CIRCUIT SCHEMATICS & PRELIMINARY ANALYSIS

RFID based wireless inventory management system

TUE-02

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Strategic Milestone Review: Accomplishments, Constructive Feedback, and Proactive Solutions

1

In the previous milestone we all read about the project , understood the major aspects. Further discussed with each other to come up with a solution of implementing the antenna design keeping all the supporting components inside the antenna loop to make the structure compact so that it can be designed as a potent commercial product/ at least serves all the purpose of inventory management for WEL-LAB.

2

Studied about the PN532 RFID module which is the most suitable for our purpose with the advantage of switching between different modes of data transmission.

3 Coming to the software part, we thought of designing a website to make the tracking of all the inventory simple and also automate the reminder system by sending automatic emails.

4 we modified our plan to make the device more advanced like instead of an website switching our focus towards making a mobile application and make the target mobile and the device communicate with each other wirelessly via Bluetooth and mobile is only used to power up the device.

Overview of project management plan

Completed with the preliminary testing phase on the RC522 reader module, validating its compatibility with the web application.

1. Completed with the preliminary testing phase on the RC522 reader module, validating its compatibility with the web application.

2. The next phase involves the completion of the PCB (Printed Circuit Board) design.

3. Creation of an Android application to enhance the overall utility of the system.

Test Plan Gantt Chart Analysis: Progress, Deviations, and Justifications

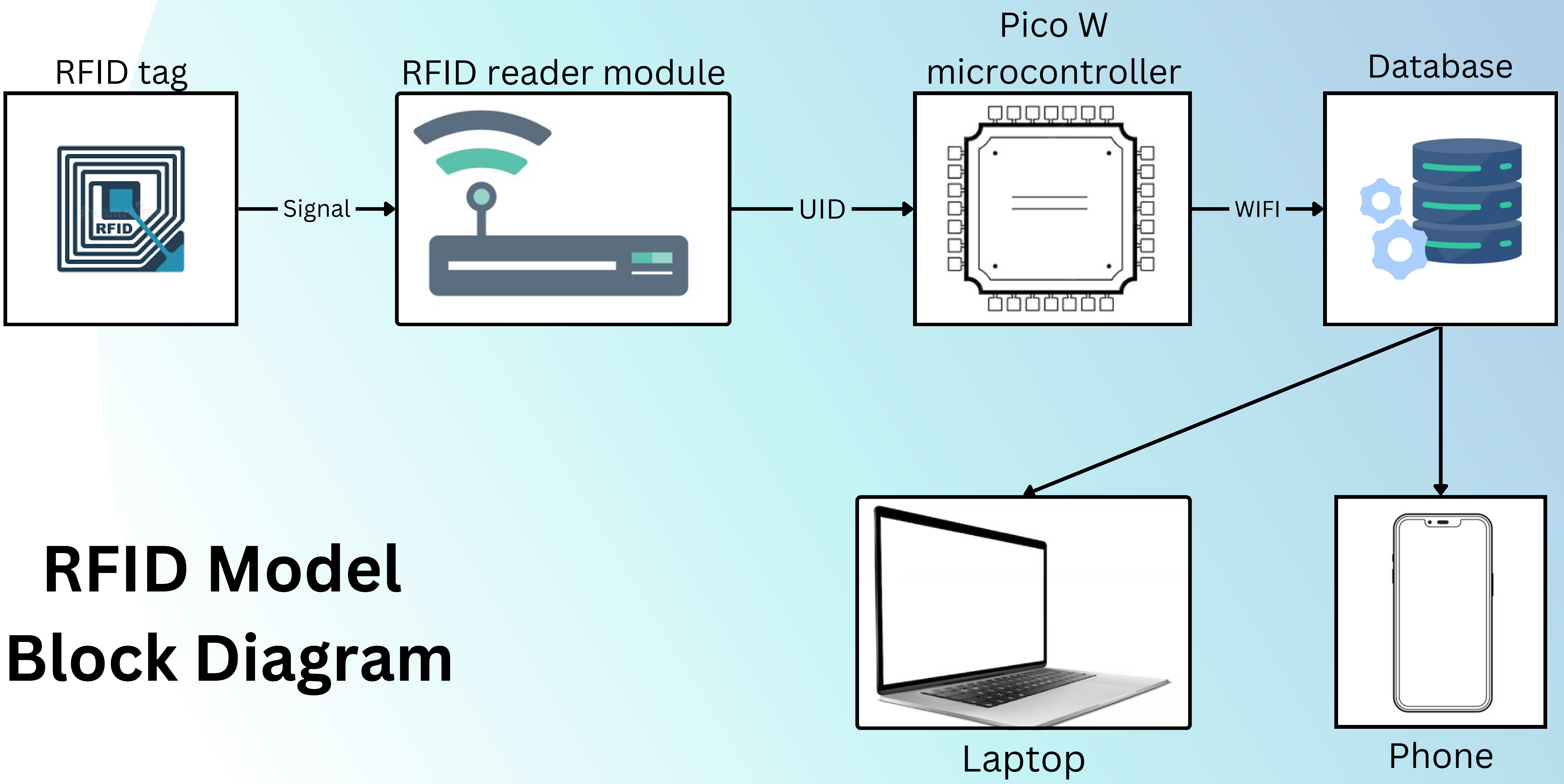
Progress and Deviation

- The hardware designing and web-development was successful.The hardware coding was not complete but we did complete some codes in alternative language (micropython which was not supposed to be used) that ran perfectly to check the working of web-interface.

- There are no deviations from plan because since we will devotee more time to the coding and complete the coding in C langauge. Also the coding will be easy further because we got to know some libraries useful for web-interfacing

