

MAD76 Academy: C. MAD76 I/O Programming

Frank Tränkle*
Hochschule Heilbronn, Germany

February 21, 2026

*frank.traenkle@hs-heilbronn.de

Contents

| | | |
|----------|--|-----------|
| 1 | Agenda | 3 |
| 2 | Functional Chain | 4 |
| 2.1 | Remote Controllers (RCs) | 5 |
| 2.2 | Functional Chain from RPi over MAD76 IO to RCs | 8 |
| 2.3 | Digital I/O of Raspberry Pi | 11 |
| 3 | Power Supply | 14 |
| 3.1 | Driver L293B | 15 |
| 3.2 | Python Code to Power On RC 1 | 17 |
| 3.3 | Python Code to Power On any RC | 19 |
| 3.3.1 | Exercises | 22 |
| 4 | Digital Potentiometers | 24 |
| 4.1 | Digital Potentiometers MCP42010 | 25 |
| 4.2 | Serial-Peripheral-Interface (SPI) | 28 |
| 4.3 | SPI for MCP42010 | 30 |
| 4.4 | Python Library to Control RC | 32 |
| 4.4.1 | Exercises | 43 |

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 (μ C) and radio controller of RC (originally from battery) |
| GND | in | 2 | GND1-4 | ground |

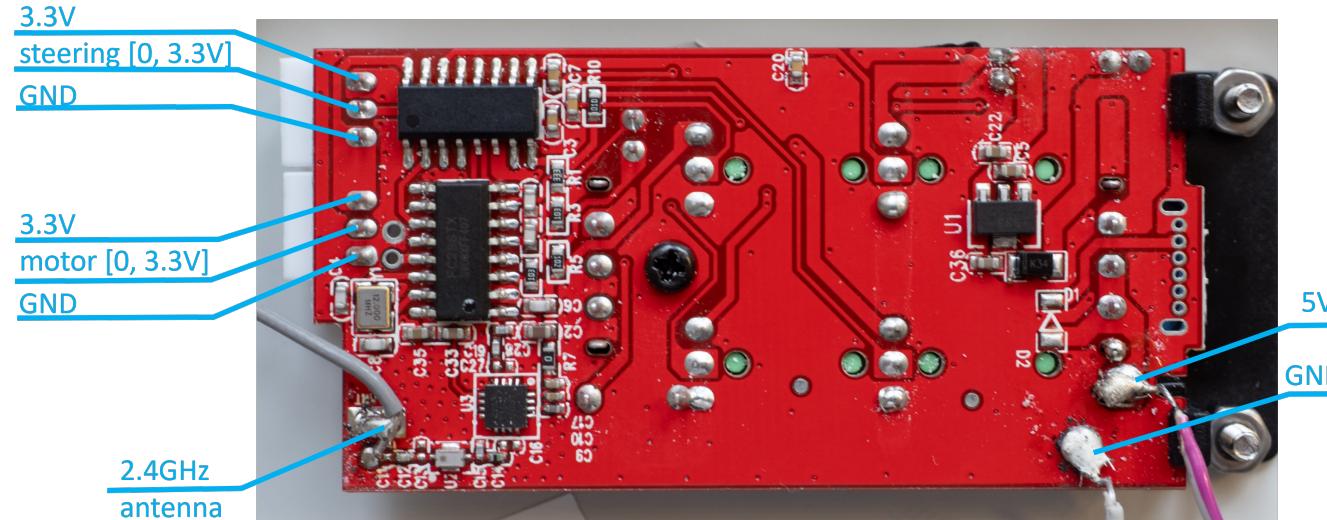
- Lower connector for motor control (thrust and braking)

| 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 μ C 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 | | | |

