# Stress tests for Raspberry Pi 4 and 3B+

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## Contents



The aim of this notebook is to stress the Raspberry Pi 4 for deciding between different cases and cooling types.

Sources:

- https://github.com/nschloe/stressberry
- https://www.pragmaticlinux.com/2020/06/check-the-raspberry-pi-cpu-temperature/

# 1 Implementation of helper functions

## 1.1 Load globally used libraries and set plot parameters

[1]:
```
import subprocess
#from time import sleep
from os import cpu_count
import threading
import time

import pandas as pd
import numpy as np
import prettytable as pt

import matplotlib.pyplot as plt
import matplotlib.dates as mdates
%matplotlib inline
```

```
# FutureWarning: Using an implicitly registered datetime converter for a matplotlib␣
↪plotting method.
# The converter was registered by pandas on import.
# Future versions of pandas will require you to explicitly register matplotlib␣
↪converters.
from pandas.plotting import register_matplotlib_converters
register_matplotlib_converters()

#import matplotlib.pyplot as plt
#%matplotlib inline

from IPython.display import set_matplotlib_formats
set_matplotlib_formats('pdf', 'png')

plt.rcParams['savefig.dpi'] = 80
plt.rcParams['savefig.bbox'] = "tight"

plt.rcParams['figure.autolayout'] = False
plt.rcParams['figure.figsize'] = 10, 6
plt.rcParams['axes.labelsize'] = 18
plt.rcParams['axes.titlesize'] = 20
plt.rcParams['font.size'] = 16
plt.rcParams['lines.linewidth'] = 2.0
plt.rcParams['lines.markersize'] = 8
plt.rcParams['legend.fontsize'] = 14

# Need to install dependent package first via 'apt install cm-super'
plt.rcParams['text.usetex'] = True
plt.rcParams['font.family'] = "serif"
plt.rcParams['font.serif'] = "cm"
#plt.rcParams['text.latex.preamble'] = r'\usepackage{subdepth},␣
↪\usepackage{type1cm}'
#plt.rcParams['text.latex.preamble'] = [r'\usepackage{amsmath}' ,␣
↪r'\usepackage[T1]{fontenc}', r'\usepackage{subdepth}', r'\usepackage{type1cm}']
#plt.rcParams['text.latex.unicode'] = True
```

```
/home/bk/jupyter-env/lib/python3.7/site-packages/ipykernel_launcher.py:25:
DeprecationWarning: `set_matplotlib_formats` is deprecated since IPython 7.23,
directly use `matplotlib_inline.backend_inline.set_matplotlib_formats()`
```

## 1.2 Variant 1: Function for reading the CPU core temperature

This implementation retrieves the temperature information from the system file `/sys/class/thermal/thermal_zone0/temp`.

[2]:
```
import os

# Function for reading the CPU core temperature
# Found here: https://www.pragmaticlinux.com/2020/06/
↪check-the-raspberry-pi-cpu-temperature/
def get_cpu_temp_old():
    """
    Obtains the current value of the CPU temperature.
    :returns: Current value of the CPU temperature if successful, zero value␣
↪otherwise.
    :rtype: float
    """
```

```
    # Initialize the result.
    result = 0.0
    # The first line in this file holds the CPU temperature as an integer times␣
↪1000.
    # Read the first line and remove the newline character at the end of the string.
    if os.path.isfile('/sys/class/thermal/thermal_zone0/temp'):
        with open('/sys/class/thermal/thermal_zone0/temp') as f:
            line = f.readline().strip()
        # Test if the string is an integer as expected.
        if line.isdigit():
            # Convert the string with the CPU temperature to a float in degrees␣
↪Celsius.
            result = float(line) / 1000
    # Give the result back to the caller.
    return result
```

### 1.3 Variant 2: Function for reading the CPU core temperature (used here)

This implementation retrieves the temperature information from the command line tool `vcgencmd`. In the bash console you can get the same result by issuing:

`$ vcgencmd measure_temp`

[3]:
```
#import subprocess

# Function for reading the CPU core temperature
# Found here: https://github.com/nschloe/stressberry/blob/main/stressberry/main.py
def get_cpu_temp(filename=None):
    """Returns the core temperature in Celsius."""
    if filename is not None:
        with open(filename) as f:
            temp = float(f.read()) / 1000
    else:
        # Using vcgencmd is specific to the raspberry pi
        out = subprocess.check_output(["vcgencmd", "measure_temp"]).decode("utf-8")
        temp = float(out.replace("temp=", "").replace("'C", ""))

    return temp
```

### 1.4 Function for reading the CPU core frequency

The frequency information is retrieved from the command line tool `vcgencmd` also. In the bash console you can get the same result by issuing:

`$ vcgencmd measure_clock arm`

[4]:
```
#import subprocess

# Function for reading the CPU core frequency
# Found here: https://github.com/nschloe/stressberry/blob/main/stressberry/main.py
def get_cpu_freq(filename=None):
    """Returns the CPU frequency in MHz"""
    if filename is not None:
        with open(filename) as f:
            frequency = float(f.read()) / 1000
    else:
        # Only vcgencmd measure_clock arm is accurate on Raspberry Pi.
```

```
        # Per: https://www.raspberrypi.org/forums/viewtopic.php?
↪f=63&t=219358&start=25
        out = subprocess.check_output(["vcgencmd", "measure_clock arm"]).
↪decode("utf-8")
        frequency = float(out.split("=")[1]) / 1000000

    return frequency
```

## 1.5 Helper functions for stressing all cores of the CPU

Stress is created by the command line tool `stress`. It has to be installed first by issuing:

```
$ sudo apt install stress
```

[5]:
```
# Helper function to call the 'stress' command line tool
def stress_cpu(num_cpus, time):
    subprocess.check_call(["stress", "--cpu", str(num_cpus), "--timeout",␣
↪f"{time}s"])
    return
```

[6]:
```
#from time import sleep
#from os import cpu_count

# Function for stressing all cores of the CPU
# Found here: https://github.com/nschloe/stressberry/blob/main/stressberry/main.py
def run_stress(stress_duration=300, idle_duration=120, cores=None):
    """Run stress test for specified duration with specified idle times
    at the start and end of the test.
    """
    if cores is None:
        cores = cpu_count()

    print(f"Preparing to stress [{cores}] CPU Cores for [{stress_duration}]␣
↪seconds")
    print(f"Idling for {idle_duration} seconds...")
    time.sleep(idle_duration)

    print(f"Starting the stress load on [{cores}] CPU Cores for [{stress_duration}]␣
↪seconds")
    stress_cpu(num_cpus=cores, time=stress_duration)

    print(f"Idling for {idle_duration} seconds...")
    time.sleep(idle_duration)
```

## 1.6 Helper function to let the CPU cool down

This function is used to let the CPU cool down first to find a stable baseline.

[7]:
```
#from time import sleep

def cpu_cooldown(interval=60, filename=None):
    """Lets the CPU cool down until the temperature does not change anymore."""
    prev_tmp = get_cpu_temp()
    while True:
        time.sleep(interval)
        tmp = get_cpu_temp()
```

```
        print(
            f"Current temperature: {tmp:4.1f}°C - "
            f"Previous temperature: {prev_tmp:4.1f}°C"
        )
        if abs(tmp - prev_tmp) < 0.2:
            break
        prev_tmp = tmp
    return tmp
```

## 1.7 Helper function for handling dataframes

First, a dataframe is created and at the same time the column headers are set. The function `dataframe_add_row()` is used to add the measured values to the dataframe in the form of new rows.

[8]:
```
#import pandas as pd

# Dataframe for the measuring values
df_meas_values = pd.DataFrame(columns=['Time', 'CPU Temperature', 'CPU Frequency'])
```

[9]:
```
def dataframe_add_row(df=None, row=[]):
    if (df is None):
        return

    # Add a row
    df.loc[-1] = row

    # Shift the index
    df.index = df.index + 1

    # Reset the index of dataframe and avoid the old index being added as a column
    df.reset_index(drop=True, inplace=True)
```

## 1.8 Main worker function

[10]:
```
#import threading
#import time

# Function for running the stress test in another thread while measuring CPU␣
↪temperature and frequency
# Found here: https://github.com/nschloe/stressberry/blob/main/stressberry/cli/run.
↪py
def run(argv=None):
    # Cool down first
    print("Awaiting stable baseline temperature ...")
    cpu_cooldown(interval=60)

    # Start the stress test in another thread
    t = threading.Thread(
        target=lambda: run_stress(stress_duration=900, idle_duration=300, cores=4),␣
↪args=()
    )
    # Init event handler for killing the thread
    t.event = threading.Event()
    # Start the thread
    t.start()
```

```
    # Init row array
    values_row = []
    # Get starting time
    start_time = time.time()
    while t.is_alive():
        try:
            # Get time relative to starting time and round to 2 decimals
            timestamp = float("{:.1f}".format(time.time() - start_time))
            # Get CPU temperature and round to 2 decimals
            temperature = float("{:.1f}".format(get_cpu_temp()))
            # Get CPU frequency and round to 1 decimal
            frequency = float("{:.1f}".format(get_cpu_freq()))

            values_row = [ timestamp,
                           temperature,
                           frequency ]

            dataframe_add_row(df_meas_values, values_row)

            print(
                    f"Time: {timestamp} s,\t"
                    f"Temperature: {temperature} °C,\t"
                    f"Frequency: {frequency} MHz"
            )

            # Choose the sample interval such that we have a respectable number of␣
↪data points
            t.join(2.0)

        except:
            print("Keyboard Interrupt ^C detected.")
            print("Bye.")
            # Stop the thread by calling the event
            t.event.set()
            break

    # Normalize times so we are starting at '0 s'
    #time0 = df_meas_values['Time'][0]
    # It's a really fancy oneliner - but not necessary at all ...
    #df_meas_values['Time'] = [tm - time0 for tm in df_meas_values['Time']]
```