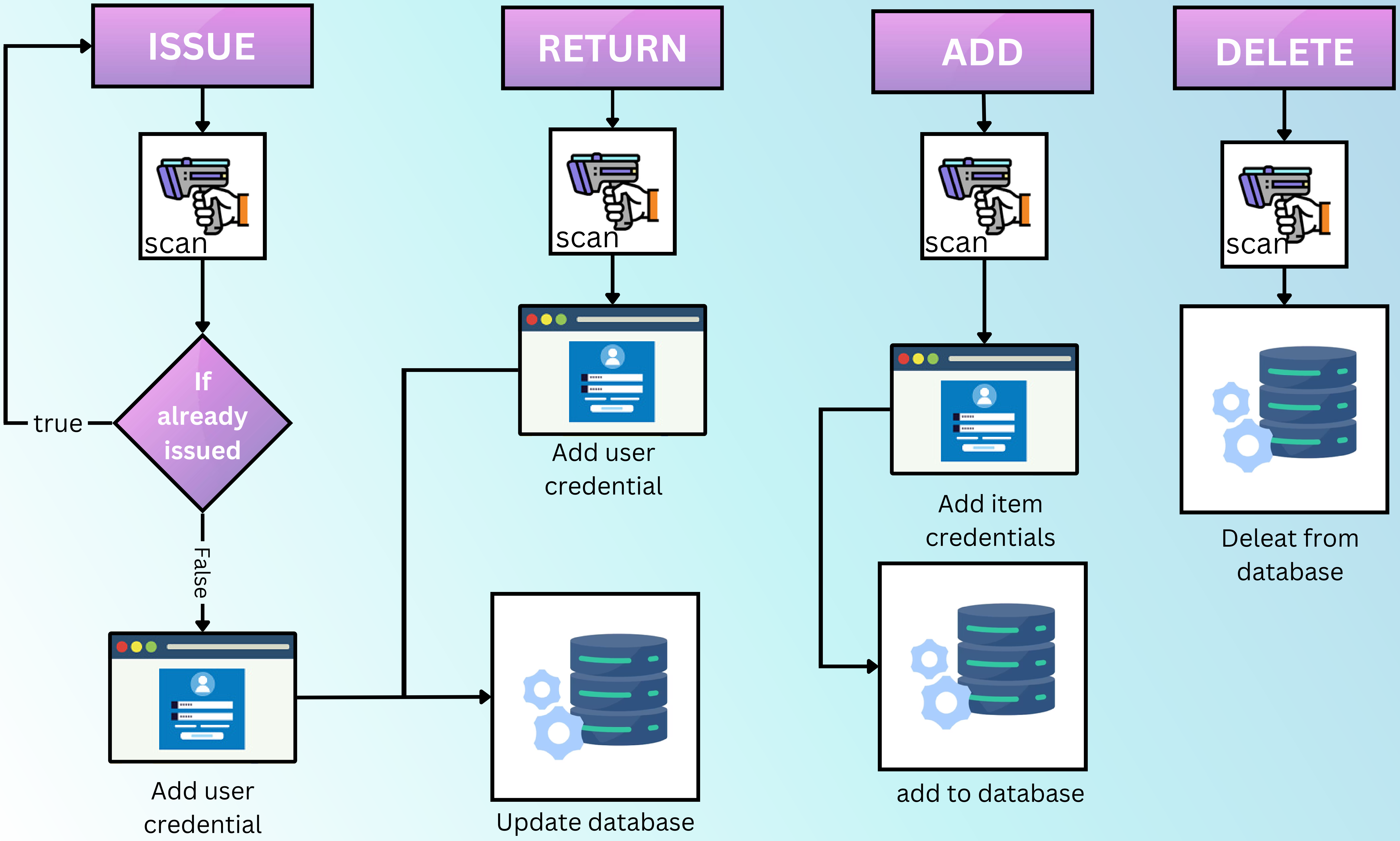
<u>Gantt Chart</u>

Project Block Diagram & Operational Principles

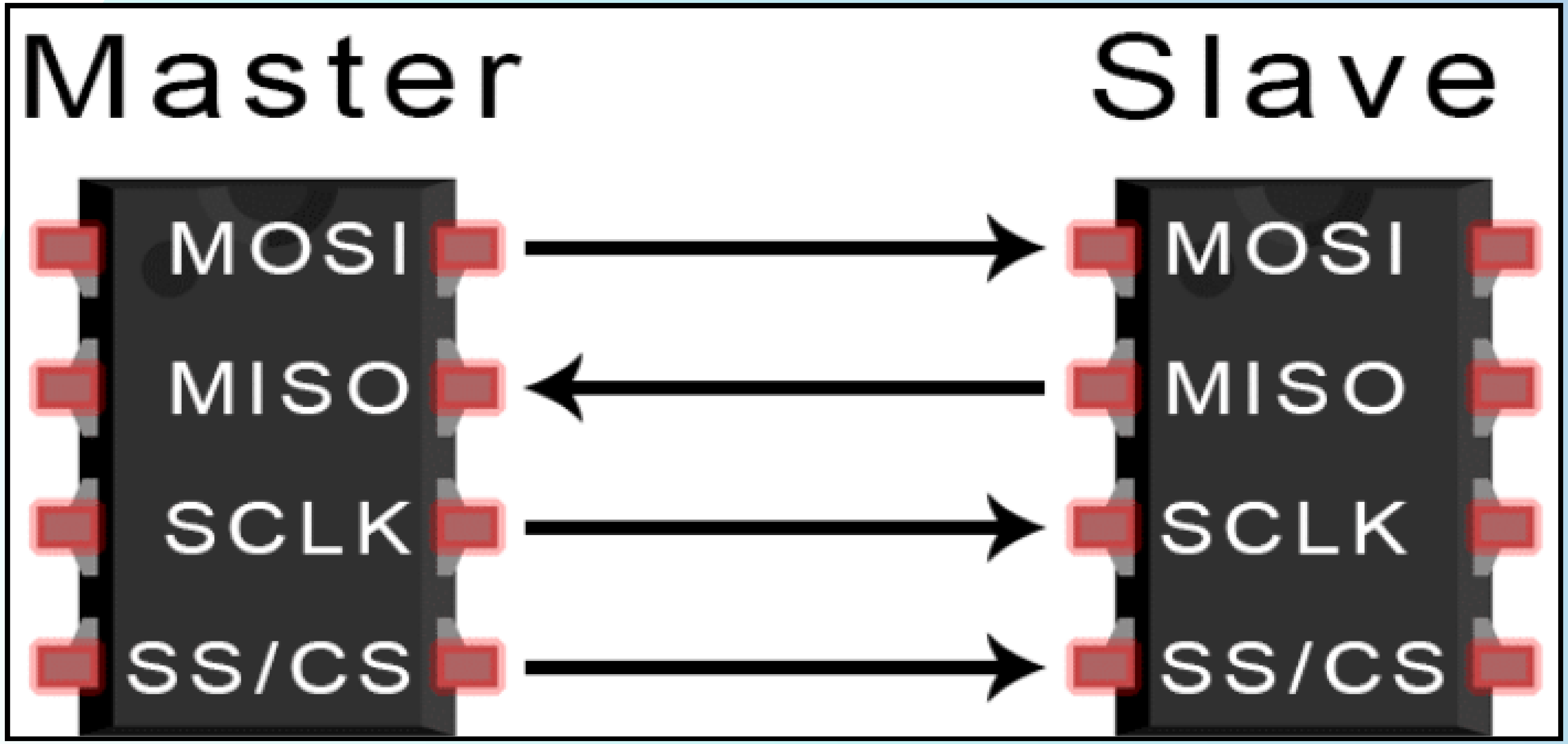


RFID Model Block Diagram

Webpage Design



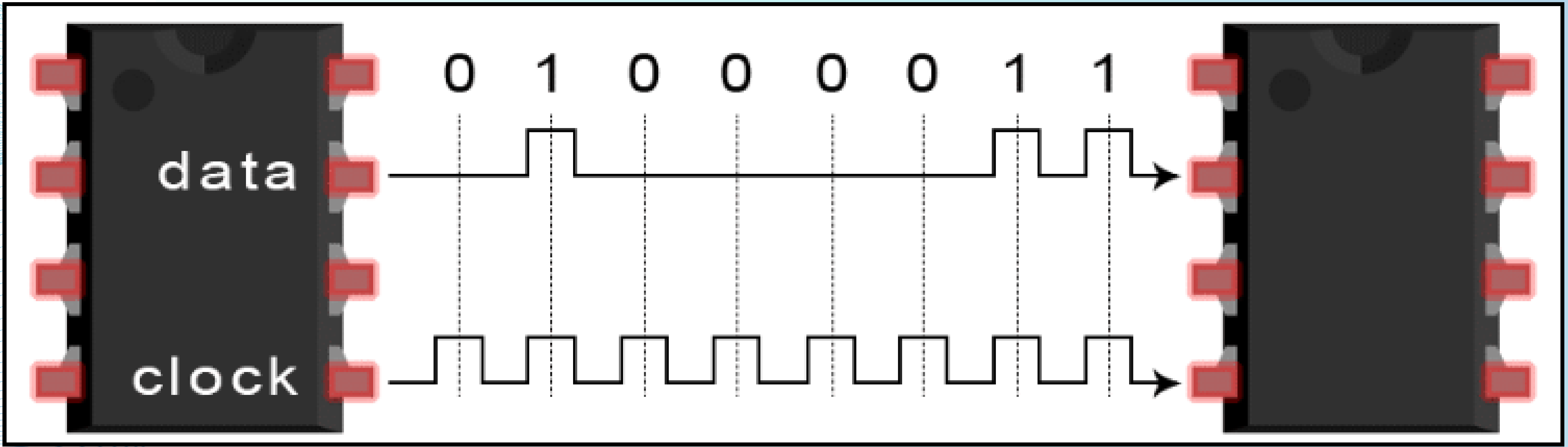
- Till now hardware coding on thonny was done(because C was time consuming but the final project coding will be done in C language).
- RC522 communicates using different protocols out of which SPI protocol suits best for our purpose. A SPI protocol module was imported to simplify the calculations.
- SPI protocol sends the data in series which means one bit after one bit. Generally using SPI protocol data can be transmitted from a single device(slave) to multiple receivers(master devices). Here in our case we have only data transmitter(the reader module) and only one data receiver(microcontroller board which is raspberry pico pi W).



- **MOSI (Master Output/Slave Input)** – Line for the master to send data to the slave.
- **MISO (Master Input/Slave Output)** – Line for the slave to send data to the master.
- **SCLK (Clock)** – Line for the clock signal.
- **SS/CS (Slave Select/Chip Select)** – Line for the master to select which slave to send data to.

HOW SPI WORKS:

- The clock signal synchronizes the output of data bits from the master to the sampling of bits by the slave. One bit of data is transferred in each clock cycle, so the speed of data transfer is determined by the frequency of the clock signal. SPI communication is always initiated by the master since the master configures and generates the clock signal.



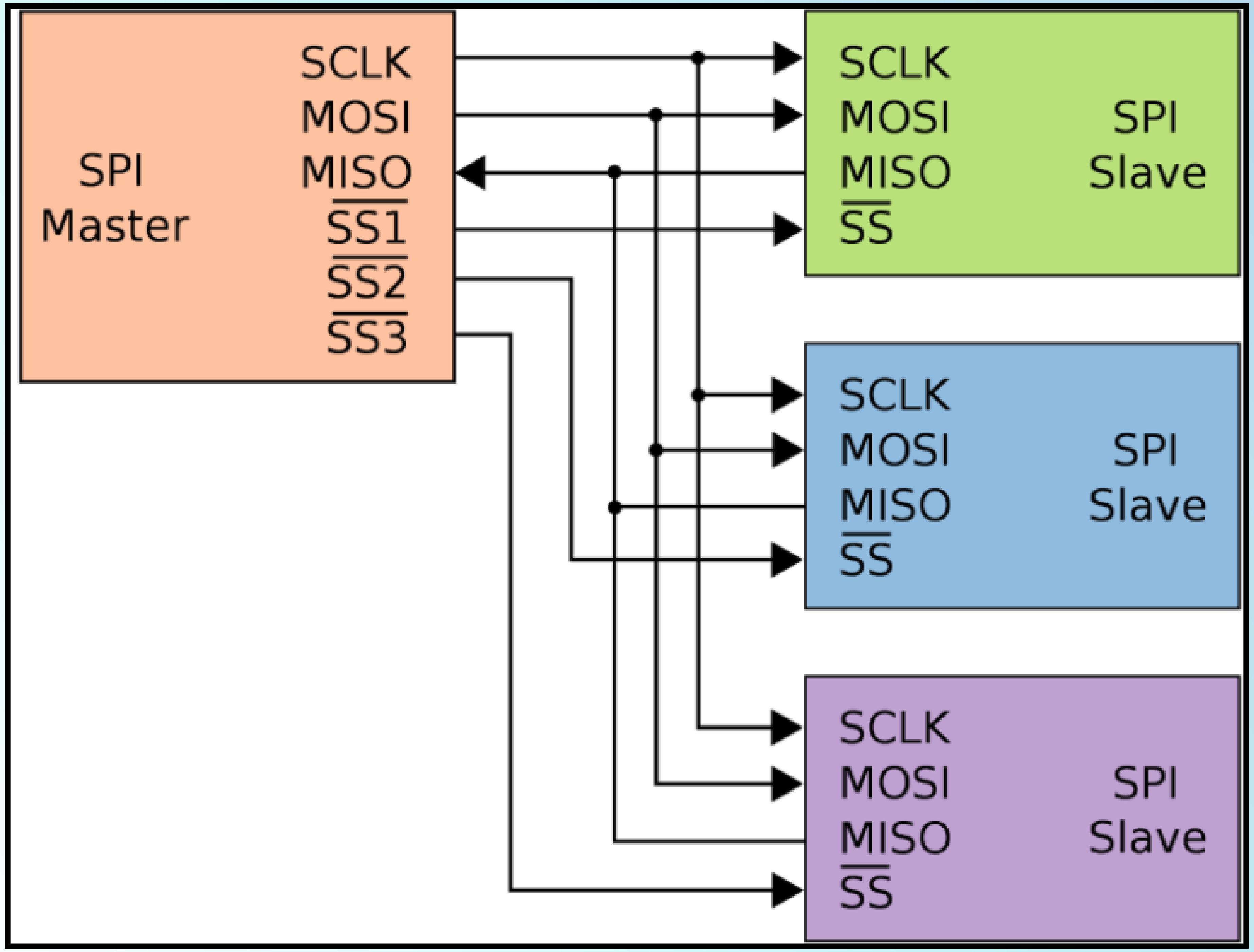
- Any communication protocol where devices share a clock signal is known as synchronous. SPI is a synchronous communication protocol.