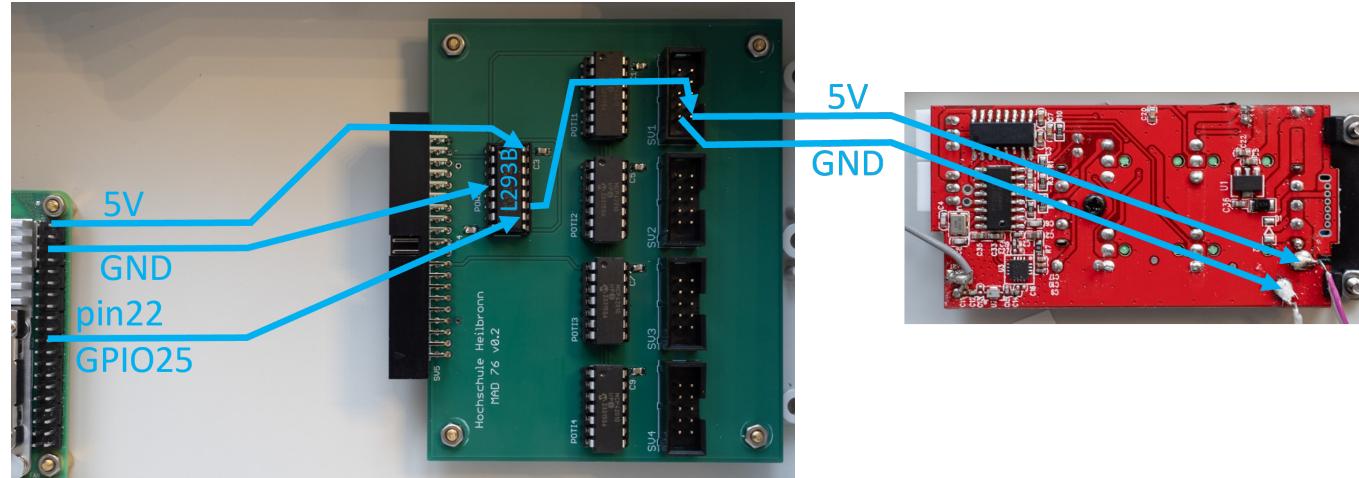
- Upper connector for steering control

| 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

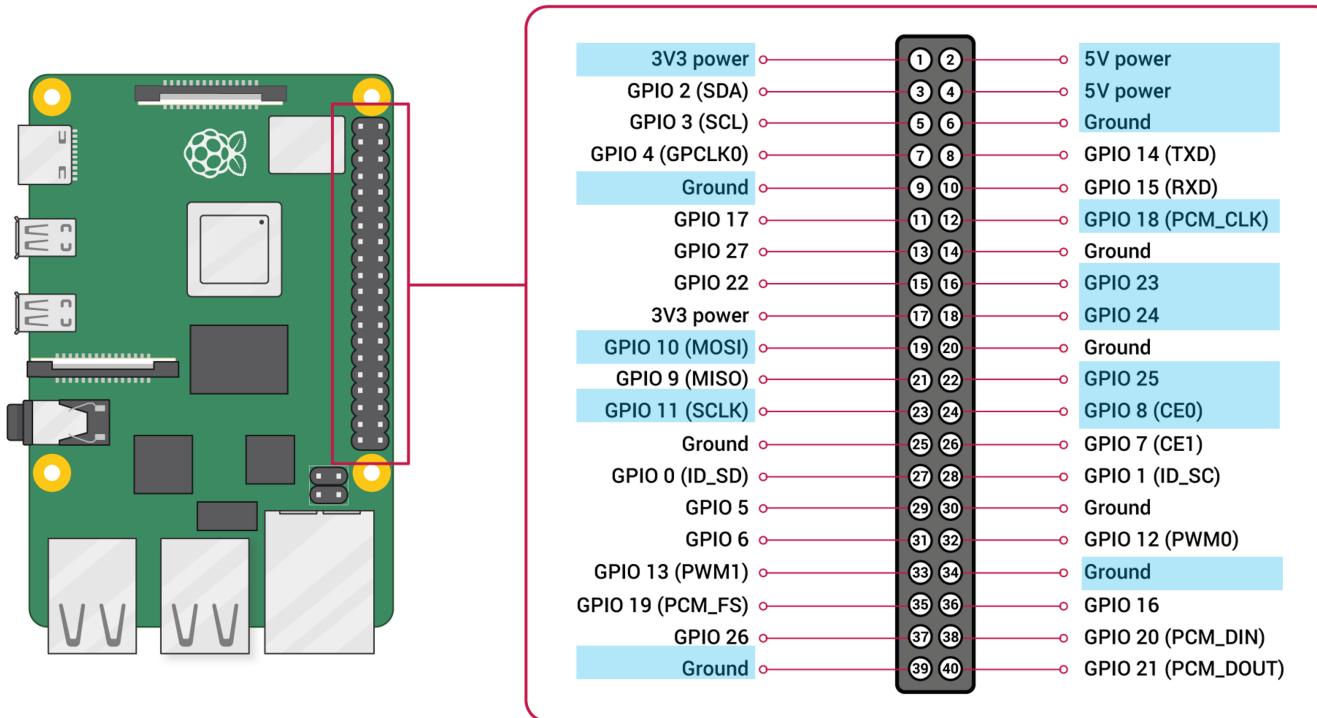


- MAD76 IO can switch RCs on and off by power switch L293B
 - L293B originally is a DC motor driver (max. 36V, 1A)
 - L293B has 4 power switches (5V), one for each RC
- Boot sequence of system must be
 1. Power off RC
 2. Switch on car
 3. Power on RC
 4. Onboard µCs of RC and car auto-calibrate steering 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-chained 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
+-----+-----+-----+-----+-----+-----+-----+
| BCM | wPi | Name | Mode | V | Physical | V | Mode | Name | wPi | BCM |
+-----+-----+-----+-----+-----+-----+-----+
|     |     | 3.3v |     |   |     |   |     | 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  | ALTO | 0  | 19  | 20 |     | 0v  |     |   |
| 9   | 13  | MISO  | ALTO | 0  | 21  | 22 | 0   | OUT | GPIO. 6 | 6  | 25 |
