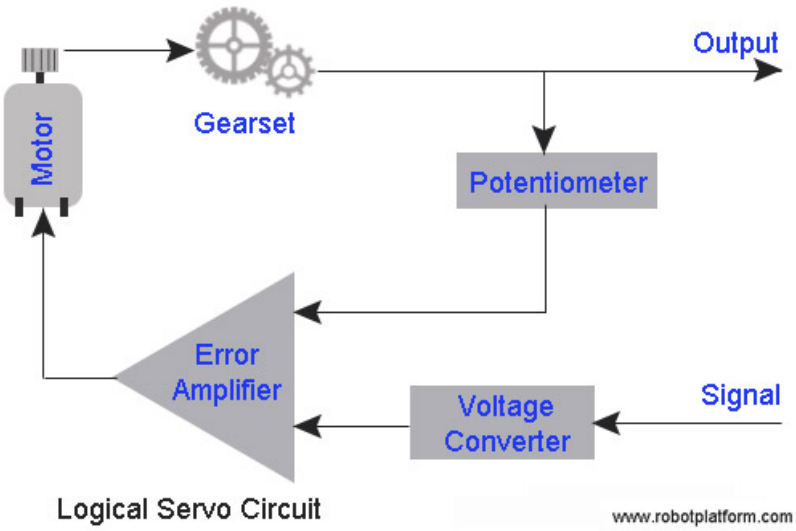
Despite what you would think, the servo circuitry is actually fairly simple compared to the motors. A PWM signal is sent from the processor, to a “voltage level translator” that takes the 3.3V STM32 PWM wave and then outputs the same wave amplified to 5.0V. The circuit inside of the servo handles translating the PWM wave into an actual rotation and angle.



Inside the Servo:

The inside of the servo works by using a potentiometer to measure the current angle of the servo. The input signal is converted from a PWM into a voltage (mapping to the same range that the potentiometer outputs), which is compared to the potentiometer output using a comparator. The output of the comparator causes the motor to rotate in the correct direction.





KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual

Wombat Servo Waveform Characteristics:

(Note: These values were experimentally obtained; not theoretical)

Formulas

D: Duty Cycle
T: Ticks
Θ: Physical Servo Angle

$D = (4.935 * 10^{-3})T + 3\%$

$D = (3.\overline{3} * 10^{-2})\Theta + 3\%$

$T = (227.\overline{5})D - 682.\overline{6}$

$\Theta = 30D - 90°$

$\Theta = 270°(\frac{T}{2047})$

Reference:

$0\ ticks\ /\ 0° = 3\%\ Duty\ Cycle$

$1024\ ticks\ /\ 135° = 7.5\%\ Duty\ Cycle$

$2047\ ticks\ /\ 270° = 12\%\ Duty\ Cycle$

How to Measure Duty Cycle

Multimeter:

1. *Put your multimeter on the Hz/% Mode*
2. *Push the Hz/% Button*
3. *Put the Positive probe on Signal; Negative on GND*

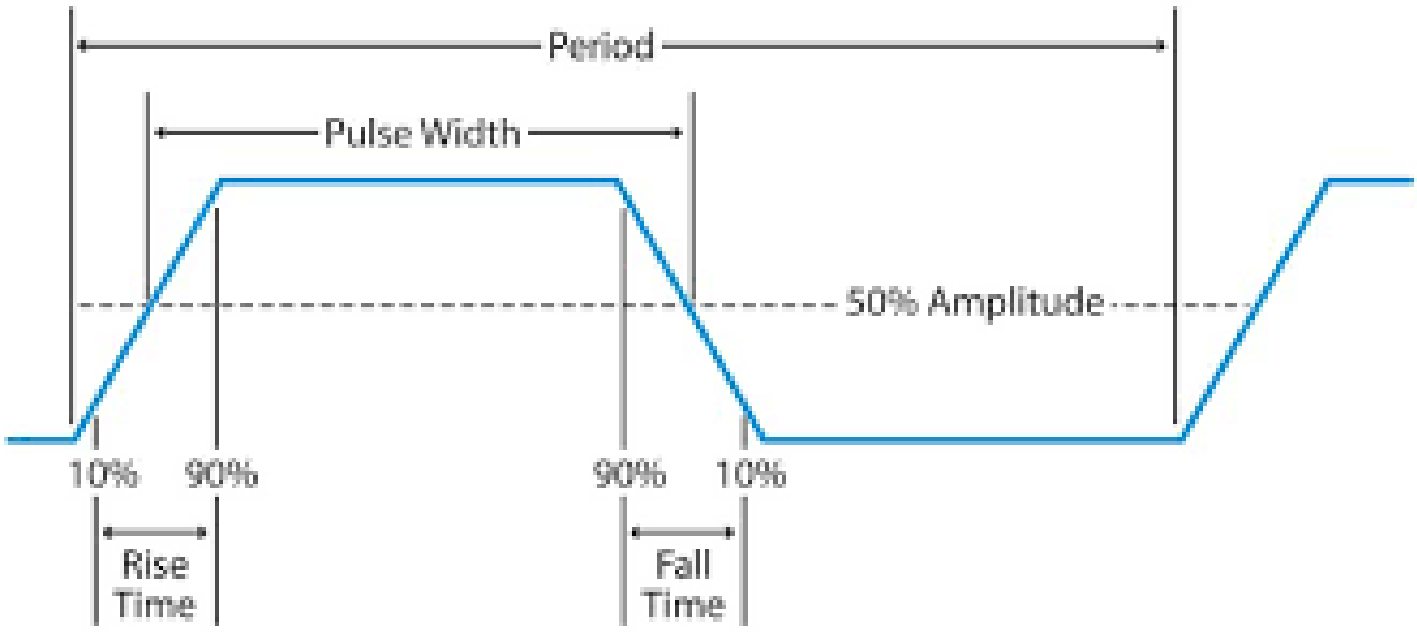
(Note: Reverse polarity flips the percent; ie 3% --> 97%)