- In serial communication, the bits are sent one by one through a single wire. The following diagram shows the serial transmission of the letter “C” in binary (01000011):

Slave select:

- The master can choose which slave it wants to talk to by setting the slave’s CS/SS line to a low voltage level. In the idle, non-transmitting state, the slave select line is kept at a high voltage level. Multiple CS/SS pins may be available on the master, which allows for multiple slaves to be wired in parallel. If only one CS/SS pin is present, multiple slaves can be wired to the master by daisy-chaining.

- Here in our design since there is only one slave, I can just simply connect the corresponding SS pins.

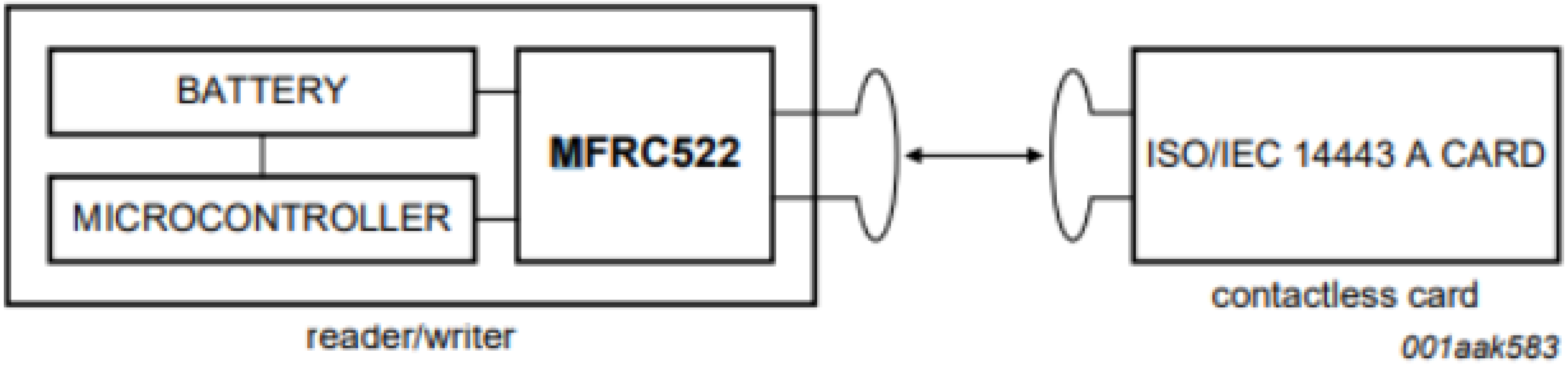


- Now just connect MOSI, MISO pins of raspberry to MOSI pins of RC522 reader.

- The master sends data to the slave bit by bit, in serial through the MOSI line. The slave receives the data sent from the master at the MOSI pin. Data sent from the master to the slave is usually sent with the most significant bit first.

- There are no start and stop bits; the data is just sent continuously.So when the module gets the signals corresponding to the tag number from the tag it simply generates a finite string of whole numbers to represent the tag number.

- That is the reason as mentioned in the start to use SPI protocol because it’s simple as there is no need of cross-checking and parity bits thus no intermixing of data.



MFRC522 Read/Write mode

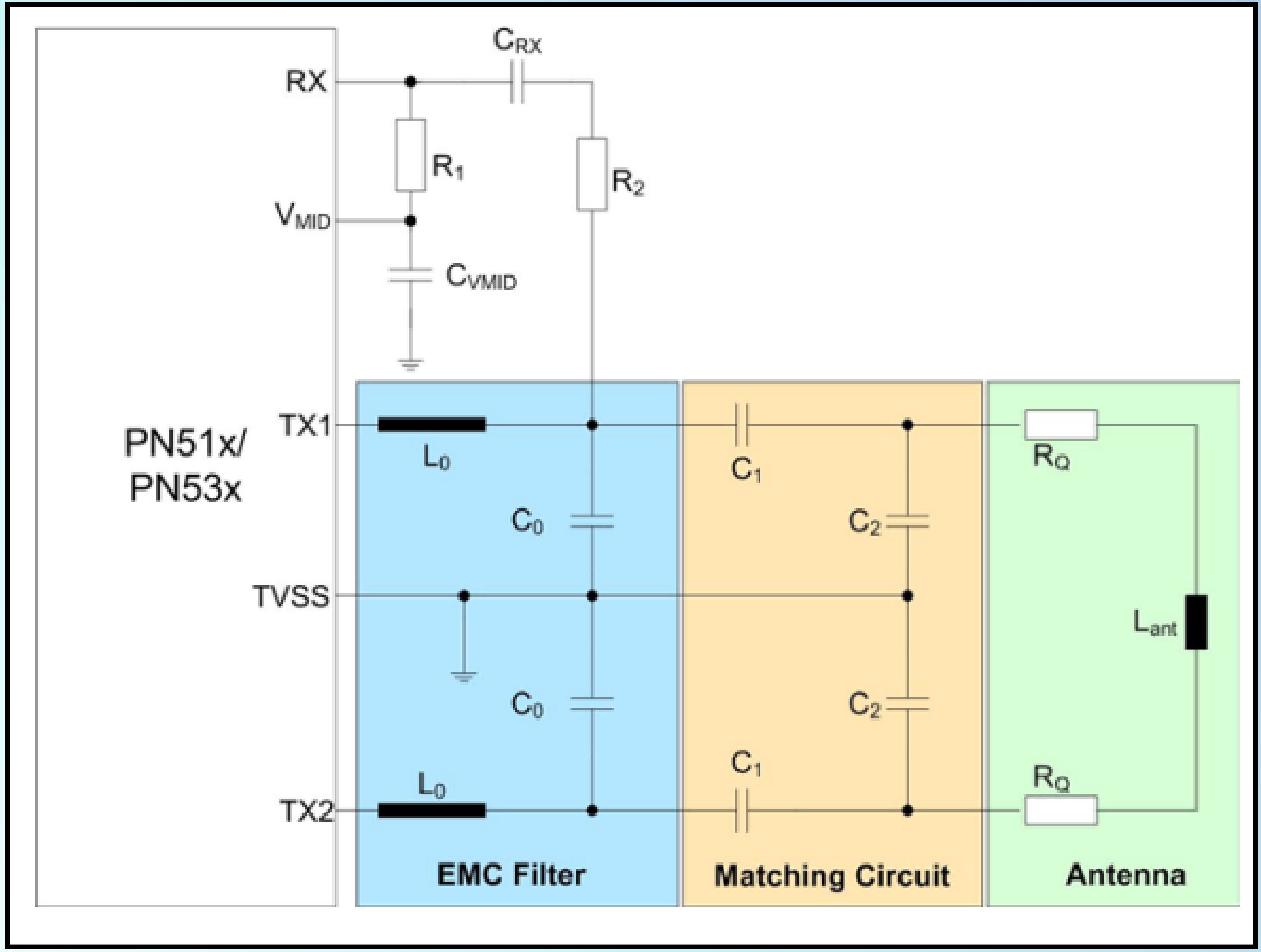
Block Diagram Validation: Analysis, Calculations, and Simulation Results

1. PCB Design Calculation:-

Our PCB design mainly consists of 3 parts:

- **EMC Filter:-** reduces 13.56 MHz harmonics and performs an impedance transformation.
- **Matching Circuit:-** acts as an impedance transformation block
- **Antenna:-** itself generates the magnetic field
- **Receiving Circuit:-** provides the received signal to the MFRC522/MFRC523/PN51x/PN53x internal receiving stage