| 11  | 14  | SCLK  | ALTO | 0  | 23  | 24 | 1   | OUT | CEO  | 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 |
+-----+-----+-----+-----+-----+-----+-----+
```

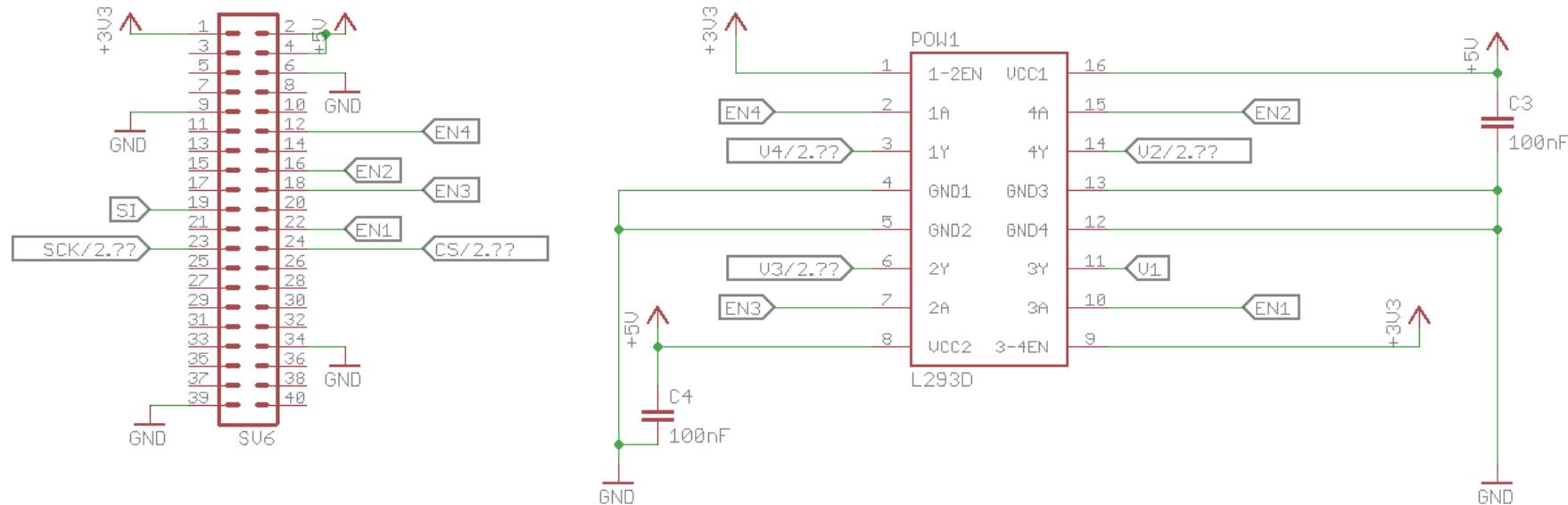
- Many programming libraries and tools are available to do GPIO and SPI on RPi
- We use
 - Python package RPi.GPIO (version python3-rpi-lgpio for RPi Zero and RPi 5)
 - Python package spidev for SPI

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

```
#!/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.BORDER)

# Configure GPIO as digital 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 arbitrary 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 digital 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 | zero-based ID of the RC to power on (0, 1, 2 or 3) |

- e.g., RC 1 (one-based, `carid==0`) is powered on by entering the following command in a terminal

```
python rcpoweron.py 0
```

- e.g., RC 2 (one-based, `carid==1`) 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.

