MAD76 Academy: C. MAD76 I/O Programming

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Contents

1 Agenda

- Functional chain of MAD76 (see Section 2)
- Power supply of remote controllers (RCs) (see Section 3)
- Potentiometer emulation for RCs (see Section 4)

Teaching Objectives

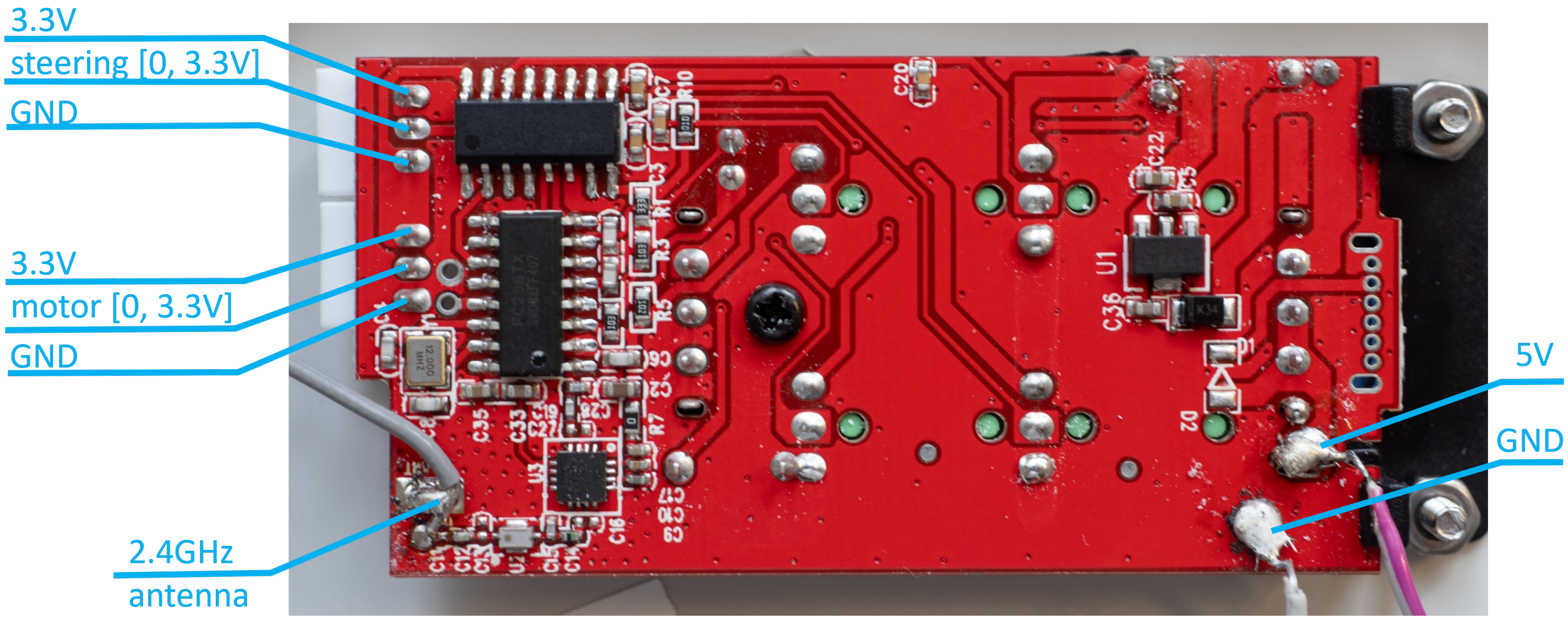
- Understand the function of remote controllers (RC) in MAD76
- Understand the General-Purpose-I/O (GPIO) of Raspberry Pi
- Understand power switches L293B
- Understand digital potis MCP42010s and voltage dividers
- Understand Serial-Peripheral-Interface (SPI) to control peripheral ICs
- Learn more about Python coding
  - digital output
  - command line arguments parsing
  - for-loops
  - SPI programming
- Measure voltages and resistances with a multimeter

2 Functional Chain

Agenda

- Remote controllers (RCs) (see Section 2.1)
- Functional chain from RPi over MAD76 IO to RCs (see Section 2.2)
- Digital I/O of RPi (see Section 2.3)

2.1 Remote Controllers (RCs)



- Each individual car is controlled by one individual RC over 2.4GHz radio channels

Each RC has the following connectors (which will be connected to MAD76 IO):

- Power supply

pin	in/out	SV1 pin	L293B	function
5V	in	1	3Y	5V power supply for microcontroller (μC) and radio controller of RC (originally from battery)
GND	in	2	GND1-4	ground

- Lower connector for motor control (thrust and braking)

pin	in/out	SV1 pin	MCP42010	function
3V3	out	8	PA0	3.3V power supply for digital poti
Digital poti wiper	in	9	PW0	motor signal $u_v \in [0V, 3.3V]$ read in by μC of RC
GND	out	10	PB0	ground for digital poti

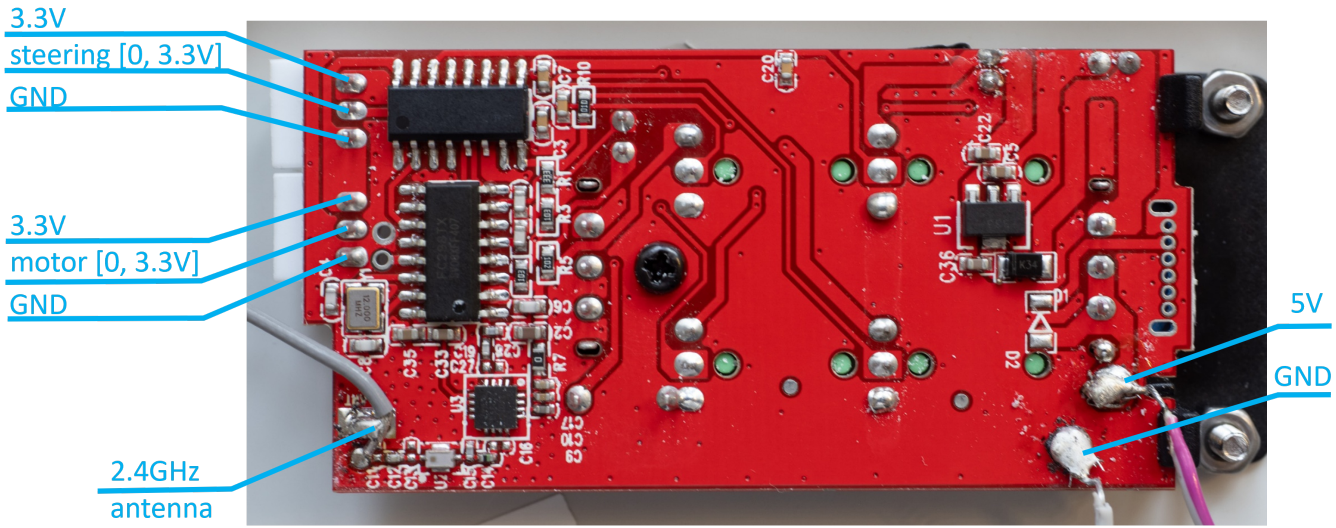
u_v	function
$1.65V = 3.3V/2$	neutral position (no thrust, no braking)
$0V$	full braking / reverse thrust
$3.3V$	full forward thrust