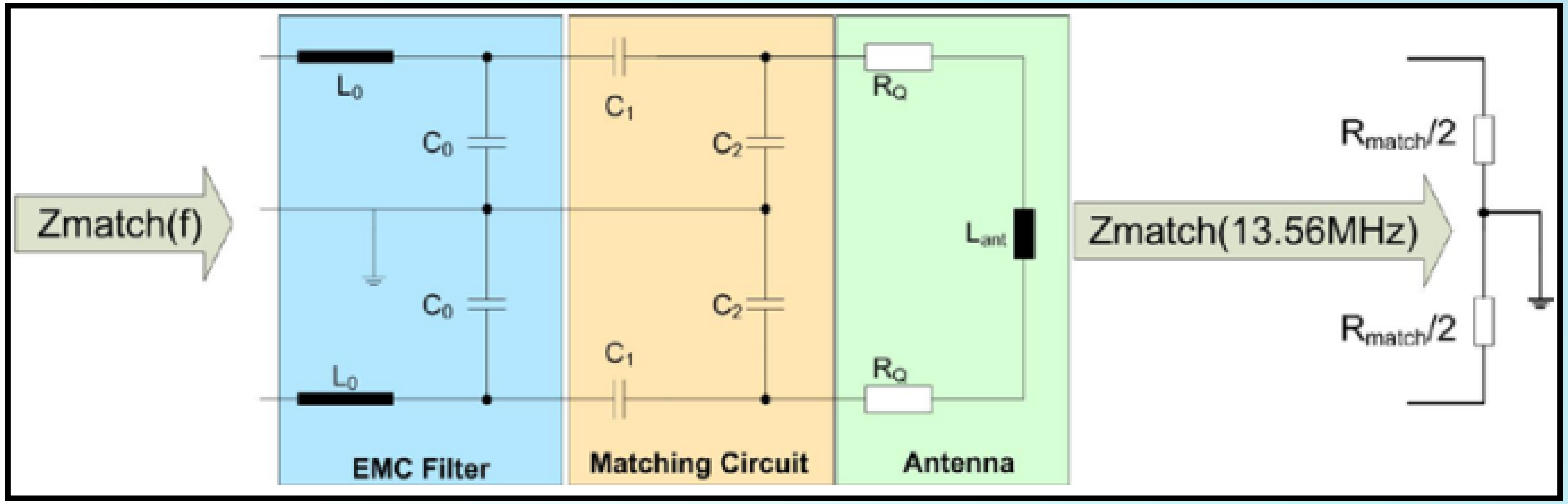
Block diagram of the complete RF part



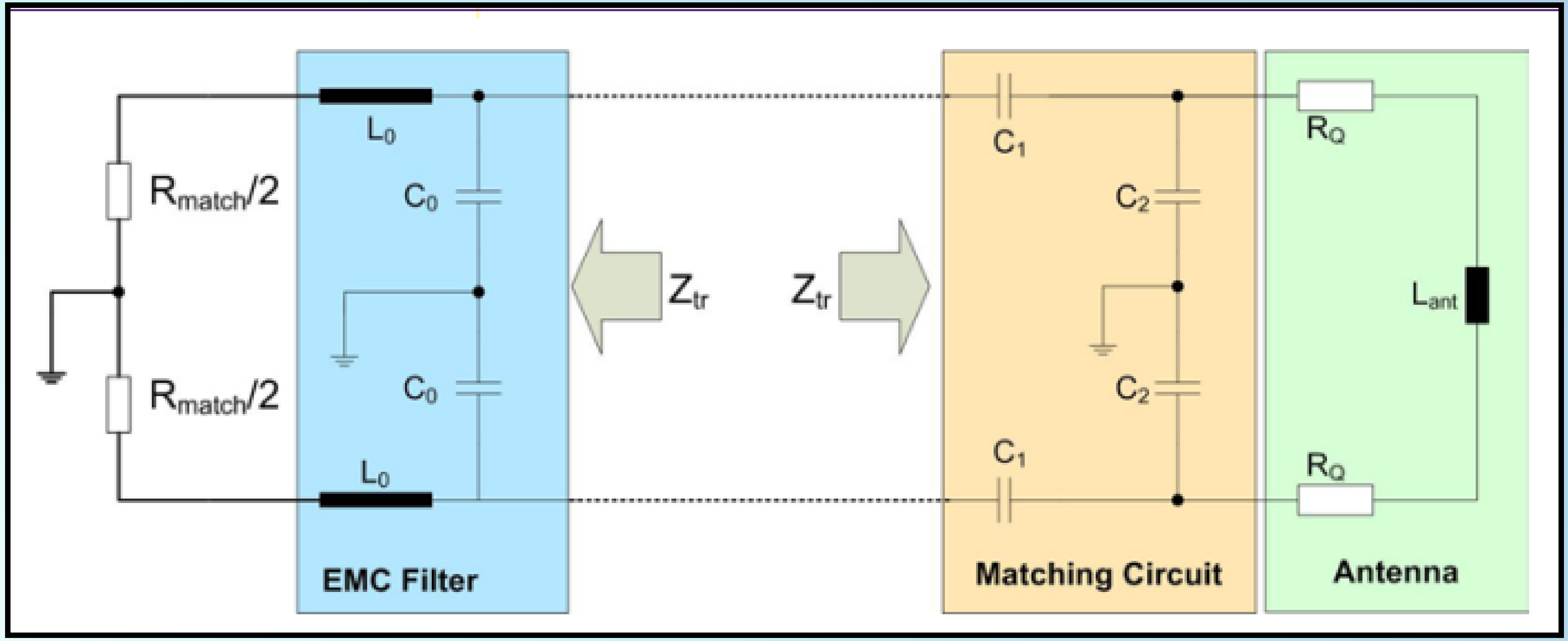
a.EMC Filter Design:-

Mainly has two function-

- Decreasing the amplitude rise time after a modulation phase
- Increasing the receiving bandwidth



Impedence Transformation



Definition of transformation impedance Ztr

$$Z_{tr} = R_{tr} + jX_{tr}$$

$$Z_{tr}^{*} = R_{tr} - jX_{tr}$$

EMC filter general design rules:

L_0 = 390 nH - 1 μH

Filter resonance frequency f_{r0} = 14.1 MHz ...14.5 MHz, => C_0

$$C_0 = \frac{1}{(2 \cdot \pi \cdot f_{r0})^2 L_0}$$

$$R_{tr} = \frac{R_{match}}{\left(1-\omega^2 \cdot L_0 \cdot C_0\right)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2}$$

$$X_{tr} = 2 \cdot \omega \cdot \frac{L_0 \cdot \left(1-\omega^2 \cdot L_0 \cdot C_0\right) - \frac{R_{match}{}^2}{4} \cdot C_0}{\left(1-\omega^2 \cdot L_0 \cdot C_0\right)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2}$$

b.Matching Filter Design:-

The following formulas apply for the series and parallel matching capacitances

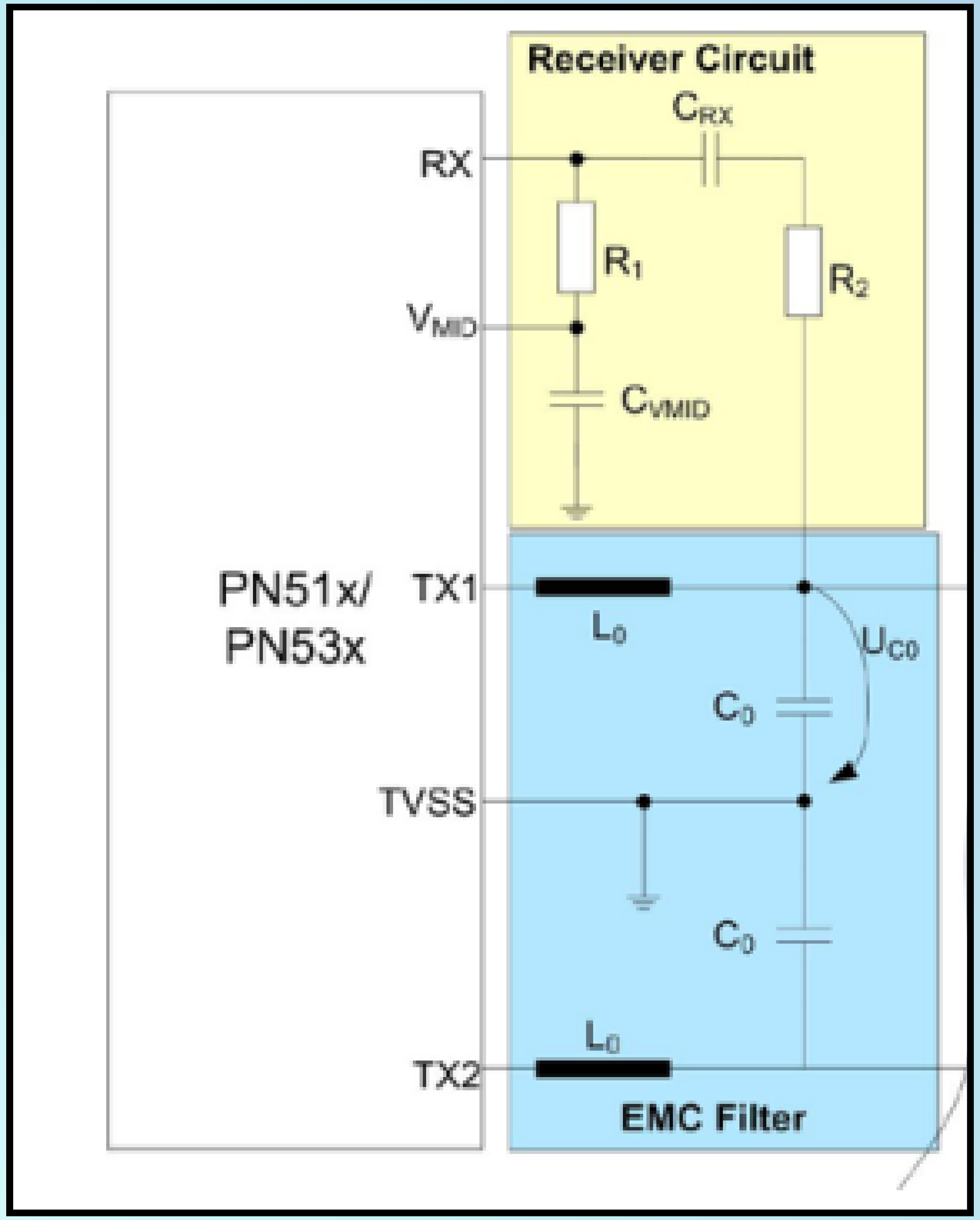
$$C_1 \approx \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{tr} \cdot R_{pa}}{4}} + \frac{X_{tr}}{2} \right)}$$

$$C_2 \approx \frac{1}{\omega^2 \cdot \frac{L_{pa}}{2}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{tr} \cdot R_{pa}}{4}}} - 2 \cdot C_{pa}$$