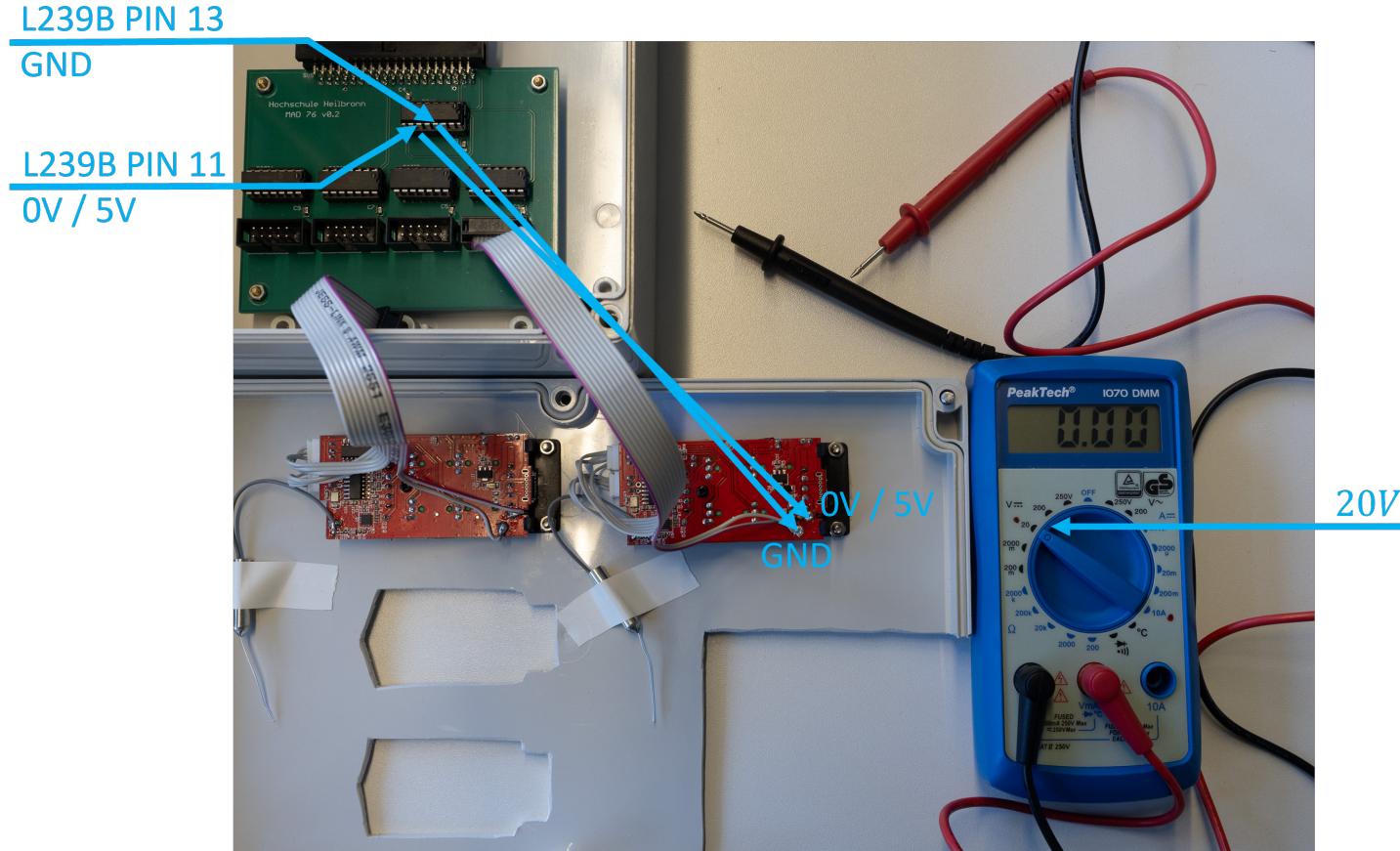


Figure 1: Exercise 2: Measure power supply voltage

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

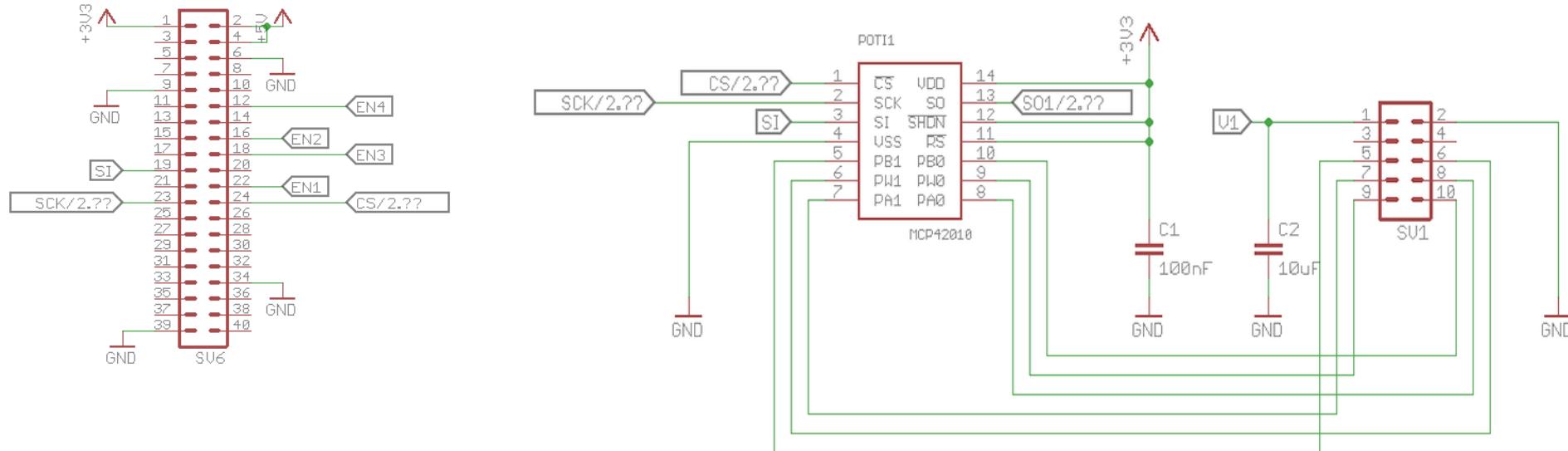


Figure 2: MAD76 IO schematics for digital poti MCP42010 [1]

- MCP42010 emulates 2 potentiometers by resistor cascades

MCP42010 has the following pins

| pin | name | in/out | function | RPi Pin | GPIO |
|-----|------|--------|---|---------|------|
| 1 | 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 | RS | in | HW reset (active low), always high \rightsquigarrow newer reset | | |