## 2 Run the heating test

[12]:
```
# Clear all data in dataframe
df_meas_values = df_meas_values.iloc[0:0]

run()
```

```
Awaiting stable baseline temperature ...
Current temperature: 56.9°C - Previous temperature: 58.0°C
Current temperature: 56.9°C - Previous temperature: 56.9°C
Preparing to stress [4] CPU Cores for [900] seconds
Idling for 300 seconds...
Time: 0.0 s,    Temperature: 56.9 °C,   Frequency: 1000.0 MHz
Time: 2.1 s,    Temperature: 56.9 °C,   Frequency: 700.0 MHz
```

```
Time: 4.2 s,    Temperature: 56.9 °C,   Frequency: 700.0 MHz
Time: 6.3 s,    Temperature: 56.9 °C,   Frequency: 700.0 MHz
Time: 8.4 s,    Temperature: 57.5 °C,   Frequency: 800.0 MHz
Time: 10.5 s,   Temperature: 56.4 °C,   Frequency: 800.0 MHz

..      ...              ...            ...

Time: 286.6 s,  Temperature: 56.4 °C,   Frequency: 700.0 MHz
Time: 288.7 s,  Temperature: 56.9 °C,   Frequency: 900.0 MHz
Time: 290.7 s,  Temperature: 56.9 °C,   Frequency: 1400.0 MHz
Time: 292.8 s,  Temperature: 57.5 °C,   Frequency: 600.0 MHz
Time: 294.9 s,  Temperature: 56.9 °C,   Frequency: 600.0 MHz
Time: 297.0 s,  Temperature: 56.9 °C,   Frequency: 800.0 MHz
Time: 299.1 s,  Temperature: 56.9 °C,   Frequency: 700.0 MHz
Starting the stress load on [4] CPU Cores for [900] seconds
Time: 301.2 s,  Temperature: 59.1 °C,   Frequency: 1400.0 MHz
Time: 303.4 s,  Temperature: 60.7 °C,   Frequency: 1200.0 MHz
Time: 305.5 s,  Temperature: 60.7 °C,   Frequency: 1200.0 MHz
Time: 307.7 s,  Temperature: 62.3 °C,   Frequency: 1200.0 MHz
Time: 309.8 s,  Temperature: 62.3 °C,   Frequency: 1200.0 MHz
Time: 312.0 s,  Temperature: 62.3 °C,   Frequency: 1200.0 MHz
Time: 314.1 s,  Temperature: 63.4 °C,   Frequency: 1200.0 MHz
Time: 316.3 s,  Temperature: 63.4 °C,   Frequency: 1200.0 MHz
Time: 318.4 s,  Temperature: 64.5 °C,   Frequency: 1200.0 MHz
Time: 320.6 s,  Temperature: 64.5 °C,   Frequency: 1200.0 MHz

..      ...              ...            ...

Time: 1191.7 s, Temperature: 80.6 °C,   Frequency: 1141.0 MHz
Time: 1193.9 s, Temperature: 80.6 °C,   Frequency: 1141.0 MHz
Time: 1196.0 s, Temperature: 80.6 °C,   Frequency: 1141.0 MHz
Time: 1198.2 s, Temperature: 80.6 °C,   Frequency: 1141.0 MHz
Idling for 300 seconds...
Time: 1200.4 s, Temperature: 80.6 °C,   Frequency: 1195.0 MHz
Time: 1202.4 s, Temperature: 78.4 °C,   Frequency: 800.0 MHz
Time: 1204.5 s, Temperature: 76.8 °C,   Frequency: 800.0 MHz
Time: 1206.6 s, Temperature: 76.3 °C,   Frequency: 1200.0 MHz
Time: 1208.7 s, Temperature: 75.2 °C,   Frequency: 700.0 MHz
Time: 1210.8 s, Temperature: 75.2 °C,   Frequency: 800.0 MHz

..      ...              ...            ...

Time: 1491.6 s, Temperature: 64.5 °C,   Frequency: 800.0 MHz
Time: 1493.7 s, Temperature: 63.9 °C,   Frequency: 900.0 MHz
Time: 1495.8 s, Temperature: 64.5 °C,   Frequency: 1200.0 MHz
Time: 1497.9 s, Temperature: 64.5 °C,   Frequency: 600.0 MHz
Time: 1500.0 s, Temperature: 63.4 °C,   Frequency: 600.0 MHz
```