- **C1 changes the magnitude of the matching impedance**
- **C2 changes mainly the imaginary part of Zmatch.**

c.Receiving Circuit Design:-

Next step, after matching and tuning the transmitting antenna, is the design and tuning of the receiver circuit



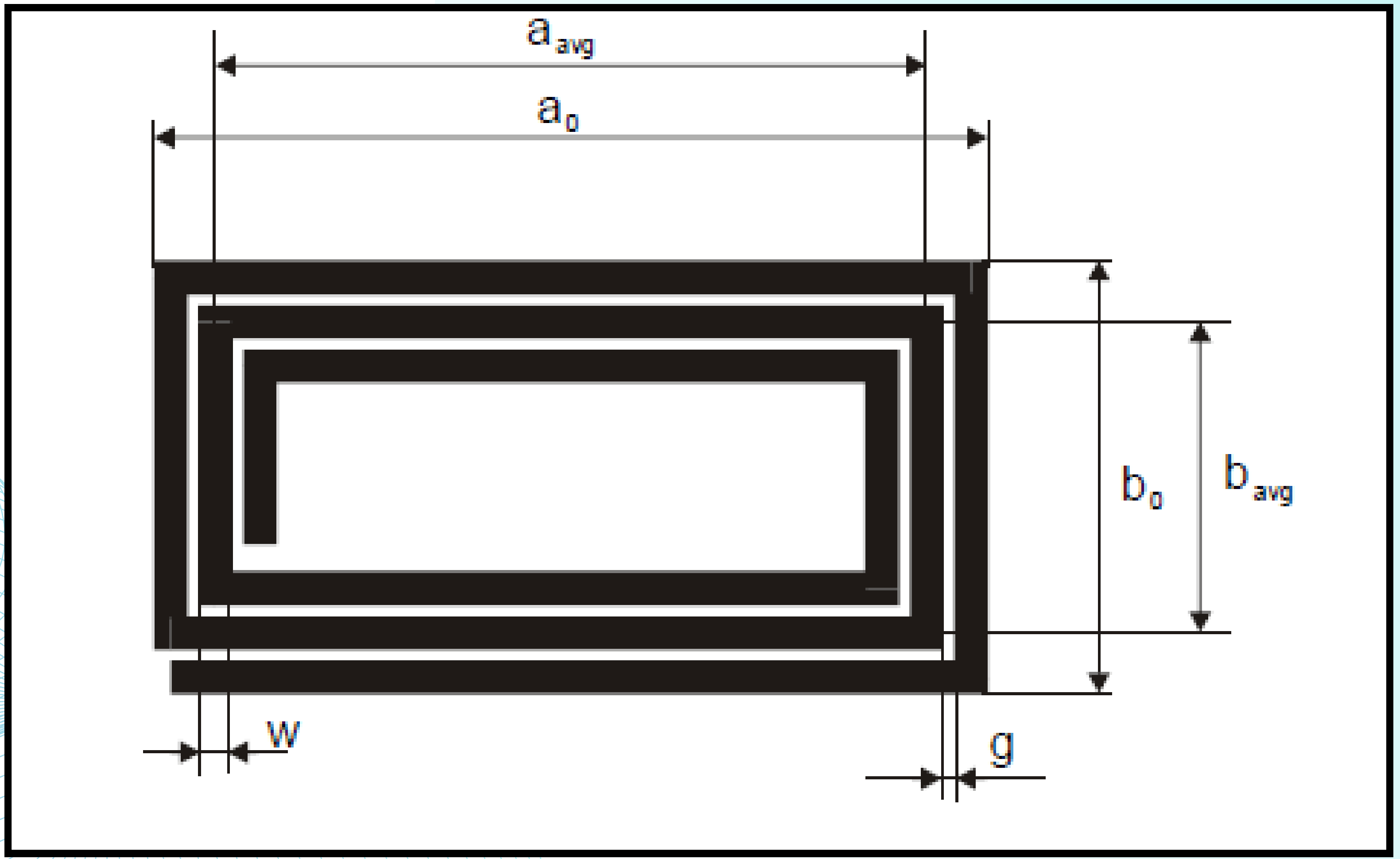
Receiving Circuit

Predefined components:
CRX = 1 nF: DC blocking capacitor
Cvmid = 100 nF: Vmid decoupling capacitance
R1 = 1 kΩ: Predefined part of the voltage divider

The voltage divider resistor R2 can be calculated by:
traget value of Urx = 1

$$R_2 = R_1 \cdot \left(\frac{U_{C0}}{U_{RX}} - 1 \right)$$

2. Antenna Design calculation



Here variables

- ao, bo   Overall dimensions of the coil
- aavg, bavg Average dimensions of the coil
- t   Track thickness
- w   Track width
- g   Gap between tracks
- Na   Number of turns
- d   Equivalent diameter of the track

Na Ranges from 1-6 turns

Calculation of equivalent inductance antenna

$$L_a = \frac{\mu_0}{\pi} \cdot [x_1 + x_2 - x_3 + x_4] \cdot N_a^{1.8}$$

With:

$$d = \frac{2 \cdot (t + w)}{\pi}$$

$$a_{avg} = a_o - N_a \cdot (g + w)$$

$$b_{avg} = b_o - N_a \cdot (g + w)$$

$$x_1 = a_{avg} \cdot \ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(a_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right]$$

$$x_2 = b_{avg} \cdot \ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(b_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right]$$

$$x_3 = 2 \cdot \left[a_{avg} + b_{avg} - \sqrt{a_{avg}^2 + b_{avg}^2}\right]$$

$$x_4 = \frac{a_{avg} + b_{avg}}{4}$$

Antenna quality factor

The quality factor is a determining constraint to design and tune an antenna.

The bandwidth B –pulse width T product is defined as:

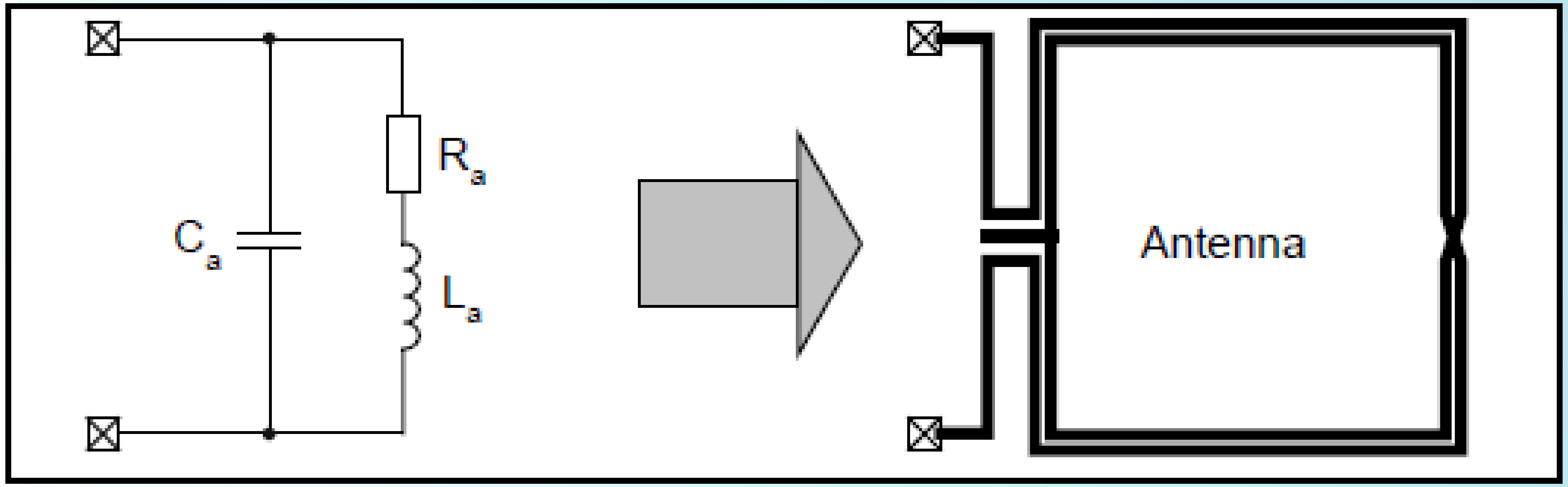
$B.T \geq 1$

With the bandwidth definition

$Q = f/B$ (operating frequency is 13.6MHz) for $T = 3\ \mu s$

The recommended antenna quality factor is $Q = 35$.

Determination of series equivalent circuit



- The antenna loop has to be connected to an impedance analyzer to measure the series equivalent components. we have taken standard PN532 for our testing case so its can calculated following formula

Calculation of antenna quality factor for damping resistor RQ

The quality factor of the antenna is

Qa = ωLa/Ra

If the calculated value of Qa is higher than the target value of 35, an external damping resistor RQ has to be inserted on each antenna side to reduce the Q-factor to a value of 35 (±10%).