| 12 | 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 CS, SCK, MOSI)

MCP42010 contains 2 voltage dividers

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

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

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

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

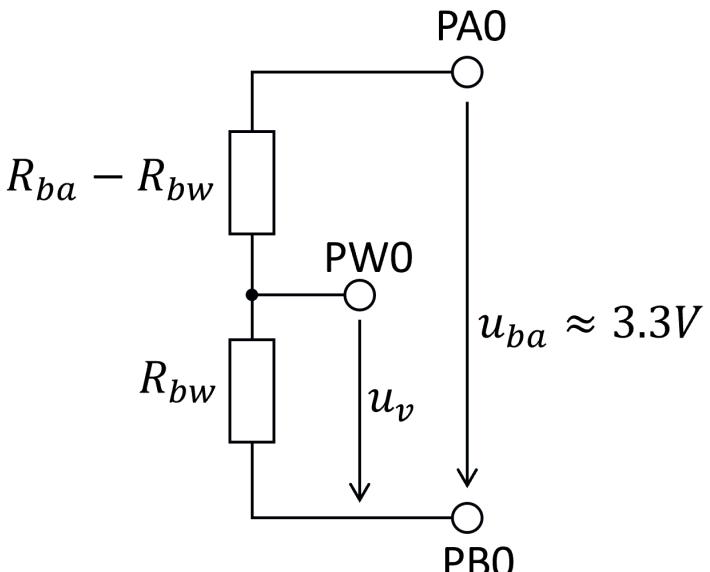
$$R_{bw} = \frac{R_{ba}}{255} \cdot u_q \in [0k\Omega, 10k\Omega] \quad (3)$$