Oscilloscope:

1. *Connect the ground clip to the GND pin*
2. *Connect the Probe to Signal*
3. *Press Autoset or use the control knobs and adjust*
4. *Press Measure and select "positive duty cycle"*

Pulse Characteristics

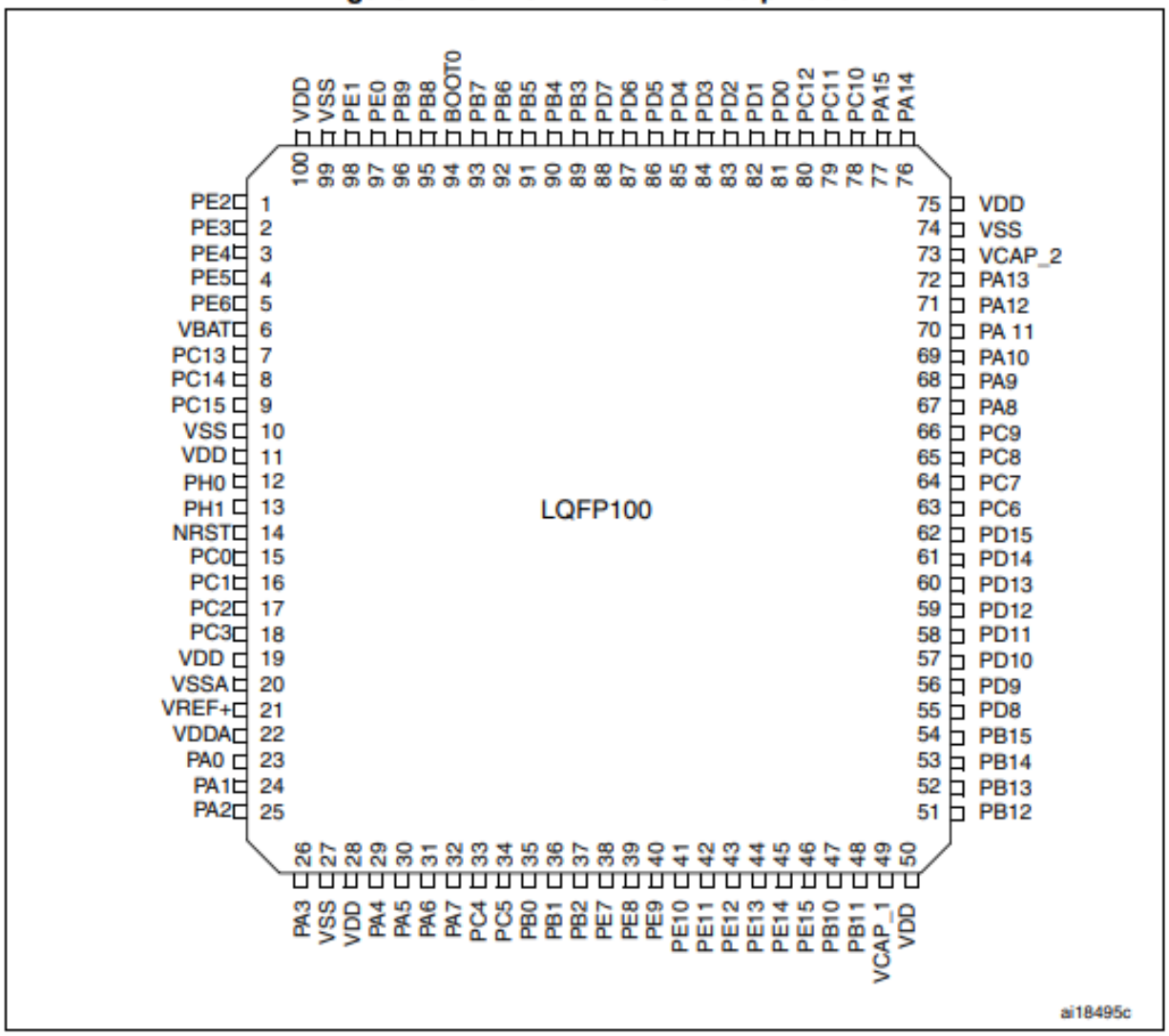
Period: 20ms
Minimum Pulse: $600\mu s\ (0\ ticks\ /\ 0°)$
Medium Pulse: $1.5ms\ (1024\ ticks\ /\ 135°)$
Maximum Pulse: $2.4ms\ (2047\ ticks\ /\ 270°)$
Rise Time: ~9µs
Fall Time: ~7µs