[13]:
```
display(df_meas_values)
```

```
       Time  CPU Temperature  CPU Frequency
0       0.0             56.9         1000.0
1       2.1             56.9          700.0
2       4.2             56.9          700.0
3       6.3             56.9          700.0
4       8.4             57.5          800.0
..      ...              ...            ...
701  1491.6             64.5          800.0
```

```
702  1493.7            63.9          900.0
703  1495.8            64.5         1200.0
704  1497.9            64.5          600.0
705  1500.0            63.4          600.0

[706 rows x 3 columns]
```

# 3 Save all to CSV files

[14]:
```
# Write dataframe to CSV file
str_file_prefix_b4 = 'RaspiB4JupyterLab_stress_measurement'
str_file_prefix_b3plus = 'RaspiB3plusEPaper_stress_measurement'

#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_woHeatSinks.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinks.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinksAndFan5V.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinksAndFan3V.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinksAndFan5Vrev.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_pinkRaspiCase_wHeatSinks.csv', sep ='\t', index = False, header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinksAndNoctuaFan5V.csv', sep ='\t', index = False,␣
↪header=True)
#df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b4 +␣
↪'_PlasticCase_wHeatSinksAndNoctuaFan3V.csv', sep ='\t', index = False,␣
↪header=True)

df_meas_values.to_csv(r'./data_files/' + str_file_prefix_b3plus +␣
↪'_PlasticCase_wHeatSinks.csv', sep ='\t', index = False, header=True)
```

# 4 Read in the CSV files and display it

## 4.1 Read in the CSV files in dataframes

[2]:
```
#import pandas as pd

# Helper function for creating dataframes from CSV files
def create_dictionary_from_csv(filename, offset=0, cols_wanted=1):
    my_dataframe = pd.read_csv(filename, sep='\t', index_col=False, decimal='.',␣
↪header=offset)

    # Delete all cloumns after the desired ones
    my_dataframe.drop(my_dataframe.columns[cols_wanted:], axis=1, inplace=True)

    return my_dataframe
```

[3]:
```
str_file_prefix_b4 = 'RaspiB4JupyterLab_stress_measurement'
str_file_prefix_b3plus = 'RaspiB3plusEPaper_stress_measurement'
```

```
str_file_name_1 = str_file_prefix_b4 + '_PlasticCase_woHeatSinks.csv'
str_file_name_2 = str_file_prefix_b4 + '_PlasticCase_wHeatSinks.csv'
str_file_name_3 = str_file_prefix_b4 + '_PlasticCase_wHeatSinksAndFan5V.csv'
str_file_name_4 = str_file_prefix_b4 + '_PlasticCase_wHeatSinksAndFan3V.csv'
str_file_name_5 = str_file_prefix_b4 + '_PlasticCase_wHeatSinksAndFan5Vrev.csv'
str_file_name_6 = str_file_prefix_b4 + '_pinkRaspiCase_wHeatSinks.csv'
str_file_name_7 = str_file_prefix_b4 + '_PlasticCase_wHeatSinksAndNoctuaFan5V.csv'
str_file_name_8 = str_file_prefix_b4 + '_PlasticCase_wHeatSinksAndNoctuaFan3V.csv'

str_file_name_9 = str_file_prefix_b3plus + '_PlasticCase_wHeatSinks.csv'

df_1_PC_woHeatSinks = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_1, offset=0, cols_wanted=3)
df_2_PC_wHeatSinks = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_2, offset=0, cols_wanted=3)
df_3_PC_wHeatSinksAndFan5V = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_3, offset=0, cols_wanted=3)
df_4_PC_wHeatSinksAndFan3V = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_4, offset=0, cols_wanted=3)
df_5_PC_wHeatSinksAndFan5Vrev = create_dictionary_from_csv(filename="./data_files/"␣
↪+ str_file_name_5, offset=0, cols_wanted=3)
df_6_RC_wHeatSinks = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_6, offset=0, cols_wanted=3)
df_7_PC_wHeatSinksAndNoctuaFan5V = create_dictionary_from_csv(filename="./
↪data_files/" + str_file_name_7, offset=0, cols_wanted=3)
df_8_PC_wHeatSinksAndNoctuaFan3V = create_dictionary_from_csv(filename="./
↪data_files/" + str_file_name_8, offset=0, cols_wanted=3)

df_9_PC_wHeatSinks = create_dictionary_from_csv(filename="./data_files/" +␣
↪str_file_name_9, offset=0, cols_wanted=3)
```