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

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

- Identical second voltage divider for steering signal

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



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{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{CS} is low

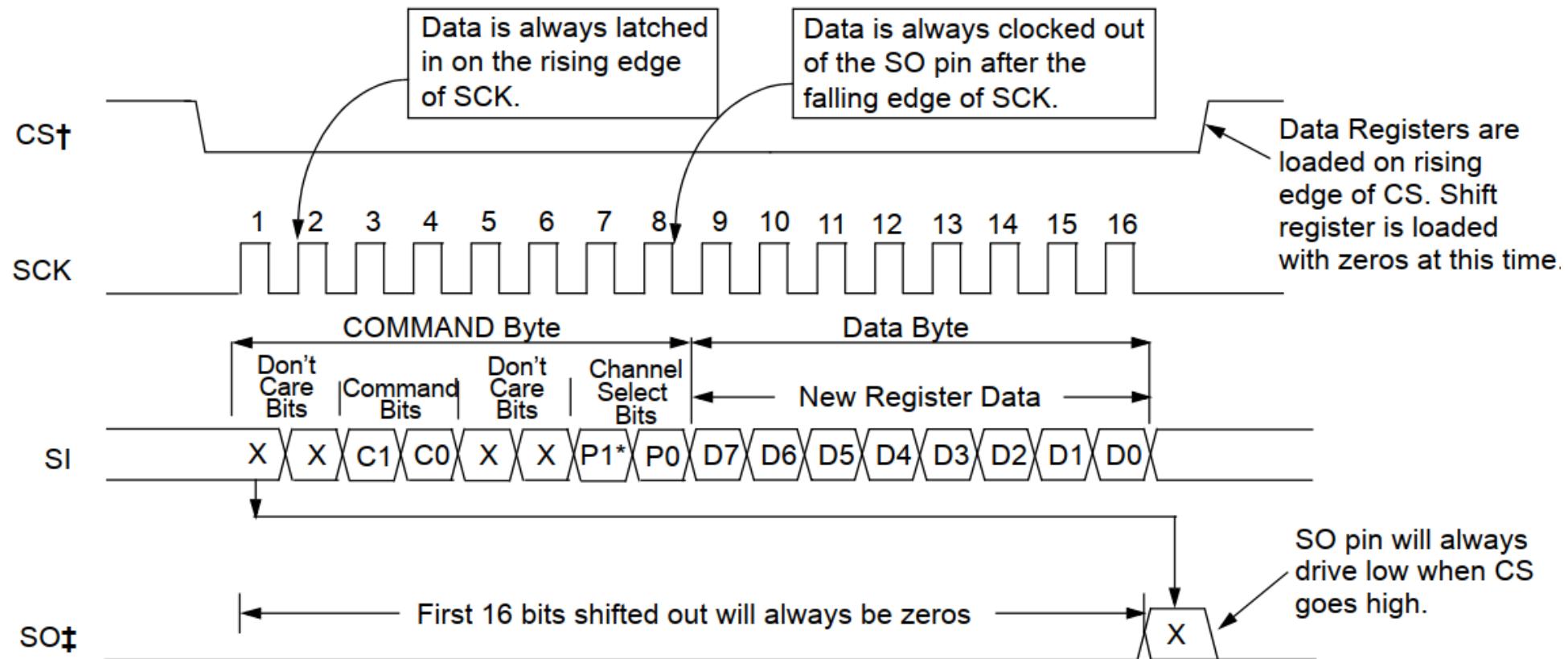


Figure 3: MCP42010 SPI timing diagram. Copied from MCP42010 data sheet [1] Figure 5.1.

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 | $u_q \in \{0, 1, \dots, 255\}$ | write data to poti 0 (motor) |
| 0x12 | $\delta_q \in \{0, 1, \dots, 255\}$ | write data to poti 1 (steering) |

- Example

| command byte | resistor data byte | |
|--------------|--------------------|--|
| 0x11 | $u_q = 128$ | sets motor signal voltage $u_v = 3.3V \cdot 128/255 = 1656mV$, 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 $3.3V \cdot 16/255 = 207mV$ |
| RC 2 0x20 $3.3V \cdot 32/255 = 414mV$ |
| RC 3 0x80 $3.3V \cdot 128/255 = 1656mV$ |
| RC 4 0xFF $3.3V \cdot 255/255 = 3300mV$ |
 - 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.
    """
```

```
"""
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
```

```
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
```

```
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 |
|---------------------|---|
| <code>spi</code> | SPI object of <code>spidev</code> |
| <code>carid</code> | RC / car ID from 0 to 3 |
| <code>pedals</code> | 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

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

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

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

- 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 |
| steering | 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()
```

```
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):

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

- 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.