(Courtesy of Tektronix)

4 Pinouts and pin description

Figure 11. STM32F42x LQFP100 pinout

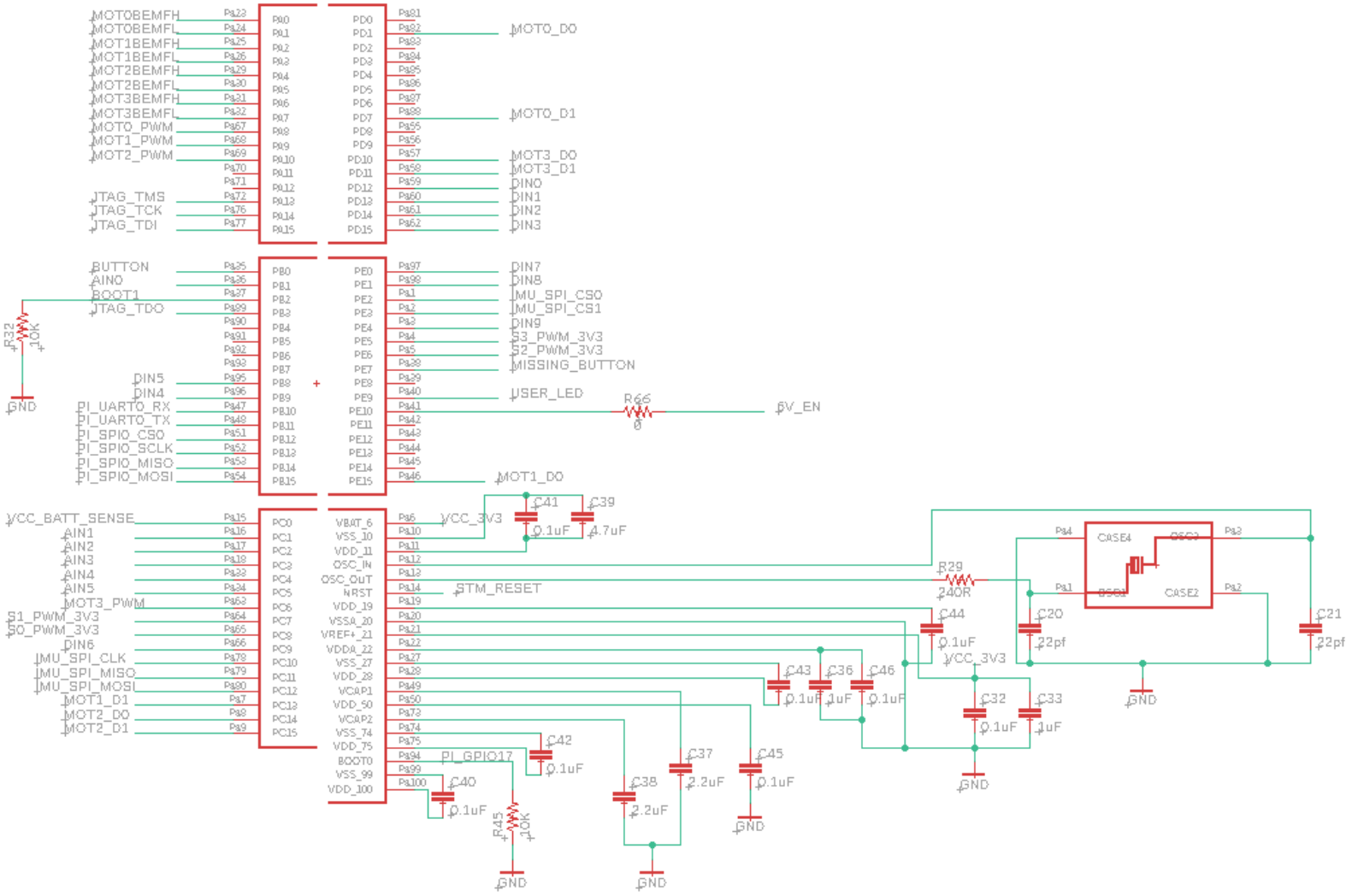


1. The above figure shows the package top view.

(Schematic Pinout on Next Page)