[4]:
```
#df_1_PC_woHeatSinks.head(6)
#df_2_PC_wHeatSinks.head(6)
#df_3_PC_wHeatSinksAndFan5V.head(6)
#df_4_PC_wHeatSinksAndFan3V.head(6)
#df_5_PC_wHeatSinksAndFan5Vrev.head(6)
#df_6_RC_wHeatSinks.head(6)
#df_7_PC_wHeatSinksAndNoctuaFan5V.head(6)
#df_8_PC_wHeatSinksAndNoctuaFan3V.head(6)

df_9_PC_wHeatSinks.head(6)
```

[4]:

| | Time | CPU Temperature | CPU Frequency |
|---|---|---|---|
| 0 | 0.0 | 56.9 | 1000.0 |
| 1 | 2.1 | 56.9 | 700.0 |
| 2 | 4.2 | 56.9 | 700.0 |
| 3 | 6.3 | 56.9 | 700.0 |
| 4 | 8.4 | 57.5 | 800.0 |
| 5 | 10.5 | 56.4 | 800.0 |

[5]:
```
#df_1_PC_woHeatSinks.dtypes
#df_2_PC_wHeatSinks.dtypes
#df_3_PC_wHeatSinksAndFan5V.dtypes
#df_4_PC_wHeatSinksAndFan3V.dtypes
#df_5_PC_wHeatSinksAndFan5Vrev.dtypes
#df_6_RC_wHeatSinks.dtypes
```

```
#df_7_PC_wHeatSinksAndNoctuaFan5V.dtypes
#df_8_PC_wHeatSinksAndNoctuaFan3V.dtypes

df_9_PC_wHeatSinks.dtypes
```

[5]:
```
Time               float64
CPU Temperature    float64
CPU Frequency      float64
dtype: object
```

## 4.2 Smoothing with a moving average filter

[6]:
```
# Smooth temperature column only!
df_1_PC_woHeatSinks['CPU Temperature'] = df_1_PC_woHeatSinks['CPU Temperature'].
 ↪rolling(window=3).mean()
df_2_PC_wHeatSinks['CPU Temperature'] = df_2_PC_wHeatSinks['CPU Temperature'].
 ↪rolling(window=3).mean()
df_3_PC_wHeatSinksAndFan5V['CPU Temperature'] = df_3_PC_wHeatSinksAndFan5V['CPU␣
 ↪Temperature'].rolling(window=3).mean()
df_4_PC_wHeatSinksAndFan3V['CPU Temperature'] = df_4_PC_wHeatSinksAndFan3V['CPU␣
 ↪Temperature'].rolling(window=3).mean()
df_5_PC_wHeatSinksAndFan5Vrev['CPU Temperature'] =␣
 ↪df_5_PC_wHeatSinksAndFan5Vrev['CPU Temperature'].rolling(window=3).mean()
df_6_RC_wHeatSinks['CPU Temperature'] = df_6_RC_wHeatSinks['CPU Temperature'].
 ↪rolling(window=3).mean()
df_7_PC_wHeatSinksAndNoctuaFan5V['CPU Temperature'] =␣
 ↪df_7_PC_wHeatSinksAndNoctuaFan5V['CPU Temperature'].rolling(window=3).mean()
df_8_PC_wHeatSinksAndNoctuaFan3V['CPU Temperature'] =␣
 ↪df_8_PC_wHeatSinksAndNoctuaFan3V['CPU Temperature'].rolling(window=3).mean()

df_9_PC_wHeatSinks['CPU Temperature'] = df_9_PC_wHeatSinks['CPU Temperature'].
 ↪rolling(window=3).mean()
```