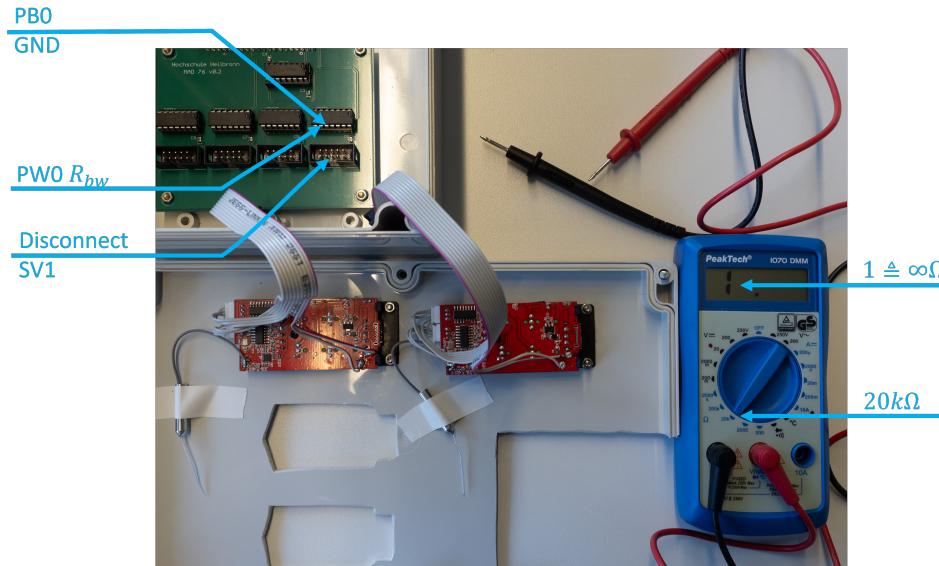


Figure 4: Exercise 1: Measure R_{bw} with a multimeter

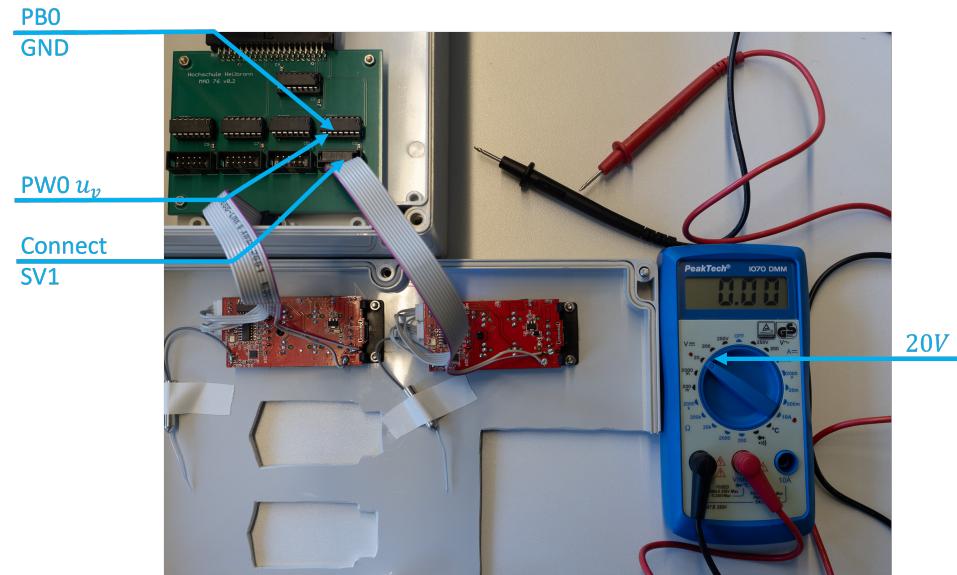


Figure 5: Exercise 2: Measure u_v with a multimeter

References

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