KISS INSTITUTE FOR PRACTICAL ROBOTICS

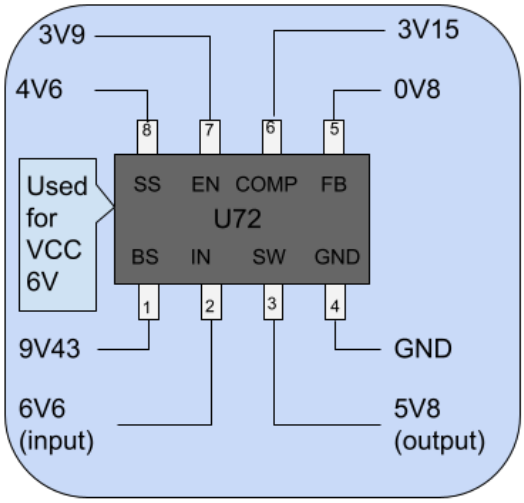
Wombat Developer Manual

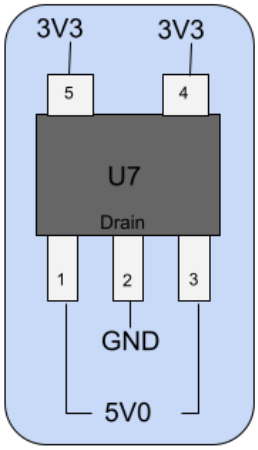


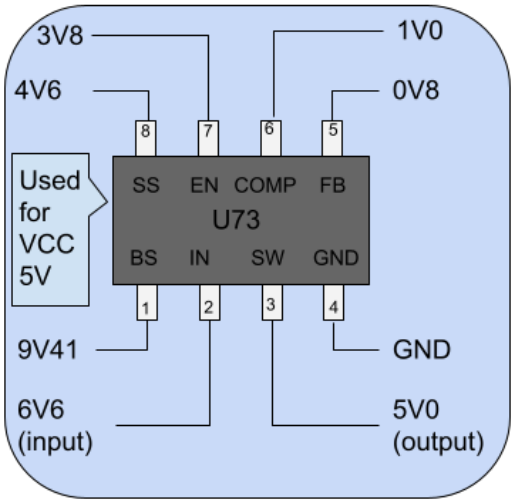
This is a quick pinout of the STM32, for information on each pin, see “STM32 Pin Explanations.pdf”.

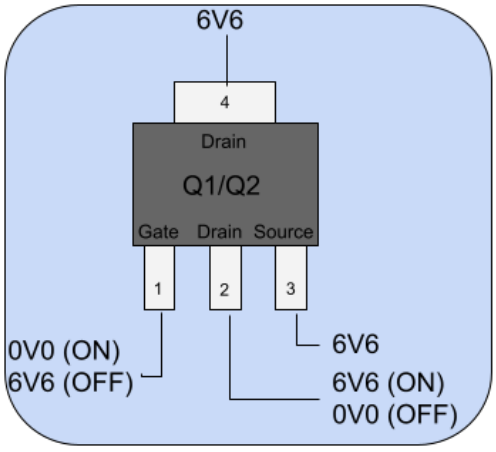
KISS INSTITUTE FOR PRACTICAL ROBOTICS

Wombat Developer Manual









Power System Diagnostic

**Values are approximate*

Chip Numbers:
U72/U73: AP65502
U7: LM3671
Q1/Q2: BSP170P

Tips:
- Test 0-Ohm resistors with continuity mode.
- If a normal resistor has MΩ resistance or 0 resistance, it is bad.
- Capacitors should not pass a continuity test (they should not short).
- Capacitor mode will not work if there are other parallel capacitors
- Inductors should pass a continuity test (there aren't many good ways to test them)

(educational chart for lab staff)

The Wombat Developer Manual is a continuously updating manual. There isn't any more information past here, but we will work to fill it with more in the future.
Want something specific added or have questions? Email zsasser@kipr.org
Check back for updates on the github page!