[7]:
```
df_9_PC_wHeatSinks
```

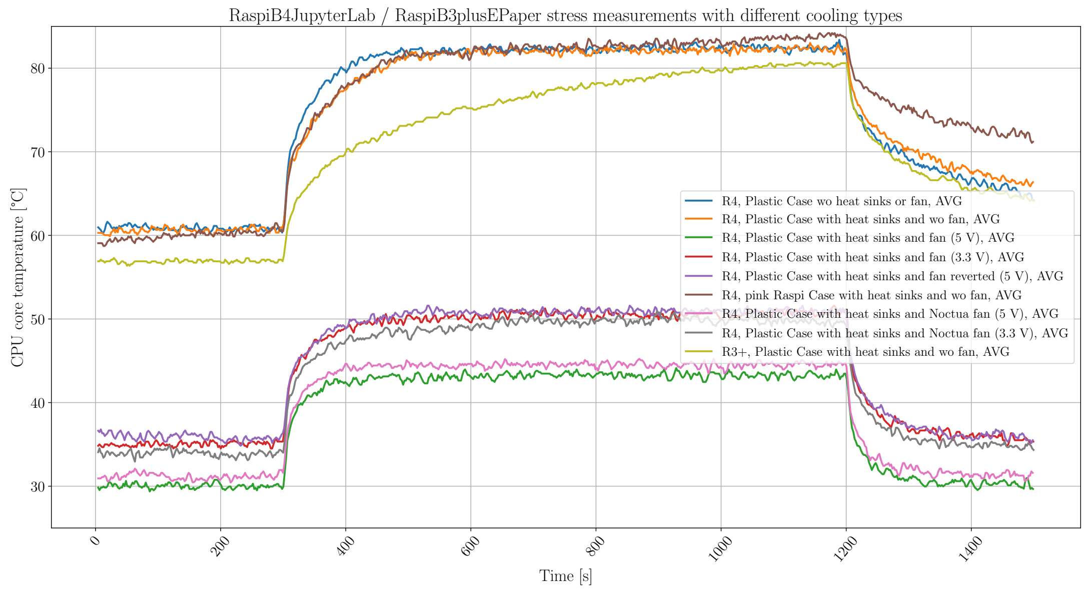
[7]:
```
        Time  CPU Temperature  CPU Frequency
0        0.0              NaN         1000.0
1        2.1              NaN          700.0
2        4.2        56.900000          700.0
3        6.3        56.900000          700.0
4        8.4        57.100000          800.0
..       ...              ...            ...
701   1491.6        64.300000          800.0
702   1493.7        64.100000          900.0
703   1495.8        64.300000         1200.0
704   1497.9        64.300000          600.0
705   1500.0        64.133333          600.0

[706 rows x 3 columns]
```

## 4.3 Display / Plot data headm dataframes

[ ]:
```
#import matplotlib.pyplot as plt
#import matplotlib.dates as mdates

#%matplotlib inline

# FutureWarning: Using an implicitly registered datetime converter for a matplotlib␣
↪plotting method.
# The converter was registered by pandas on import.
# Future versions of pandas will require you to explicitly register matplotlib␣
↪converters.
#from pandas.plotting import register_matplotlib_converters
#register_matplotlib_converters()
```