- Upper connector for steering control

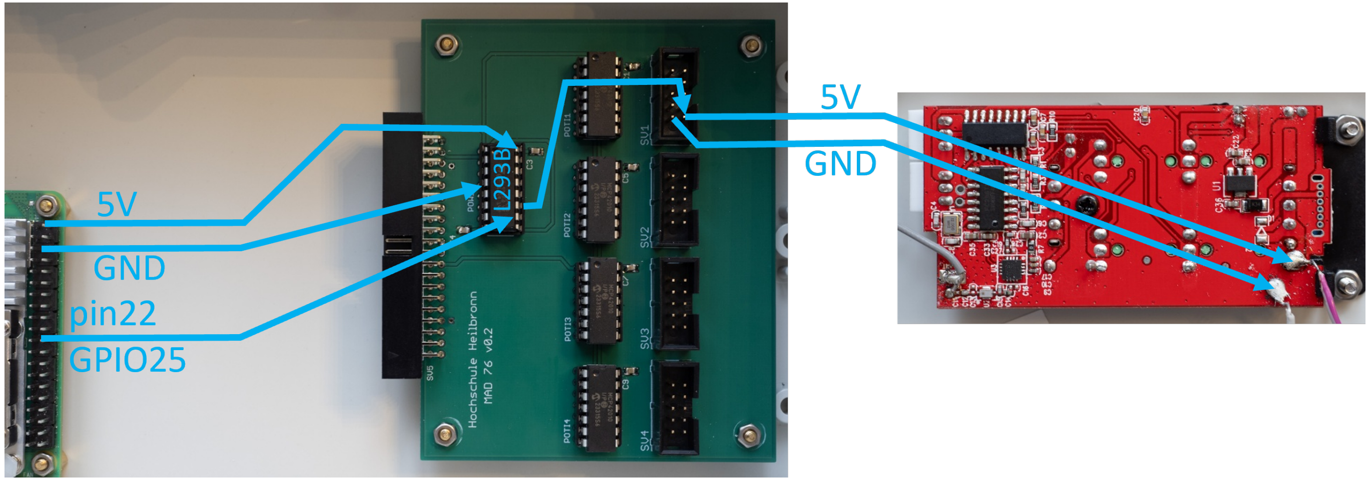
pin	in/out	SV1 pin	MCP42010	function
3V3	out	5	PA1	3.3V power supply for digital poti
Digital poti wiper	in	6	PW1	steering signal $\delta_v \in [0V, 3.3V]$ read in by μC of RC
GND	out	7	PB1	ground for digital poti

δ_v	function
$1.65V = 3.3V/2$	neutral position (straight driving)
$0V$	full right cornering
$3.3V$	full left cornering

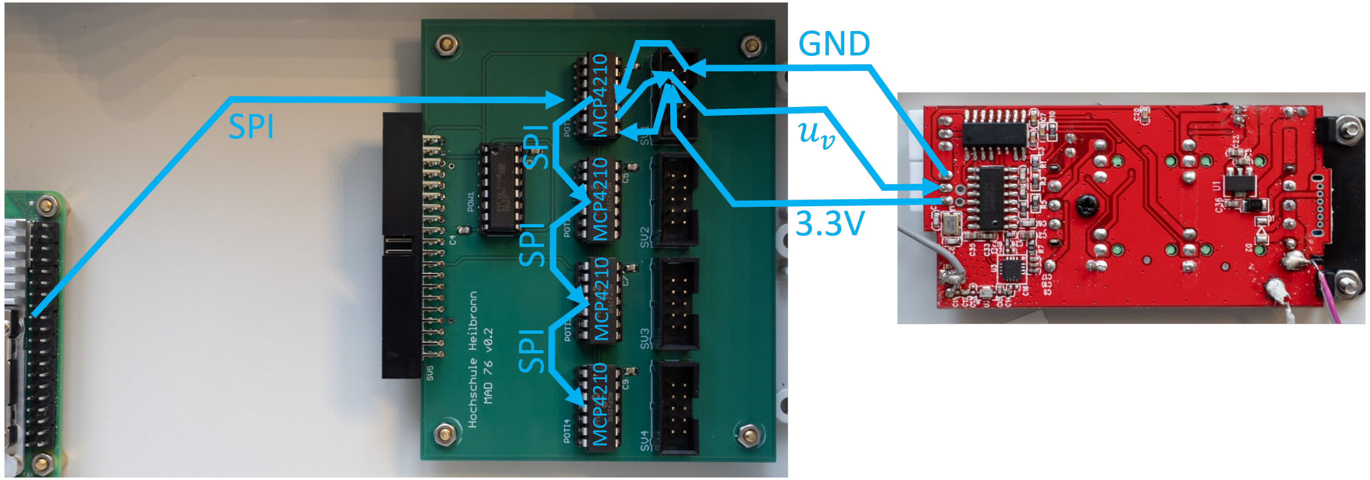
2.2 Functional Chain from RPi over MAD76 IO to RCs



- Python or C++ code running on RPi CPU controls a car by
  - switching on/off the power supply of the RC
  - manipulating motor signal for thrust and braking
  - manipulating steering signal