The value of RQ calculates as:

$$R_Q = 0.5 \cdot \left(\frac{\omega \cdot L_a}{35} - R_a \right)$$

For Series equivalent circuit

The following characteristic circuit elements can be determined by measurements at characteristic points

Rs Equivalent resistance at f = 1 MHz

La Equivalent inductance at f = 1 MHz

Rp Equivalent resistance at the self-resonance frequency

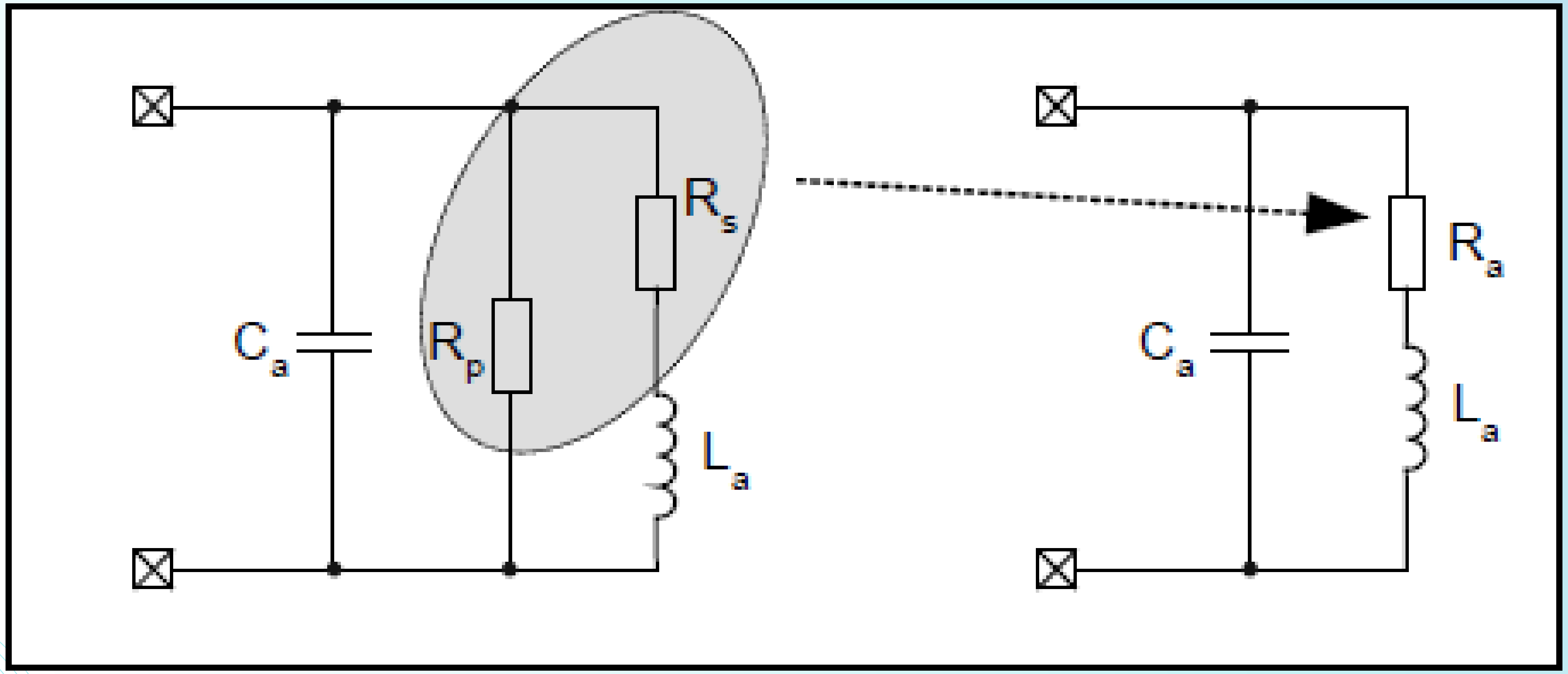
fra Self-resonance frequency of the antenna

The antenna capacitance Ca can be calculated with:

$$C_a = \frac{1}{(2 \cdot \pi \cdot f_{ra})^2 L_a}$$

Series equivalent resistance calculation

The series equivalent resistance of the antenna at the operating frequency fop = 13.56 MHz can be calculated out of the characteristic circuit with:



$$R_a = R_s + \frac{\left(2 \cdot \pi \cdot f_{op} \cdot L_a\right)^2}{R_p}$$

Calculations

Antenna Matching Calculations

calculated				
to be filled in				

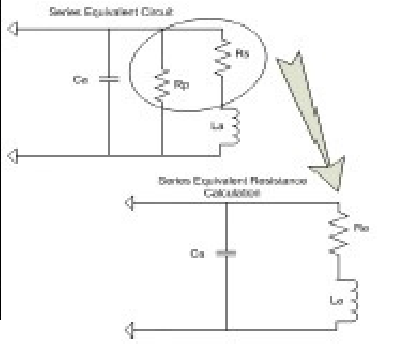
Step 1

	value	unit	annotation
f =	1.356E+07	[Hz]	
omega =	8.520E+07	[s^{-1}]	
L_0 =	5.600E-07	[H]	
f_{r0} =	1.440E+07	[Hz]	
$C_{0\ calculated}$ =	2.181E-10	[F]	
C_0 =	2.200E-10	[F]	chosen value for C0
R_{match} =	5.000E+01	[Ω]	
R_{tr} =	2.167E+02		
X_{tr} =	-5.783E+01		

fres = 1.434E+07

Step 2

1st Iteration: Measurement of Antenna parameter L_a, R_s, R_p, f_{ra}			
Antenna:	linear view	unit	annotation
L_a =	8.680E-07	[H]	
R_s =	2.000E-01	[Ω]	
R_p =	4.200E+03	[Ω]	at self resonance frequency
f_{ra} =	8.542E+07	[Hz]	self resonance frequency of the antenna
Rp (13.56MHz) =	1.054E+04	[Ω]	Skin effect included
R_a =	0.719	[Ω]	
C_a =	3.999E-12	[F]	
Q_a =	**102.881**		
R_Q =	0.873	[Ω]	Resistance for a Q_a-value of 30



Step 3

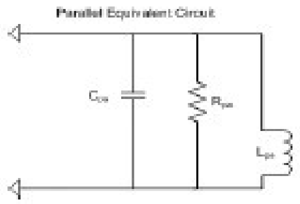
choose an appropriate value for R_Q and perform a 2nd antenna measurement for L_a, R_s, R_p, f_{ra}

Step 4

2nd Iteration: Measurement of Antenna parameter L_a, R_s, R_p, f_{ra}			
Antenna:	linear view	unit	annotation
L_a =	8.680E-07	[H]	
R_s =	2.200E+00	[Ω]	
R_p =	4.200E+03	[Ω]	at self resonance frequency
f_{ra} =	8.542E+07	[Hz]	self resonance frequency of the antenna
Rp (13.56MHz) =	1.054E+04		Skin effect included
R_a =	2.719	[Ω]	
C_a =	3.999E-12	[F]	
Q_a =	**27.201**		

Step 5

Antenna:	linear view	unit	annotation
L_{pa} =	8.680E-07	[H]	
C_{pa} =	3.999E-12	[F]	
R_{pa} =	2.012E+03	[Ω]	
Q_{pa} =	27.201		



Step 6

Calculate Matching Components			
Matching Circuit:	value	unit	annotation
C1 =	3.897E-11	[F]	
C2 =	2.739E-10	[F]	

Step 7

if antenna topology II will be applied please continue with the worksheet "C1 split calculation for AT II"

Simulation results:

main.py data_read.py mfrc522.py

```python
import urequests
import data_read

# Your Google Sheets API endpoint
sensor = 0
date = ""
# Function to read UID tag
def read_uid():
    return data_read.read_uid()

# Connect to WiFi
wlan = network.WLAN(network.STA_IF)
wlan.active(True)
wlan.connect('iQOO Z7 Pro 5G', 'Soumyadeep')
```

Shell

```
MPY: soft reboot
CARD ID: 1282216987
Date of scanning: 2024-03-05
Time of scanning: 15:43:27
```

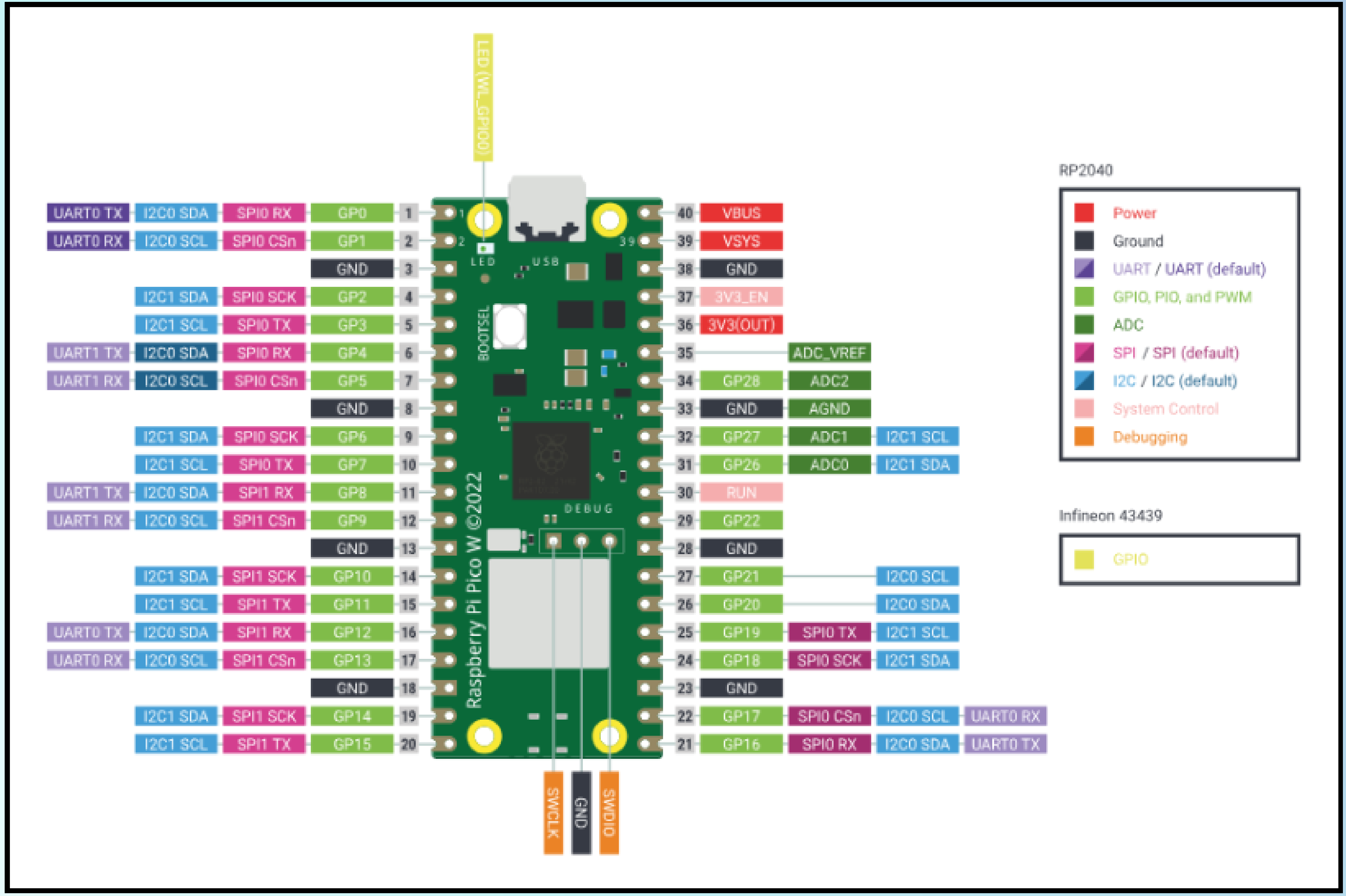
main.py data_read.py mfrc522.py

```python

    # Send HTTP GET request to update sensor value
    response = urequests.get(sheets_api_url)

    # Print response content
    #print(response.content)

    # Close the response
    response.close()

    # Wait for one minute
    utime.sleep(10)

```

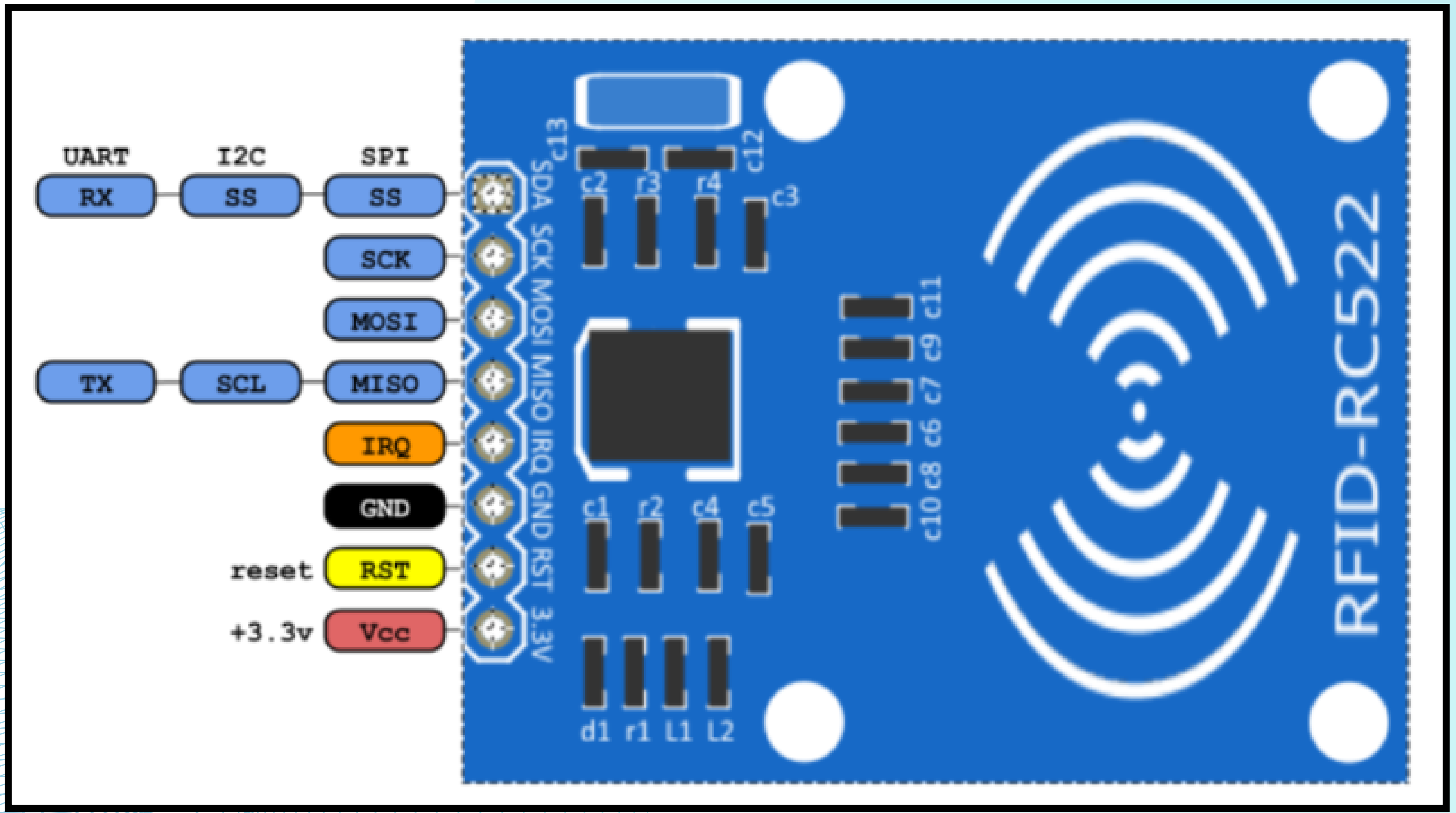
Shell

```
MPY: soft reboot
CARD ID: 1309147668
Date of scanning: 2024-03-05
Time of scanning: 15:46:10
```

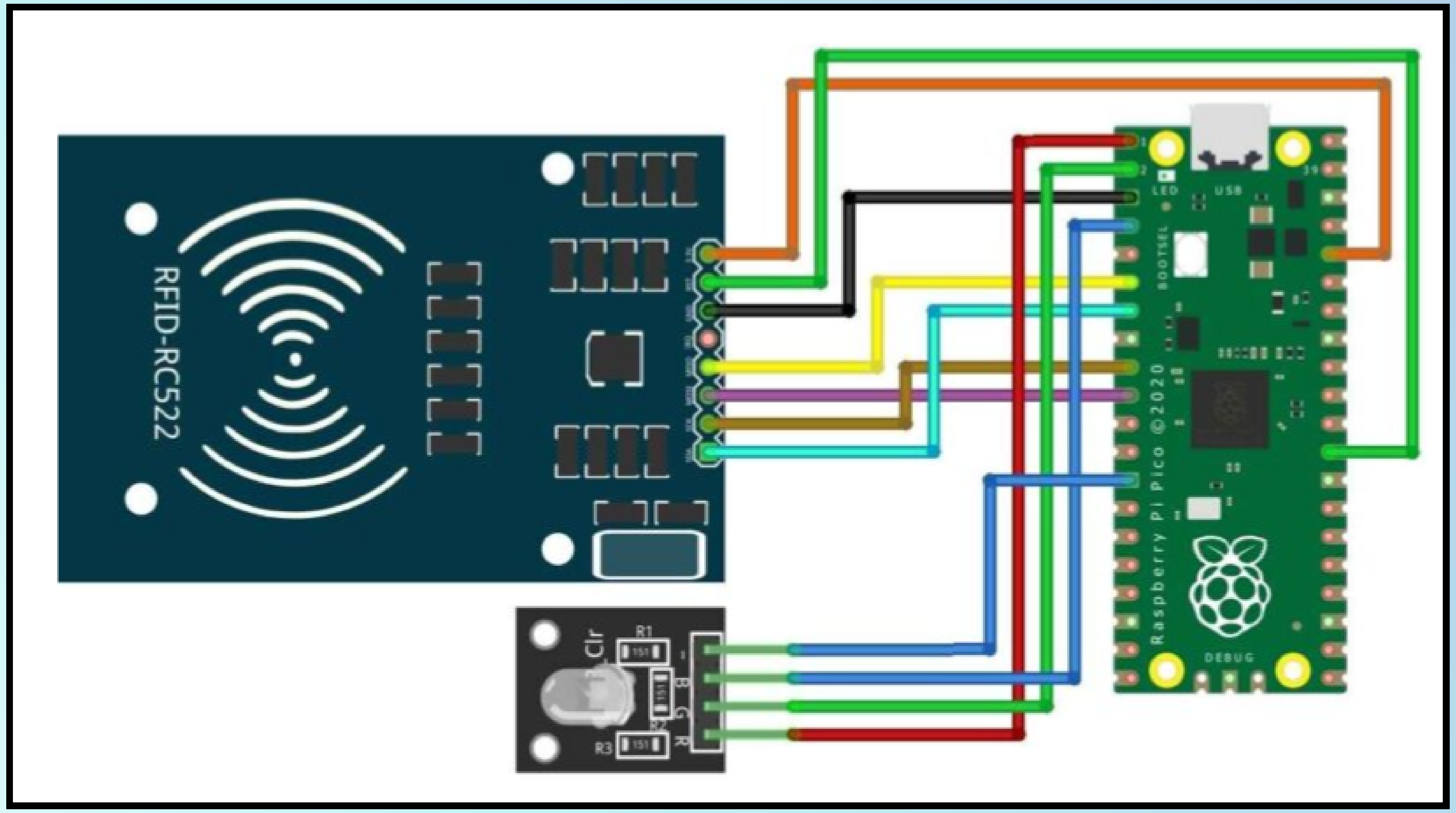
PIN diagram of board and circuit diagrams:

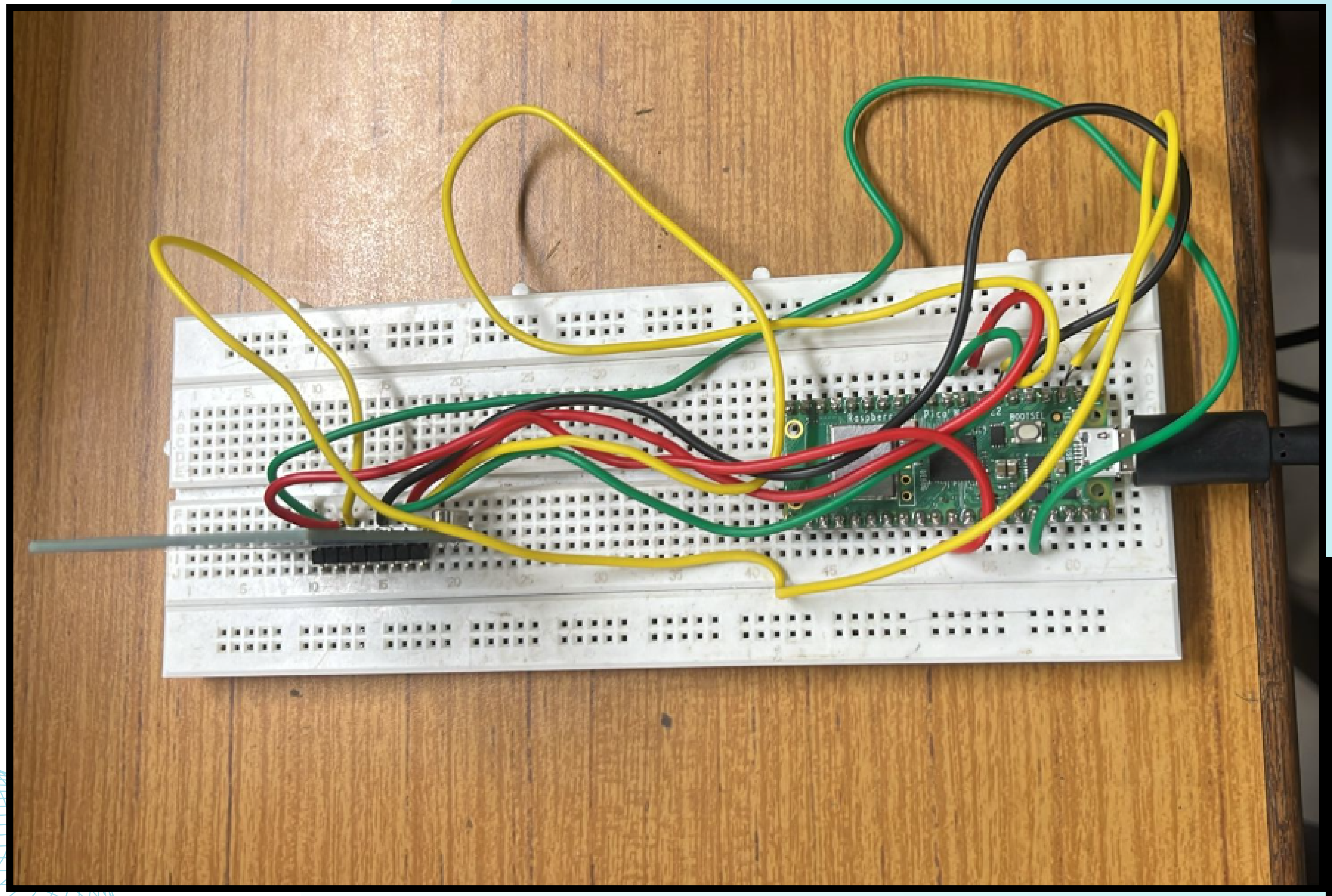


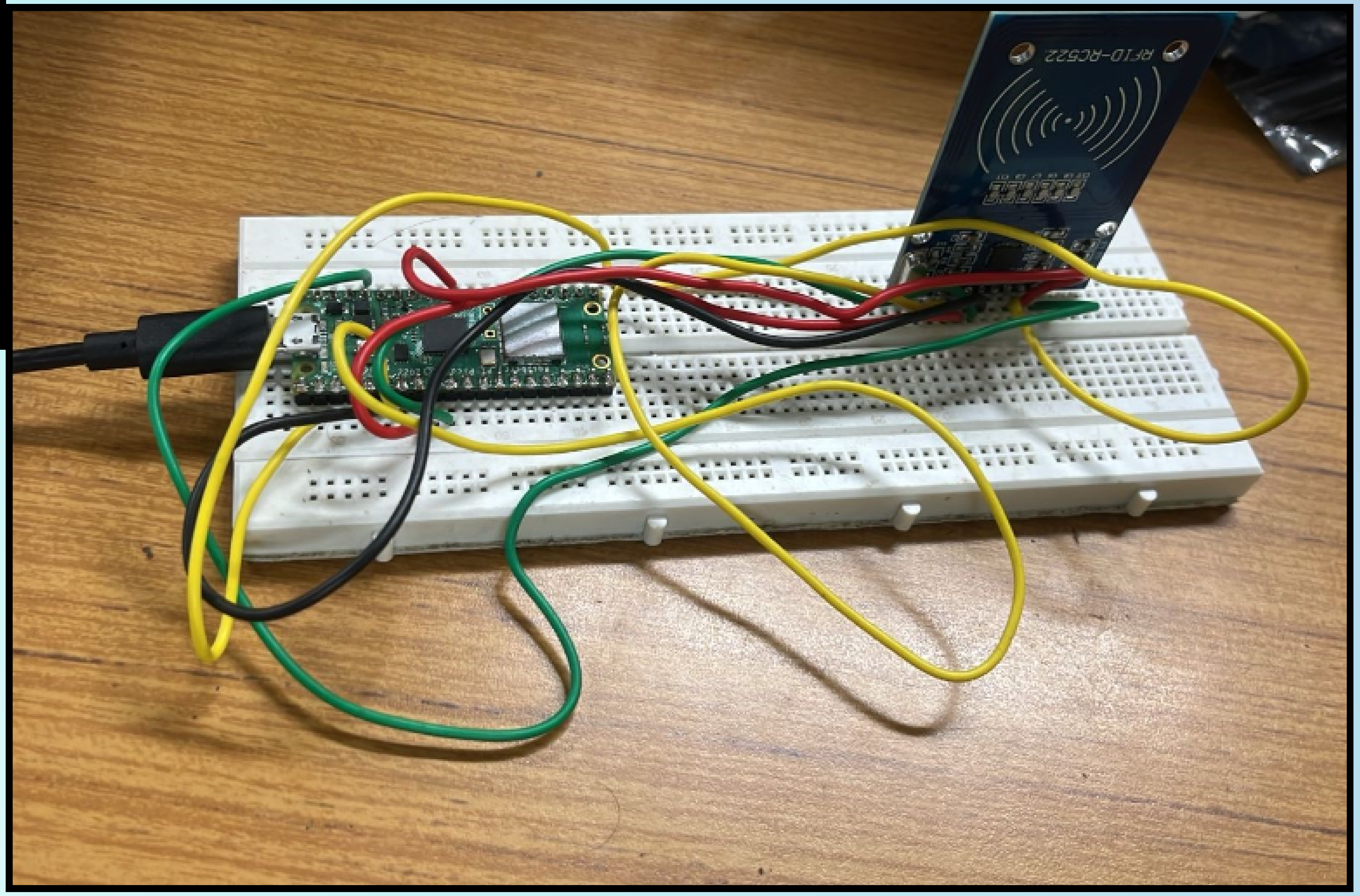
PN532 RFID module



Circuit Diagram






RFID-RC522

Details of test plans for preliminary testing, intermediate testing and final testing:

Preliminary Testing:

- We are actually trying to replicate the PN532 reader module, but for that the coding should be done to run the PN532 module and read the tag. Since WEL lab doesn’t have the PN532 module codes were written to run and read data from RC522 module to read the UID tag from RC522 tag using RC522 reader modules and upload the tag number to our website.

- Conducted successful preliminary testing of the MFRC (MIFARE) reader module with the web application, confirming its functionality and compatibility.

Intermediate Testing:

- We still didn’t receive the PN532 modules due to delay in the delivery.So by the milestone-2 deadline we had no chance to test the PN532 module but as soon as we get the modules, modifying the previous codes according to the protocols of PN532 testing on PN532 will be done.
- Coding was done in micropython. So currently we are trying to do the same in C language on VScode.
- Currently trying to implement automated email notifications to borrowers three days before the due date for product returns

Final Testing:

- Once the codes for PN532 run successfully we will implement the codes with the antenna design designed our ourselves on PCB and check it’s compatibility with the app developed.

Preliminary Testing: Results, Discussion, and Plans

- Could write micropython for scanning the UID tag number of RC522 tags with RC522 reader modules on Thonny and successfully uploaded the data onto a website made.

- Hypothesis is that actually we are thinking that the coding part will be similar for that of Pn532 and RC522 reader modules.

- Till now there are no explicit deviations from expected results.

- One major issue is coding in C language. We still didn't figure out how to code in C and still learning the syntax.

- But we are now trying to accelerate as coding in micropython is done. So can compare the syntax and know about any libraries, if needed can be added with prior knowledge and thus save time in learning the syntax.

Thinking ahead to next milestone:

- So we tested with the commercial RC-522 module now we will design the PN532 reader module
- PCB circuits and replace the primitive components and joints adding a 3D design to give it a good look and try to make it commercial as possible
- Implement automated email notifications to borrowers three days before the due date for product returns

Thank You…