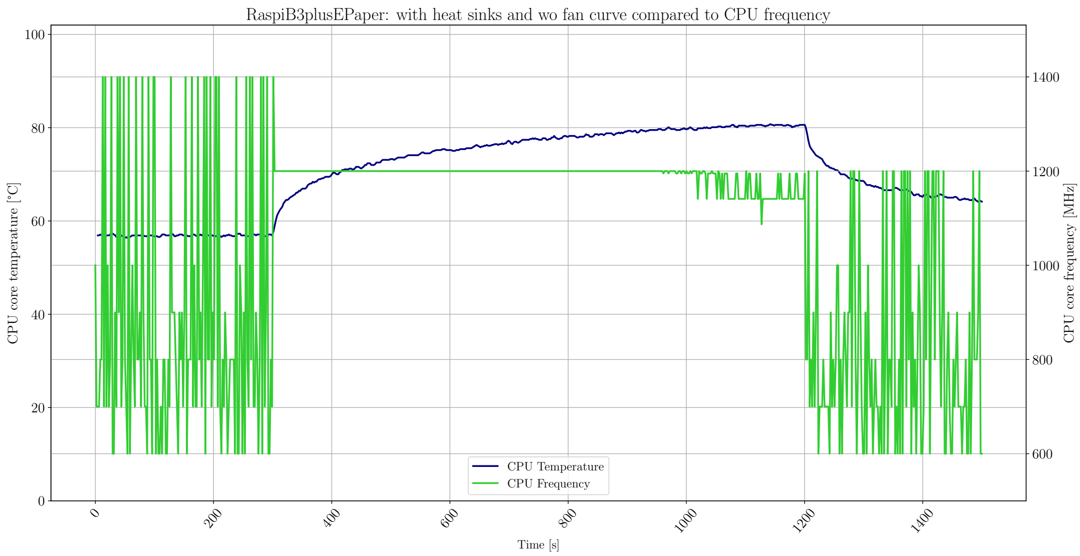
[8]:
```
# figsize: a tuple (width, height) in inches
plt.figure(num=0, figsize=(20, 10), dpi=80, facecolor='w', edgecolor='k')
axes = plt.gca()

#xfmt = mdates.DateFormatter('%H:%M:%S')
#axes.xaxis.set_major_formatter(xfmt)

plt.title('RaspiB4JupyterLab / RaspiB3plusEPaper stress measurements with different␣
↪cooling types')

#plt.plot(df_1_PC_woHeatSinks['Time'], df_1_PC_woHeatSinks['CPU Temperature'], '-',␣
↪label='Plastic Case wo heat sinks or fan')
#plt.plot(df_2_PC_wHeatSinks['Time'], df_2_PC_wHeatSinks['CPU Temperature'], '-',␣
↪label='Plastic Case with heat sinks and wo fan')
#plt.plot(df_3_PC_wHeatSinksAndFan5V['Time'], df_3_PC_wHeatSinksAndFan5V['CPU␣
↪Temperature'], '-', label='Plastic Case with heat sinks and fan (5 V)')
#plt.plot(df_4_PC_wHeatSinksAndFan3V['Time'], df_4_PC_wHeatSinksAndFan3V['CPU␣
↪Temperature'], '-', label='Plastic Case with heat sinks and fan (3.3 V)')
#plt.plot(df_5_PC_wHeatSinksAndFan5Vrev['Time'], df_5_PC_wHeatSinksAndFan5Vrev['CPU␣
↪Temperature'], '-', label='Plastic Case with heat sinks and fan reverted (5 V)')
#plt.plot(df_6_RC_wHeatSinks['Time'], df_6_RC_wHeatSinks['CPU Temperature'], '-',␣
↪label='pink Raspi Case with heat sinks and and wo fan')

plt.plot(df_1_PC_woHeatSinks['Time'], df_1_PC_woHeatSinks['CPU Temperature'], '-',␣
↪label='R4, Plastic Case wo heat sinks or fan, AVG')
plt.plot(df_2_PC_wHeatSinks['Time'], df_2_PC_wHeatSinks['CPU Temperature'], '-',␣
↪label='R4, Plastic Case with heat sinks and wo fan, AVG')
plt.plot(df_3_PC_wHeatSinksAndFan5V['Time'], df_3_PC_wHeatSinksAndFan5V['CPU␣
↪Temperature'], '-', label='R4, Plastic Case with heat sinks and fan (5 V), AVG')
plt.plot(df_4_PC_wHeatSinksAndFan3V['Time'], df_4_PC_wHeatSinksAndFan3V['CPU␣
↪Temperature'], '-', label='R4, Plastic Case with heat sinks and fan (3.3 V), AVG')
plt.plot(df_5_PC_wHeatSinksAndFan5Vrev['Time'], df_5_PC_wHeatSinksAndFan5Vrev['CPU␣
↪Temperature'], '-', label='R4, Plastic Case with heat sinks and fan reverted (5␣
↪V), AVG')
plt.plot(df_6_RC_wHeatSinks['Time'], df_6_RC_wHeatSinks['CPU Temperature'], '-',␣
↪label='R4, pink Raspi Case with heat sinks and wo fan, AVG')
plt.plot(df_7_PC_wHeatSinksAndNoctuaFan5V['Time'],␣
↪df_7_PC_wHeatSinksAndNoctuaFan5V['CPU Temperature'], '-', label='R4, Plastic Case␣
↪with heat sinks and Noctua fan (5 V), AVG')
```

```
plt.plot(df_8_PC_wHeatSinksAndNoctuaFan3V['Time'], df_8_PC_wHeatSinksAndNoctuaFan3V['CPU Temperature'], '-', label='R4, Plastic Case with heat sinks and Noctua fan (3.3 V), AVG')

plt.plot(df_9_PC_wHeatSinks['Time'], df_9_PC_wHeatSinks['CPU Temperature'], '-', label='R3+, Plastic Case with heat sinks and wo fan, AVG')

plt.xlabel('Time [s]')
plt.ylabel('CPU core temperature [°C]')

plt.ylim(25, 85)

plt.grid(True)

plt.setp(plt.gca().xaxis.get_majorticklabels(), 'rotation', 50)

plt.legend()

# Save plot to PNG and PDF
str_image_name = 'RaspiB4JupyterLab_stress_measurement'
plt.savefig(r'./data_files/' + str_image_name + '.png')
plt.savefig(r'./data_files/' + str_image_name + '.pdf')

plt.show()
```