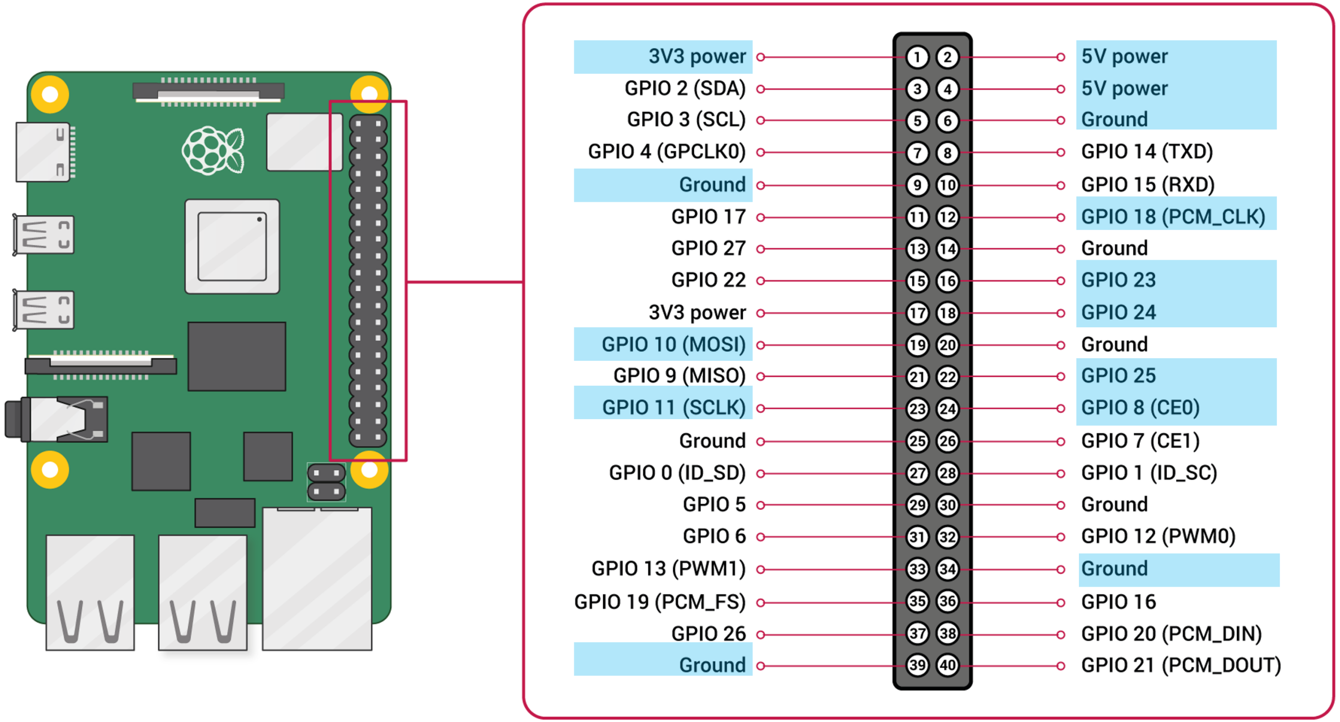


- MAD76 IO can switch RCs on and off by power switch L293B
  - L293B originally is a DC motor driver (max. 36V, 1A)
  - L293B has 4 power switches (5V), one for each RC
- Boot sequence of system must be
  1. Power off RC
  2. Switch on car
  3. Power on RC
  4. Onboard μCs of RC and car auto-calibrate steering and motor as soon as radio connection is established
- RPi controls L293B by digital outputs
  - e.g., GPIO25 for RC 1



- MAD76 IO emulates 8 potentiometers for 4 RCs by 4 MCP42010s
  - One MCP42010 per each RC and car
    - 1 digital poti for motor (PA0, PW0, PB0)
    - 1 digital poti for steering (PA1, PW1, PB1)
  - RPi controls MCP42010 by Serial-Peripheral-Interface (SPI)
  - MCP42010s are daisy-changed by SPI

2.3 Digital I/O of Raspberry Pi



- Some general-purpose input/output (GPIO) pins have multiple and alternative functions

- List the current GPIO pin configuration and their assigned functions

```
lab01@madp02:~ $ gpio readall
 +-----+-----+---------+------+---+---Pi 5---+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 |     |     |    3.3v |      |   |  1 || 2  |   |      | 5v      |     |     |
 |   2 |   8 |   SDA.1 |   -  | 0 |  3 || 4  |   |      | 5v      |     |     |
 |   3 |   9 |   SCL.1 |   -  | 0 |  5 || 6  |   |      | 0v      |     |     |
 |   4 |   7 | GPIO. 7 |   -  | 0 |  7 || 8  | 0 |  -   | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 0 |  -   | RxD     | 16  | 15  |
 |  17 |   0 | GPIO. 0 |   -  | 0 | 11 || 12 | 0 | OUT  | GPIO. 1 | 1   | 18  |
 |  27 |   2 | GPIO. 2 |   -  | 0 | 13 || 14 |   |      | 0v      |     |     |
 |  22 |   3 | GPIO. 3 |   -  | 0 | 15 || 16 | 0 | OUT  | GPIO. 4 | 4   | 23  |
 |     |     |    3.3v |      |   | 17 || 18 | 0 | OUT  | GPIO. 5 | 5   | 24  |
 |  10 |  12 |    MOSI | ALT0 | 0 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO | ALT0 | 0 | 21 || 22 | 0 | OUT  | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK | ALT0 | 0 | 23 || 24 | 1 | OUT  | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 1 | OUT  | CE1     | 11  | 7   |
 |   0 |  30 |   SDA.0 |   IN | 1 | 27 || 28 | 1 | IN   | SCL.0   | 31  | 1   |
 |   5 |  21 | GPIO.21 |   -  | 0 | 29 || 30 |   |      | 0v      |     |     |
 |   6 |  22 | GPIO.22 |   -  | 0 | 31 || 32 | 0 |  -   | GPIO.26 | 26  | 12  |
 |  13 |  23 | GPIO.23 |   -  | 0 | 33 || 34 |   |      | 0v      |     |     |
 |  19 |  24 | GPIO.24 |   -  | 0 | 35 || 36 | 0 |  -   | GPIO.27 | 27  | 16  |
 |  26 |  25 | GPIO.25 |   -  | 0 | 37 || 38 | 0 |  -   | GPIO.28 | 28  | 20  |
 |     |     |      0v |      |   | 39 || 40 | 0 |  -   | GPIO.29 | 29  | 21  |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+---Pi 5---+---+------+---------+-----+-----+
```

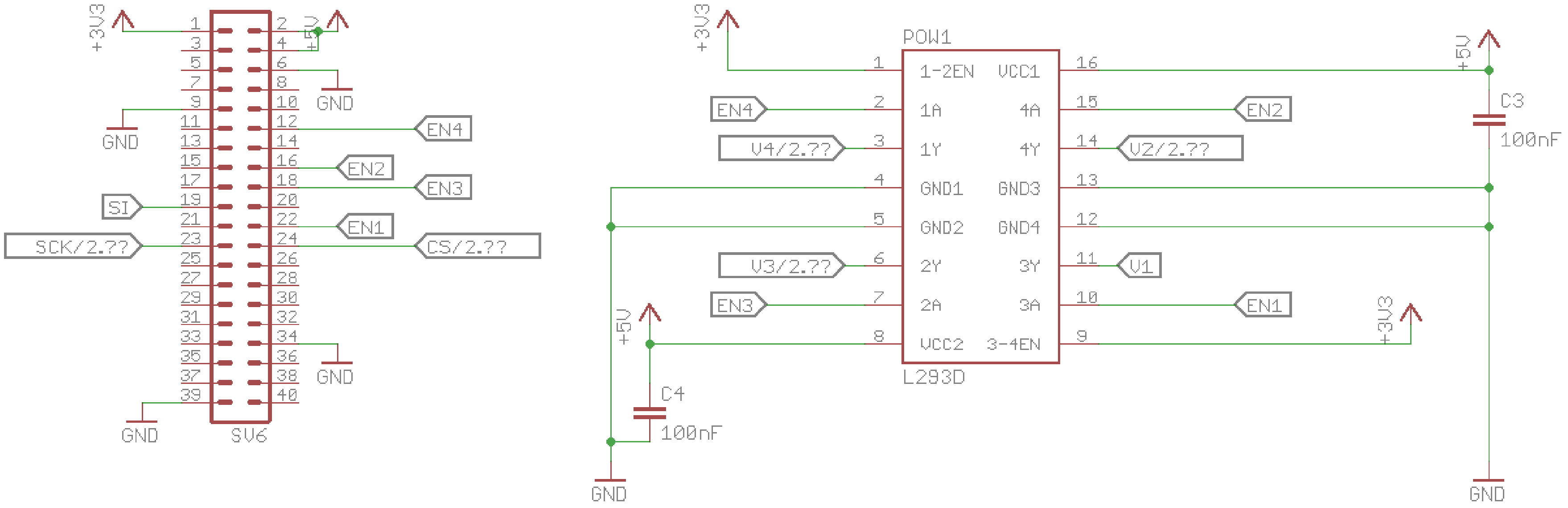
- Many programming libraries and tools are available to do GPIO and SPI on RPi
- We use
  - Python package `RPi.GPIO` (version `python3-rpi-lgpio` for RPi Zero and RPi 5)
  - Python package `spidev` for SPI

3 Power Supply

Agenda

- Driver L293B (see Section 3.1)
- Python code to power RC 1 (see Section 3.2)
- Python code to switch on / off any RC (see Section 3.3)

3.1 Driver L293B



- Datasheet: `https://www.st.com/resource/en/datasheet/l293b.pdf`
- L293B controls the power supplies of all 4 RCs

L293B has the following pins

pin	name	in/out	function	RPi Pin	GPIO
1	1-2EN	in	Enable power switches 1 and 2 permanently		
2	1A	in	If high then RC 4 is powered on, else if low then RC 4 is powered off	12	GPIO18
3	1Y	out	Power supply for RC 4, 5V if powered on, 0V if powered off		
4	GND1	in	ground		
5	GND2	in	ground		
6	2Y	out	Power supply for RC 3, 5V if powered on, 0V if powered off		
7	2A	in	If high then RC 3 is powered on, else if low then RC 3 is powered off	18	GPIO24
8	VCC2	in	5V power supply for L293B		
9	3-4EN	in	Enable power switches 3 and 4 permanently		
10	3A	in	If high then RC 1 is powered on, else if low then RC 1 is powered off	22	GPIO25
11	3Y	out	Power supply for RC 1, 5V if powered on, 0V if powered off		
12	GND4	in	ground		
13	GND3	in	ground		
14	4Y	out	Power supply for RC 2, 5V if powered on, 0V if powered off		
15	4A	in	If high then RC 2 is powered on, else if low then RC 2 is powered off	16	GPIO23
16	VCC1	in	5V power supply for L293B		

- RPi sets digital outputs GPIO25, GPIO23, GPIO24, GPIO18 to high or low to switch RC 1, 2, 3, 4 on/off

3.2 Python Code to Power On RC 1

- Python package `RPi.GPIO` provides functions to control GPIO pins of RPi
- The following code powers RC 1 on for 5 seconds and then powers it off
- Create a new directory and a new Python module `rctestpower1.py` with VS Code

```
cd
mkdir -p src/madpi_ws/src/rcpi/scripts
cd src/madpi_ws/src/rcpi/scripts
code rctestpower1.py
```

- Copy the following code into `rctestpower1.py` and run it

```python
#!/usr/bin/env python3

import time
import sys
import RPi.GPIO as io

POWER_PIN = 25 # GPIO25 (pin 22)

if __name__ == "__main__":
    # Use GPIO BCM mode for pin numbering
    io.setmode(io.BCM)
    # Alternatively use board pin numbering
```

```
#io.setmode(io.BOARD)

# Configure GPIO as dital output
io.setup(POWER_PIN, io.OUT)

# Power on RC 1
io.output(POWER_PIN, io.HIGH)
time.sleep(5)

# Power off RC 1
io.output(POWER_PIN, io.LOW)

# Cleanup GPIO
io.cleanup()

# exit cleanly
sys.exit(0)
```

3.3 Python Code to Power On any RC

- The following code may power on any of the RCs
- Create a new Python module `rcpoweron.py`

```
#!/usr/bin/env python3

import sys
import RPi.GPIO as io

CAR_CNT = 4  # Total number of cars in RCs
POWER_PINS = [ 25, 23, 24, 18 ]

def usage():
    """Print usage information."""
    print("Usage: python rcpoweron.py <carid>")
    print("This script tests powering on one RC on a Raspberry Pi.")

def command_line_args():
    """Parse command line arguments."""
    # default values
    success = True
    carid = 0 # integer with arbitray wordlength
    if len(sys.argv) < 2:
        success = False
```

```
    try:
        carid = int(sys.argv[1])
        if carid < 0 or carid >= CAR_CNT:
            raise ValueError("carid must be between 0 and {}".format(CAR_CNT - 1))
    except (ValueError, IndexError):
        success = False
    return success, carid



if __name__ == "__main__":
    [ success, carid ] = command_line_args()
    if not success:
        usage()
        sys.exit(1)

    # Use GPIO BCM mode
    io.setmode(io.BCM)

    # Configure GPIO as dital output
    io.setup(POWER_PINS[carid], io.OUT)

    # Power on RC 1
    io.output(POWER_PINS[carid], io.HIGH)
```

```
    # Cleanup GPIO
    #io.cleanup()

    # exit cleanly
    sys.exit(0)
```

- `rcpoweron.py` parses the command line and has the following command line argument

argument	description
`carid`	ID of the RC to power on (0, 1, 2 or 3)

- e.g., RC 1 is powered on by entering the following command in a terminal

```
python rcpoweron.py 0
```

- e.g., RC 2 is powered on by

```
python rcpoweron.py 1
```

3.3.1 Exercises

C.3.3.1 Program `rcpoweroff.py` to power off all 4 RCs at once.

- You may use the Python command `for` and the Python function `range()` to program a for-loop.

Required results are:

- Python code `rcpoweroff.py`

C.3.3.2 Measure the voltage at the power supply of RC 1 with a multimeter (see Figure 1)

- Disconnect RC 1 from socket SV 1
- Run `rcpoweron.py 0`
- Measure the voltage between pins 13 and 11 of L293B
- Run `rcpoweroff.py`
- Repeat the measurement
- Connect RC 1 to socket SV 1
- Check if blue LED switches with power

No results need to be documented for this exercise.

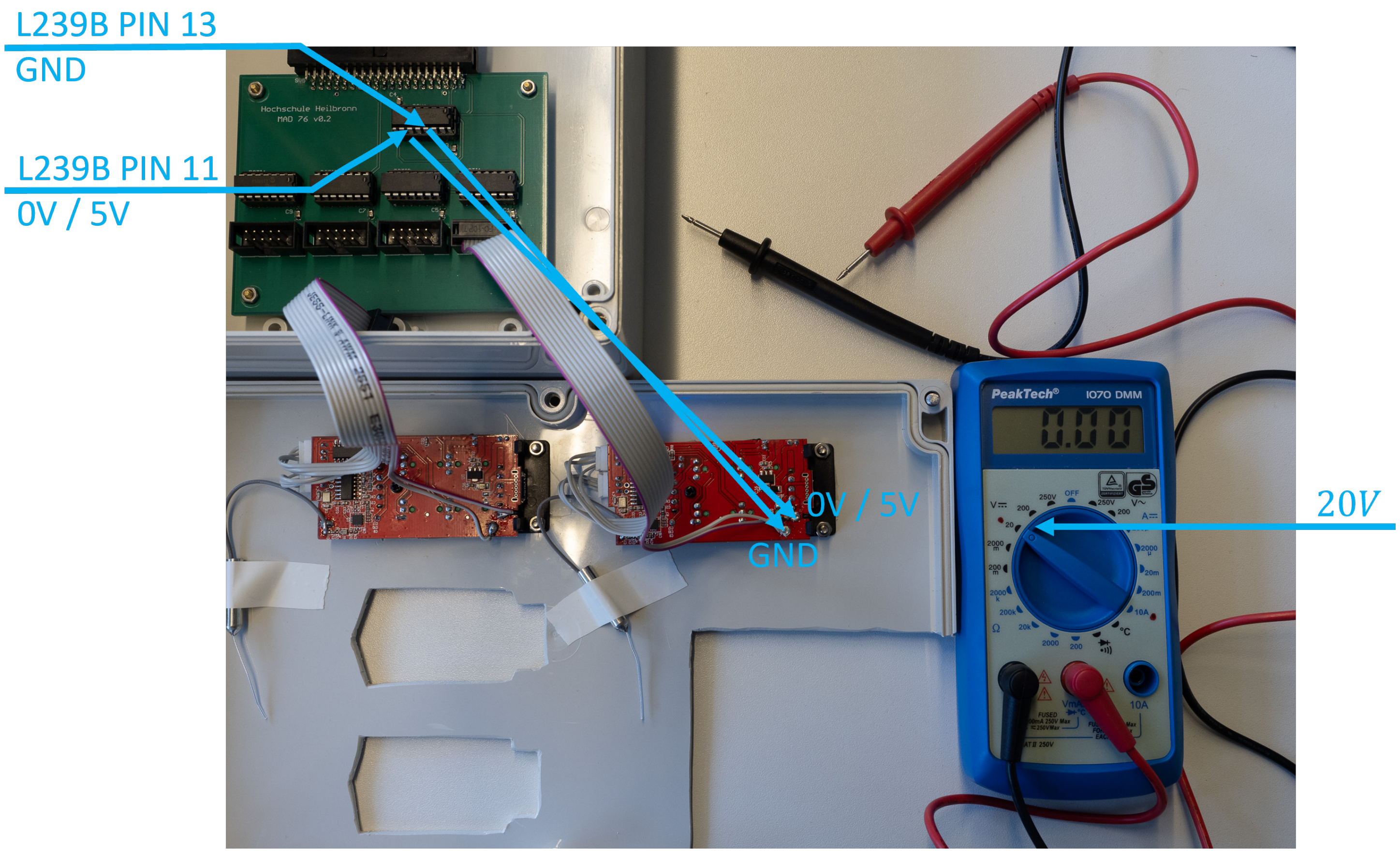


Figure 1: Exercise 2: Measure power supply voltage

4 Digital Potentiometers

Agenda

- Digital Potentiometers MCP42010 (see Section 4.1)
- Serial-Peripheral-Interface (SPI) (see Section 4.2)
- SPI for MCP42010 (see Section 4.3)
- Python library to control RC (see Section 4.4)

4.1 Digital Potentiometers MCP42010

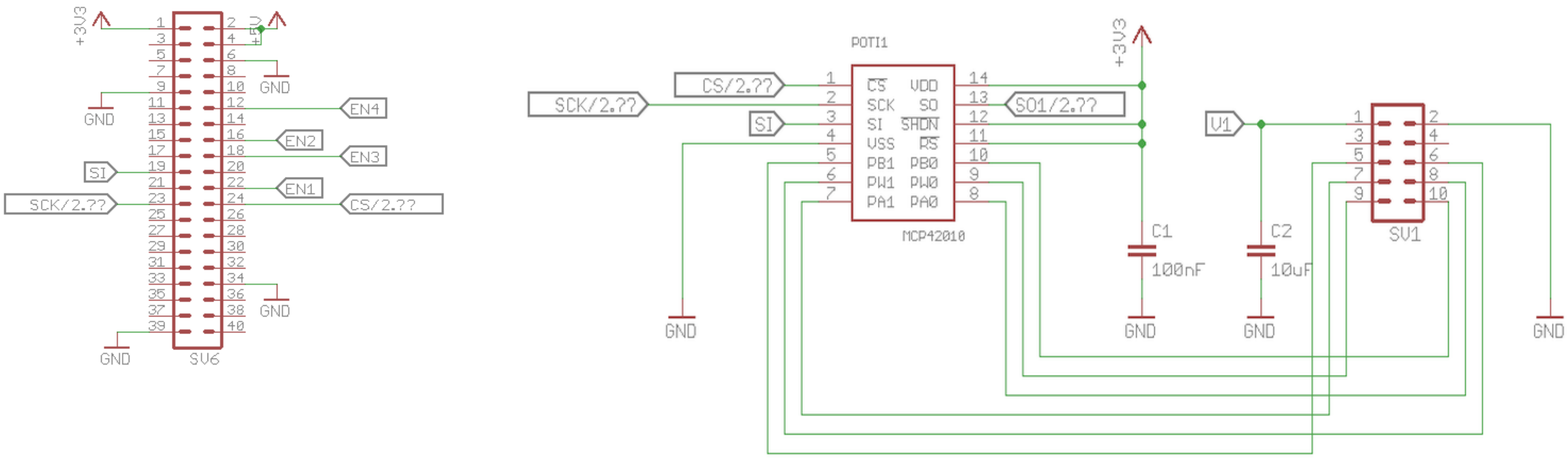


Figure 2: MAD76 IO schematics for digital poti MCP42010 [1]

- MCP42010 emulates 2 potentiometers by resistor cascades

MCP42010 has the following pins

pin	name	in/out	function	RPi Pin	GPIO
1	$\overline{\text{CS}}$	in	SPI chipselect (active low)	24	
2	SCK	in	SPI serial clock	23	
3	SI	in	SPI MOSI (master-out slave-in)	19	
4	VSS	in	ground		
5	PB1	in	ground for poti 1 from RC		
6	PW1	out	poti 1 wiper for steering signal $\delta_v \in [0V, 3.3V]$		
7	PA1	in	3.3V supply for poti 1 from RC		
8	PA0	in	3.3V supply for poti 0 from RC		
9	PW0	out	poti 0 wiper for motor signal $u_v \in [0V, 3.3V]$		
10	PB0	in	ground for poti 0 from RC		
11	$\overline{\text{RS}}$	in	HW reset (active low), always high $\rightsquigarrow$ newer reset		
12	$\overline{\text{SHDN}}$	in	HW shutdown (active low), always high $\rightsquigarrow$ newer shutdown		
13	SO	out	SPI MISO (master-in slave-out) for daisy-chaining 4 MCP42010s		
14	VDD	in	3.3V power supply for MCP42010		

- RPi sets poti resistor values by SPI communication (pins $\overline{\text{CS}}$, SCK, MOSI)

MCP42010 contains 2 voltage dividers

- Input (PA0, PB0): power supply generated by RC $u_{ba} \approx 3.3\text{V}$
- Output (PW0): motor signal voltage

$$u_v = \frac{R_{bw}}{R_{ba}} \cdot u_{ba} = \frac{R_{bw}}{10\text{k}\Omega} \cdot 3.3\text{V} \in [0\text{V}, 3.3\text{V}] \quad (1)$$

- Input (SCK, SI): SPI sets integer values for wiper potentiometer

$$u_q \in \{0, 1, ..., 255\} \quad (2)$$

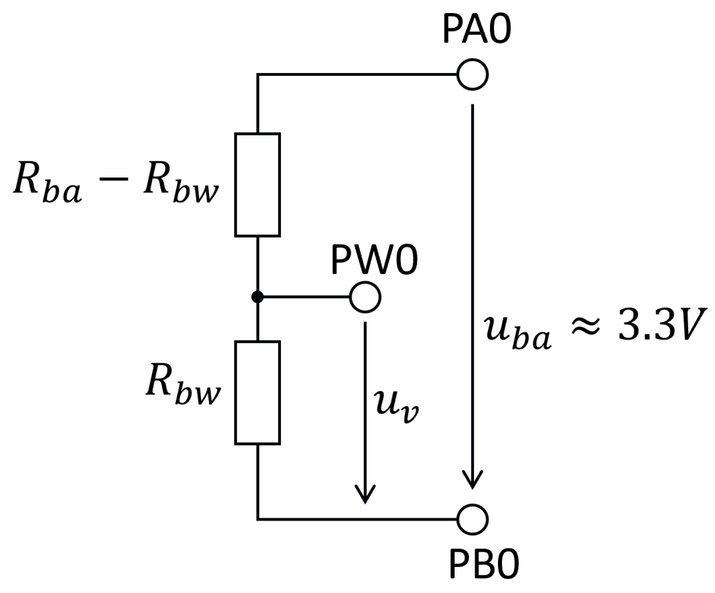
$$R_{bw} = \frac{R_{ba}}{255} \cdot u_q \in [0\text{k}\Omega, 10\text{k}\Omega] \quad (3)$$

- Resulting wiper voltage: (3) in (1)

$$u_v = \frac{u_{ba}}{255} \cdot u_q = \frac{3.3\text{V}}{255} \cdot u_q \in [0\text{V}, 3.3\text{V}] \quad (4)$$

- Identical second voltage divider for steering signal

$$\delta_v = \frac{3.3\text{V}}{255} \cdot \delta_q \in [0\text{V}, 3.3\text{V}] \quad (5)$$



4.2 Serial-Peripheral-Interface (SPI)

- SPI is a widely-used synchronous serial communication protocol
- SPI is used to control peripheral integrated circuits (ICs) like MCP42010 or for communication between CPUs and microcontrollers
- SPI is a synchronous serial communication protocol
- SPI uses a master-slave architecture
  - master = RPi
  - slave = MCP42010
- SPI uses 4 wires

$\overline{\text{CS}}$	chip select (active low) for slave selection
SCK	serial clock
MOSI (SI)	master-out slave-in data
MISO (SO)	master-in slave-out data

- SCK is clocked by the master with frequency $f = 1\text{MHz} \in [1\text{MHz}, 70\text{MHz}]$
- Data bits are sent synchronously to SCK
- Slave only reads data if $\overline{\text{CS}}$ is low

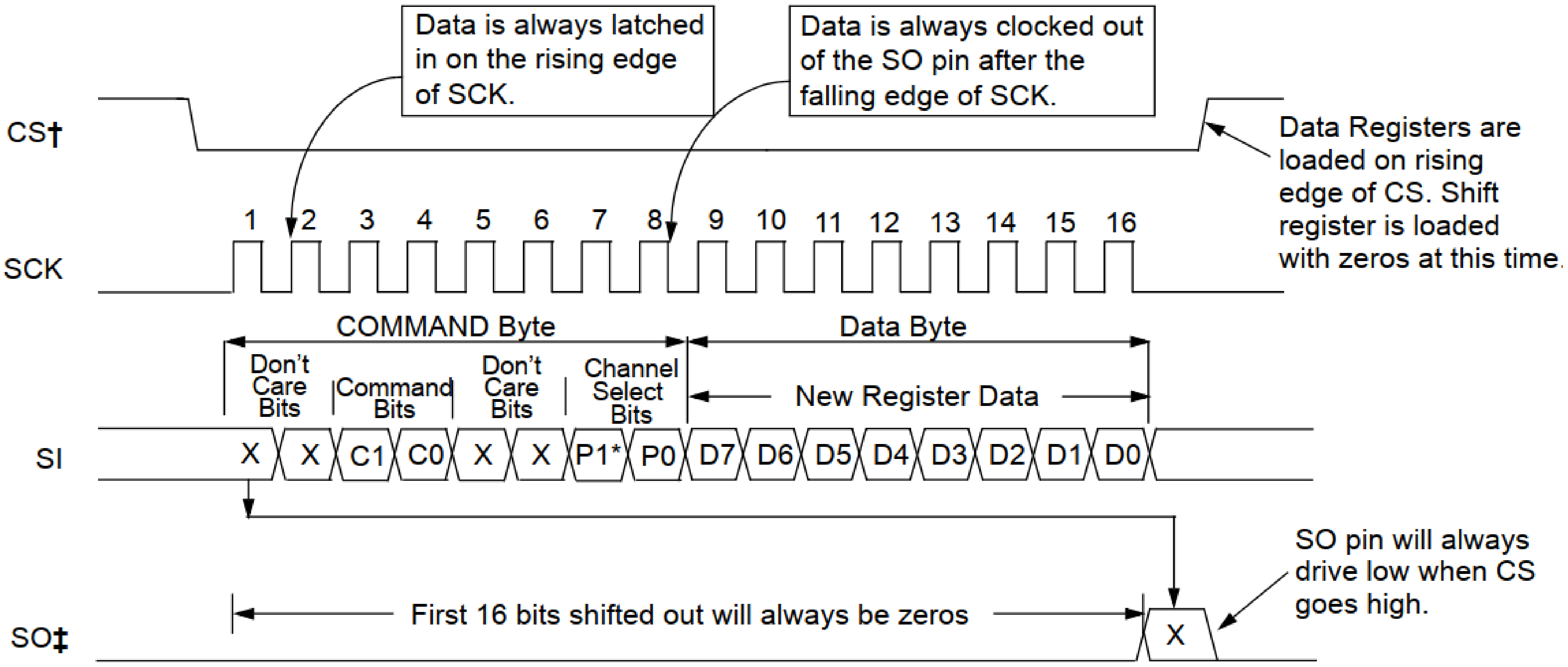


Figure 3: MCP42010 SPI timing diagram. Copied from MCP42010 data sheet [1] Figure 5.1.

4.3 SPI for MCP42010

- MCP42010 reads in 16-bit data words consisting of two 8-bit bytes [1]

command byte	resistor data byte

- Commands used by MAD76 are

command byte	resistor data byte	
`0x11`	$u_q \in \{0, 1, ..., 255\}$	write data to poti 0 (motor)
`0x12`	$\delta_q \in \{0, 1, ..., 255\}$	write data to poti 1 (steering)

- Example

command byte	resistor data byte	
`0x11`	$u_q = 128$	sets motor signal voltage $u_v = 3.3\text{V} \cdot 128/255 = 1656\text{mV}$, see equation (4)

- 4 MCP42010s can be daisy-chained by connecting the MISO of one to the MOSI of the next
  - RPi sends sequences of 4 16-bit data words to this daisy chain
  - One transmission sets the motor resistors of all 4 MCP42010s
    - Example: `0x11 0xFF 0x11 0x80 0x11 0x20 0x11 0x10` sets the following motor signal voltages

RC 1	`0x10`	$3.3\mathrm{V} \cdot 16/255 = 207\mathrm{mV}$
RC 2	`0x20`	$3.3\mathrm{V} \cdot 32/255 = 414\mathrm{mV}$
RC 3	`0x80`	$3.3\mathrm{V} \cdot 128/255 = 1656\mathrm{mV}$
RC 4	`0xFF`	$3.3\mathrm{V} \cdot 255/255 = 3300\mathrm{mV}$

  - A further transmission sets the steering resistors of all 4 MCP42010s
    - Example: `0x12 0x40 0x12 0x30 0x12 0x20 0x12 0x10` sets all 4 steering signal voltages

4.4 Python Library to Control RC

- Create a new Python module `mbmadrclib.py` in directory `~/src/madpi_ws/src/rcpi/scripts` or you may copy existing code with the following commands

```
cd ~/src/madpi_ws/src/rcpi/scripts
cp ~labor/src/mad76/madpi_ws/src/rcpi/scripts/mbmadrclib.py .
```

```
#!/usr/bin/env python3

"""
mbmadrclib.py
-------------

MAD76 RCLib for Raspberry Pi GPIO and SPI

Copyright (C) 2025, Frank Traenkle, Hochschule Heilbronn
"""

import spidev
import RPi.GPIO as io

CAR_CNT = 4 # number of cars
POWER_PINS = [ 25, 23, 24, 18 ] # { GPIO25, pin22 ; GPIO23, pin16 ; GPIO24, pin18 ; GPIO18, pin12 }
PEDALS_MAX = 1.0 # maximum pedals value
```

```
STEERING_MAX = 1.0 # maximum steering value
SPI_CHANNEL = 0 # SPI channel for communication with the car
SPI_SPEED = 1000000 # SPI speed in Hz
SPI_CMD_PEDALS = 0x11 # command to write pedals
SPI_CMD_STEERING = 0x12 # command to write steering

pedals_data = [ 0x00 ] * CAR_CNT * 2
steering_data = [ 0x00 ] * CAR_CNT * 2

def signal_to_spi_value(value, max_value):
    """Convert a signal value to an SPI value."""
    if value < -max_value or value > max_value:
        raise ValueError("Value must be between {} and {}".format(-max_value, max_value))
    return int((value + max_value) / (2.0 * max_value) * 255.0)

def initialize_spi():
    """
    Initialize the SPI interface.

    Args:
        device (int): SPI device number (default: 0).
        speed (int): SPI speed in Hz (default: 1000000).

    Returns:
        spidev.SpiDev: Configured SPI device.
```

```python
    """
    spi = spidev.SpiDev()
    spi.open(0, SPI_CHANNEL)
    spi.max_speed_hz = SPI_SPEED
    spi.mode = 0b00
    spi.bits_per_word = 8
    spi.lsbfirst = False
    spi.cshigh = False

    for i in range(CAR_CNT):
        pedals_data[2*i] = SPI_CMD_PEDALS
        pedals_data[2*i+1] = signal_to_spi_value(0.0, PEDALS_MAX)
        steering_data[2*i] = SPI_CMD_STEERING
        steering_data[2*i+1] = signal_to_spi_value(0.0, STEERING_MAX)

    return spi

def initialize_gpio():
    """Initialize GPIO pins for power control.
    """
    io.setmode(io.BCM)
    for pin in POWER_PINS:
        io.setup(pin, io.OUT)
        io.output(pin, io.LOW)  # Set all power pins to LOW initially
```

```python
def cleanup_gpio():
    """Clean up GPIO pins.
    """
    io.cleanup()  # Reset all GPIO pins to their default state

def switchon_rcpower(carid):
    """Switch on the power for the specified car.

    Args:
        carid (int): Car ID (0 to CAR_CNT-1).
    """
    if carid < 0 or carid >= CAR_CNT:
        raise ValueError(f"carid must be between 0 and {CAR_CNT - 1}")
    io.output(POWER_PINS[carid], io.HIGH)  # Set the specified power pin to HIGH

def switchoff_rcpower(carid):
    """Switch off the power for the specified car.

    Args:
        carid (int): Car ID (0 to CAR_CNT-1).
    """
    if carid < 0 or carid >= CAR_CNT:
        raise ValueError(f"carid must be between 0 and {CAR_CNT - 1}")
    io.output(POWER_PINS[carid], io.LOW)  # Set the specified power pin to LOW
```

```python
def write_pedals(spi, carid, pedals):
    """Write pedals value to the specified car.

    Args:
        spi (spidev.SpiDev): Configured SPI device.
        carid (int): Car ID (0 to CAR_CNT-1).
        pedals (float): Pedals value (-PEDALS_MAX to PEDALS_MAX).
    """
    if carid < 0 or carid >= CAR_CNT:
        raise ValueError(f"carid must be between 0 and {CAR_CNT - 1}")
    id = CAR_CNT - carid - 1  # Reverse order for SPI communication
    pedals_data[id * 2 + 1] = signal_to_spi_value(pedals, PEDALS_MAX)
    spi.writebytes(pedals_data)

def write_steering(spi, carid, steering):
    """Write steering value to the specified car.

    Args:
        spi (spidev.SpiDev): Configured SPI device.
        carid (int): Car ID (0 to CAR_CNT-1).
        steering (float): Steering value (-STEERING_MAX to STEERING_MAX).
    """
    if carid < 0 or carid >= CAR_CNT:
        raise ValueError(f"carid must be between 0 and {CAR_CNT - 1}")
    id = CAR_CNT - carid - 1  # Reverse order for SPI communication
```

```
    steering_data[id * 2 + 1] = signal_to_spi_value(steering, STEERING_MAX)
    spi.writebytes(steering_data)
```

- Python library `mbmadrclib.py` provides functions
  - to power on / off the RCs via L293B (see Section 3)
  - to set the motor and steering signal voltages of the RCs by sending SPI commands to MCP42010s
- Function `write_pedals` sets the motor signal voltages u_v

argument	description
`spi`	SPI object of `spidev`
`carid`	RC / car ID from 0 to 3
`pedals`	Normalized motor signal $u_n \in [-1, 1]$. -1 is full brake / reverse, 1 is full forward thrust.

  - `write_pedals` limits u_n to the range $[-1, 1]$ which is an important *safety measure*
  - `write_pedals` computes the SPI value u_q for the resistor from u_n

$$u_q = 255 \cdot (u_n + 1)/2 \in [0, 255] \tag{6}$$

  - Inserting this equation into (4) yields the motor signal voltage for the RC

$$u_v = \frac{3.3\text{V}}{255} \cdot u_q = 3.3\text{V} \cdot (u_n + 1)/2 \in [0, 3.3\text{V}] \tag{7}$$

- Function `write_steering` sets the steering signal voltages δ_v and is similar to `write_pedals`

argument	description
`spi`	SPI object of `spidev`
`carid`	RC / car ID from 0 to 3
`pedals`	Normalized steering signal $u_n \in [-1, 1]$. -1 is full right, 1 is full left cornering.

- The Python module `rctest.py` is an extension of `rcpoweron.py` from Section **??**
  - It uses the new library `mbmadrclib.py` to power on the RCs and to set the motor and steering signals
  - It provides a simple command line interface to control the RCs
- Create Python module `rctest.py` in directory `~/src/madpi_ws/src/rcpi/scripts` or copy existing `rctest.py` with the following commands

```
cd ~/src/madpi_ws/src/rcpi/scripts
cp ~labor/src/mad76/madpi_ws/src/rcpi/scripts/rctest.py .
```

```
#!/usr/bin/env python3

"""
rctest.py
---------
```

```
Script to test the GPIO pins on a Raspberry Pi.

Copyright (C) 2025, Frank Traenkle, Hochschule Heilbronn
"""

import time
import sys
import signal
import mbmadrclib as rc

# This script is used to test the GPIO pins on a Raspberry Pi.


def signal_handler(signal, frame):
    """Handle the signal to clean up GPIO on exit."""
    rc.cleanup_gpio()
    sys.exit(0)

def usage():
    """Print usage information."""
    print("Usage: python rctest.py <carid> <pedals> <delta>")
    print("This script tests the GPIO pins on a Raspberry Pi.")

def command_line_args():
    """Parse command line arguments."""
```

```
    # default values
    success = True
    carid = 0 # integer with arbitray wordlength
    pedals = 0.0 # 64bit float
    steering = 0.0
    if len(sys.argv) < 3:
        success = False
    try:
        carid = int(sys.argv[1])
        if carid < 0 or carid >= rc.CAR_CNT:
            raise ValueError("carid must be between 0 and {}".format(rc.CAR_CNT - 1))
        pedals = float(sys.argv[2])
        if pedals < -rc.PEDALS_MAX or pedals > rc.PEDALS_MAX:
            raise ValueError("pedals must be between {} and {}".format(-rc.PEDALS_MAX, rc.PEDALS_MAX))
        steering = float(sys.argv[3])
        if steering < -rc.STEERING_MAX or steering > rc.STEERING_MAX:
            raise ValueError("steering must be between {} and {}".format(-rc.STEERING_MAX, rc.STEERING_MAX))
    except (ValueError, IndexError):
        success = False
    return success, carid, pedals, steering



if __name__ == "__main__":
    [ success, carid, pedals, steering ] = command_line_args()
```

```python
    if not success:
        usage()
        sys.exit(1)

    # initialize signal handling
    signal.signal(signal.SIGINT, signal_handler)
    signal.signal(signal.SIGTERM, signal_handler)

    # initialize SPI
    spi = rc.initialize_spi()
    if not spi:
        print("Failed to initialize SPI.")
        sys.exit(1)

    # initialize GPIO
    rc.initialize_gpio()

    # switch on power for the specified car
    rc.switchon_rcpower(carid)

    # wait for a short time to ensure power is stable
    time.sleep(1)

    # write pedals
    rc.write_pedals(spi, carid, pedals)
```

```
    # # write pedals
    rc.write_steering(spi, carid, steering)

    # exit cleanly
    sys.exit(0)
```

- `rctest.py` parses the command line and has the following command line arguments

argument	description
`carid`	ID of the RC and car (0, 1, 2 or 3)
`pedals`	normalized motor signal $u_n \in [-1, 1]$
`steering`	normalized steering signal $\delta_n \in [-1, 1]$

4.4.1 Exercises

C.4.4.1 Measure the resistance values R_{bw} of the digital potis of RC 1 with a multimeter (see Figure 4)

- Disconnect RC 1 from socket SV 1 (see Figure 2)
- Set $u_n = 0$ and $\delta_n = 0$ by running

```
python rctest.py 0 0.0 0.0
```

- Measure the resistance R_{bw} for motor control between pins PB0 and PW0 of the first MCP42010 (Poti 1)
- Measure the resistance R_{bw} for steering control between pins PB1 and PW1
- Re-run `rctest.py`, modify the pedal and steering values $u_n, \delta_n \in [-1, 1]$ and check if the resistance values match to the expected values according to equations (3) and (6):

$$R_{bw} = \frac{R_{ba}}{255} \cdot u_q = 10\text{k}\Omega \cdot (u_n + 1)/2 \in [0\text{k}\Omega, 10\text{k}\Omega]$$

Required results are:

- Table with columns for u_n, expected R_{bw}/Ω, measured R_{bw}/Ω and at least 3 rows for different u_n values

C.4.4.2 Measure the motor and steering signal voltages of the digital potis of RC 1 with a multimeter (see Figure 5)

- Connect RC 1 to socket SV 1: now the RC supplies 3.3V to MCP42010 on PA0 and PA1
- Re-run `rctest.py`, change the pedal and steering values $u_n, \delta_n \in [-1, 1]$
- Measure the motor signal voltage u_v for motor control between pins PB0 and PW0
- Measure the steering signal voltage δ_v for steering control between pins PB1 and PW1
- Check the voltages match to the expected voltages according to equation (7):

$$u_v = 3.3\mathrm{V} \cdot (u_n + 1)/2 \in [0, 3.3\mathrm{V}]$$

Required results are:

- Table with columns for motor signal u_n, expected u_v/V, measured u_v/V and at least 3 rows for different u_n values
- Optional: same table for steering signals δ_n and δ_v

C.4.4.3 Calibrate the remote control according to Remote Control Cabling and Calibration. No results need to be documented for this exercise.

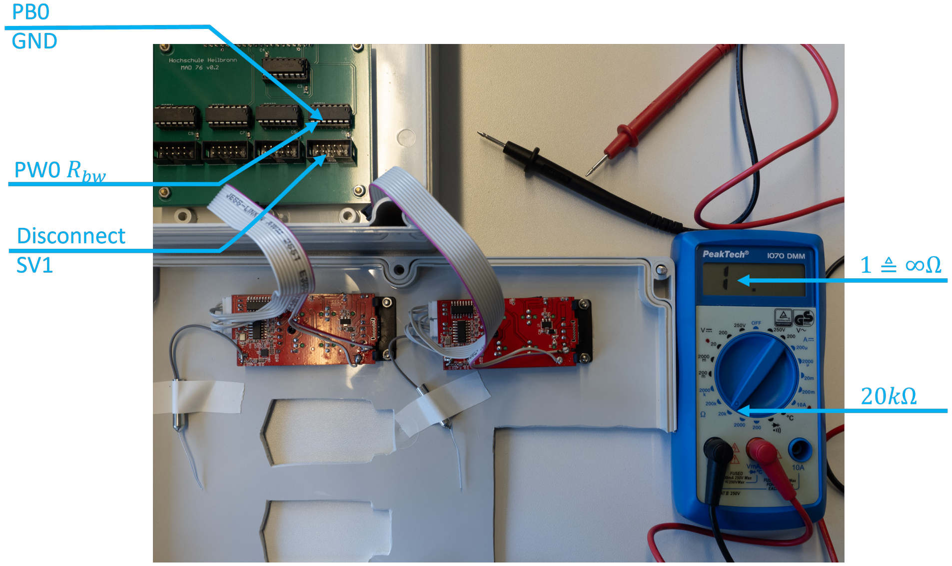


Figure 4: Exercise 1: Measure R_{bw} with a multimeter

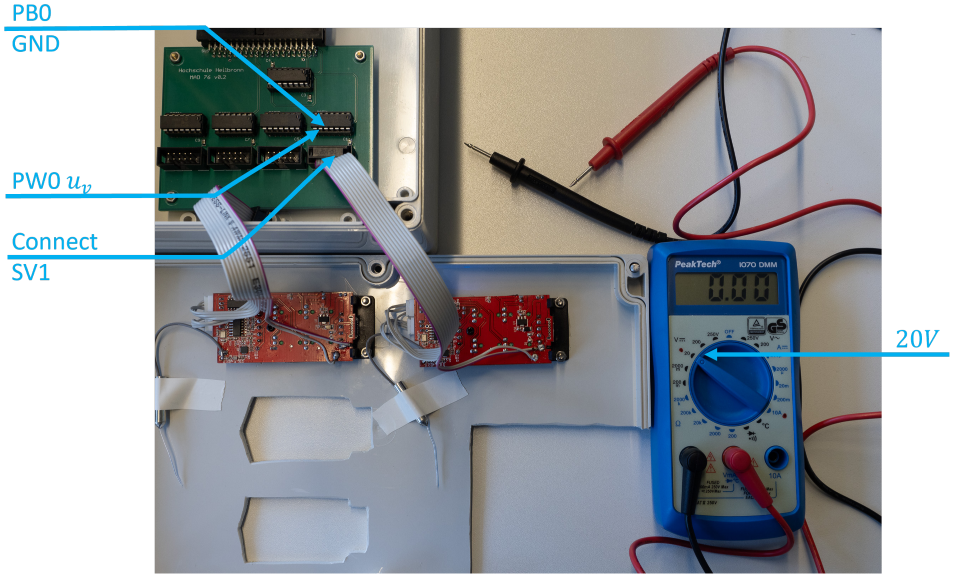


Figure 5: Exercise 2: Measure u_v with a multimeter

References

[1] *Microchip MCP42010 Data Sheet*. Accessed: 2025-02-05. 2025. URL: https://ww1.microchip.com/downloads/aemDocuments/documents/OTH/ProductDocuments/DataSheets/11195c.pdf.