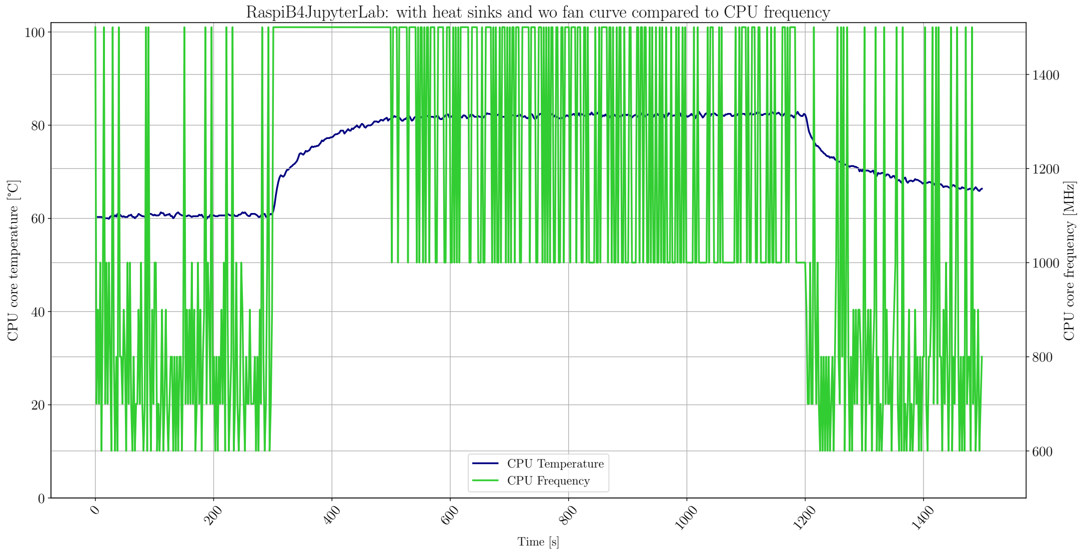

[20]:
```
# Figsize: a tuple (width, height) in inches
# Create figure and axis objects with subplots()
fig, ax1 = plt.subplots(num=0, figsize=(20, 10), dpi=80, facecolor='w', edgecolor='k')

axes = plt.gca()

plt.title('RaspiB3plusEPaper: with heat sinks and wo fan curve compared to CPU frequency')
```

```
line1 = ax1.plot(df_9_PC_wHeatSinks['Time'], df_9_PC_wHeatSinks['CPU Temperature'],␣
 ↪color='navy', label='CPU Temperature')

# Set x-axis label
ax1.set_xlabel('Time [s]', fontsize=14)
# Set y-axis label
ax1.set_ylabel('CPU core temperature [°C]', fontsize=16)
ax1.set_ylim(0, 102)
ax1.grid(True)
plt.xticks(rotation=50)

# Twin object for two different y-axis on the same plot
ax2 = ax1.twinx()

line2 = ax2.plot(df_9_PC_wHeatSinks['Time'], df_9_PC_wHeatSinks['CPU Frequency'],␣
 ↪color='limegreen', label='CPU Frequency')

# Set y-axis label
ax2.set_ylabel('CPU core frequency [MHz]', fontsize=16)
ax2.set_ylim(500, 1510)
ax2.grid(True)

# Add all lines to the same legend box
lines_all = line1+line2
labels = [l.get_label() for l in lines_all]
ax1.legend(lines_all, labels, loc='lower center')

# Save plot to PNG and PDF
str_image_name = 'RaspiB4JupyterLab_stress_measurement'
plt.savefig(r'./data_files/' + str_image_name + '.png')
plt.savefig(r'./data_files/' + str_image_name + '.pdf')

plt.show()
```




[19]:
```
# Figsize: a tuple (width, height) in inches
# Create figure and axis objects with subplots()
```

```python
fig, ax1 = plt.subplots(num=0, figsize=(20, 10), dpi=80, facecolor='w',␣
↪edgecolor='k')

axes = plt.gca()

plt.title('RaspiB4JupyterLab: with heat sinks and wo fan curve compared to CPU␣
↪frequency')

line1 = ax1.plot(df_2_PC_wHeatSinks['Time'], df_2_PC_wHeatSinks['CPU Temperature'],␣
↪color='navy', label='CPU Temperature')

# Set x-axis label
ax1.set_xlabel('Time [s]', fontsize=14)
# Set y-axis label
ax1.set_ylabel('CPU core temperature [°C]', fontsize=16)
ax1.set_ylim(0, 102)
ax1.grid(True)
plt.xticks(rotation=50)

# Twin object for two different y-axis on the same plot
ax2 = ax1.twinx()

line2 = ax2.plot(df_2_PC_wHeatSinks['Time'], df_2_PC_wHeatSinks['CPU Frequency'],␣
↪color='limegreen', label='CPU Frequency')

# Set y-axis label
ax2.set_ylabel('CPU core frequency [MHz]', fontsize=16)
ax2.set_ylim(500, 1510)
ax2.grid(True)

# Add all lines to the same legend box
lines_all = line1+line2
labels = [l.get_label() for l in lines_all]
ax1.legend(lines_all, labels, loc='lower center')

# Save plot to PNG and PDF
#str_image_name = 'RaspiB4JupyterLab_stress_measurement'
#plt.savefig(r'./data_files/' + str_image_name + '.png')
#plt.savefig(r'./data_files/' + str_image_name + '.pdf')

plt.show()
```



RaspiB4JupyterLab: with heat sinks and wo fan curve compared to CPU frequency
CPU core temperature [°C]
CPU core frequency [MHz]
Time [s]
CPU Temperature
CPU Frequency


[ ]: