TBBL Impedance Data Analysis

By: Jian Ruan
Time: June 9, 2022
Goal: Automate IDE impedance data analysis process. Avoid copy & paste!

Follow these steps for Accelerated Aging Testing!

Data Collection (about 3min / device)

Step 1: Setup the IDE in the Ferrari Cage. (1min/IDE)

Step 2: Turn on Autolab and connect to the lab Dell PC.

Step 3: Open Nova2.1.4 software with the procedure **"FRA MUX 1ch 50mV 10k-10Hz - automated"**.

Step 4: Change the export file-name to corresponding IDE.
E.g:
IDE-12-8-m means IDE-12, 12μm, mutual.
IDE-16-16-s means IDE-16, 16μm, shunt

Step 5: Click on the run button and wait for the test result. (1min/IDE)

Step 6: Nova2.1.4 will auto-generate a csv file for each IDE in the ASCI format. File location:Desktop/IDE-data.

Step 7: Edit the **"date.csv"** file to keep track of the experiment dates.

Step 8: Clean the IDE and put it back to the Lab Armor.

Data Analysis

Step 1: Open the Jupyter Notebook **"[20220609]TBBL-Impedance Data Analysis"**.

Step 2: Make sure you change to the right file address so Jupter can access the impedance data.

Step 3: Run Jupyter Notebook and get your awesome data graphs!

In [9]:
```
# Step 0: Import Library & Check system requirement
import numpy as np
import pandas as pd
import matplotlib as mpl
import matplotlib.pyplot as plt
import seaborn as sns
import datetime

mpl.rc('axes', labelsize=16, titlesize=20)

# Python Version Requirement
print("Matplotlib Version", mpl.__version__)  #> 3.0.0
print("Seaborn Version", sns.__version__, "\n")  #> 0.9.0


# Step 1: Define IDE as a class for recurring use.
class IDE:
    def __init__(self, name, miu_m, capa, data_format):
        """
            Built-in function to intialize the IDE object
            self: no need to put in parameters, built-in structures in Python Class
            name: a string, number of the IDE
            miu_m: a list, tested channels (E.g: [2,4,8,16])
            capa: a list, type of capacidance ("m": mutual, "s": shunt)
            data_format: a string, file format ("csv")
        """
        # Initialize IDE object
        self.name = name
        self.miu_m = miu_m
        self.capa = capa
        self.data_format = data_format
        self.data_list = []
        self.num_channels = 0

    def setData(self):
        """
        Auto-generate a list of data file for each IDE
        E.g:
            IDE_20 = IDE(20, [2,16], ["m","s"], "csv")
            Will generate
            data_list = [
                "20-2-m.csv",
                "20-2-s.csv",
                "20-16-m.csv",
                "20-16-s.csv"]
            Totally 4 data .csv files for IDE_20.

        """
        for m in self.miu_m:
            for c in self.capa:
                file_name = str(self.name) + "-" + str(m) + "-" + c + "." + self.da
                self.data_list.append(file_name)

        #Number of tested channels
        self.num_channels = len(self.data_list)

    def getDataFile(self):
        return self.data_list

    def getName(self):
        return "IDE-" + str(self.name)

    def cleanData(self, df):
        # Add one row for checking if the freq is in the first row

        for idx, row, in df.iterrows():
            # idx is the index of the row
            # row is a Series: Frequency f = row[0], Impedance Z = row[1], -Phase =
            # Resistance Rs = row[3], Rct = row[4], Capacitance C = row[5]
```

```
            if "Frequency" in row[0]:
                idx_stamp = idx

            if (idx - idx_stamp) > 25:
                # For our impedance testing, only the first 25 data are important.
                df = df.drop(idx)

        #Export cleaned data
        df.to_csv(file, index=False)

    def extractImped(self, df, freq):
        """
        freq: an int representing the frequency we want to extract
        df: IDE datafile - e.g 12-8-m.csv
        """
        impe_freq = []

        for idx, row, in df.iterrows():
            # idx is the index of the row
            # row is a Series: Frequency f = row[0], Impedance Z = row[1], -Phase =
            # Resistance Rs = row[3], Rct = row[4], Capacitance C = row[5]
            if "Frequency" not in row[0]:
                if float(row[0]) == freq:
                    impe_freq.append(float(row[1]))
        return impe_freq

    def plotImpeFreq(self, file, df, freq_list):
        # Plot impedance change with respect to time
        fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(21, 7), constrained_layout=Tr
        ax1.set_xlabel("T (Day)", fontsize=20)
        ax1.set_ylabel("Z (Ω)", fontsize=20)
        ax1.grid(color='lightgrey', linestyle='-', linewidth=0.5)


        ax2.set_xlabel("T", fontsize=20)
        ax2.set_ylabel("Z / Z0", fontsize=20)
        ax2.grid(color='lightgrey', linestyle='-', linewidth=0.5)


        imped_freq_1K = []

        for freq in freq_list:
            imped_freq = self.extractImped(df, freq)
            if freq == 1000:
                imped_freq_1K = imped_freq
            ax1.plot(imped_freq, label = str(freq) + "Hz", marker='o')

        #1000Hz is our reference freq for failure criteria
        if 'm' in file:
            start_wet = imped_freq_1K[1]
        elif "s" in file:
            start_wet = imped_freq_1K[0]

        ratio = []

        for imped in imped_freq_1K:
            ratio.append(imped / start_wet)

        ax2.plot(ratio, label = "1000 Hz",  marker='o')
        ax2.axhline(y = 1, label = "1", color = 'r', linestyle='dotted')
        ax2.axhline(y = 1.2, label = "1.2", color = 'b', linestyle='dotted')
        ax2.axhline(y = 0.33, label = "0.33", color = 'g', linestyle='dotted')

        ax1.legend(loc='upper right', fontsize = 20)
```



```
        ax2.legend(loc='upper right', fontsize = 20)

        plt.show()
        print('\n \n')

    def getGraph(self, IDE_name, df, df_date, date_idx, Rs, Rct, C):
        # iloc[1:27, 0] means row 1 to 27, and colum 0

        date_list = df_date.iloc[date_idx, 1:]
        #datetime.date(2022, 5, 31)

        # Create the IDE Graph Canvas (1 row, 2 coluns)
        fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(20, 10), constrained_layout=T
        fig.suptitle('IDE-' + file[:-4], fontsize = 30)

        # Set the axis scales & both axes to log scale
        ax1.set(xlim=(10, 100000), ylim=(10000, 10000000000), xscale="log", yscale=
        ax1.set_xlabel("F (Hz)", fontsize=20)
        ax1.set_ylabel("Z (Ω)", fontsize=20)
        ax1.grid(color='lightgrey', linestyle='-', linewidth=0.5)

        ax2.set(xlim=(10, 100000), ylim =(0, 90), xscale ="log")
        ax2.set_xlabel("F (Hz)", fontsize=20)
        ax2.set_ylabel("-Phase (°)", fontsize=20)
        ax2.grid(color='lightgrey', linestyle='-', linewidth=0.5)

        #Create the Rs, Rct, and C canvas (1 row, 3 columns)
        fig2, (ax3, ax4, ax5) = plt.subplots(1, 3, figsize=(21, 7), constrained_lay

        ax3.set_xlabel("Index", fontsize=20)
        ax3.set_ylabel("Rs (Ω)", fontsize=20)
        ax3.grid(color='lightgrey', linestyle='-', linewidth=0.5)

        ax4.set_xlabel("Index", fontsize=20)
        ax4.set_ylabel("Rct (Ω)", fontsize=20)
        ax4.grid(color='lightgrey', linestyle='-', linewidth=0.5)

        ax5.set_xlabel("Index", fontsize=20)
        ax5.set_ylabel("C (F)", fontsize=20)
        ax5.grid(color='lightgrey', linestyle='-', linewidth=0.5)

        i = 0
        j = 0
        day_idx = 0

        #Distinguish mutal vs shunt (mutual has dry, shunt doesn't)

        if date_list[0] == "dry":
            start = date_list[1]
        else:
            start = date_list[0]

        start = self.getDatetime(start)

        day_actual_list = []

        while j < len(df):
            i += 1 # ith is Title, Data starts from i+1
            j = i + 25
            x_freq = df.iloc[i:j,0].astype(float) #frequency
            y_imped = df.iloc[i:j,1].astype(float) #impedance
            y_phase = df.iloc[i:j,2].astype(float) #-phase
            date = date_list[day_idx]
            if date == "dry":
```

```
                prefix = "Day-0"
                day_actual_list.append(0)
            else:
                date = self.getDatetime(date)
                day_diff = date - start
                day_actual = self.getActualDates(day_diff.days, 70.5, 37.0)

                prefix = "Day-" + str(1 + day_diff.days) + "(" + str(1 + day_actua
                date = date_list[day_idx]

                day_actual_list.append(1 + day_actual)

            # Graph 1: Imepdance Z(Ω) vs Frequency(Hz) - labeled by dates
            ax1.plot(x_freq, y_imped, 'o-', label = prefix + ": " + date)

            # Graph 2: -Phase(°) vs Frequency(Hz) - labeled by dates
            ax2.plot(x_freq, y_phase, 'o-', label = prefix + ": " + date)

            i = j
            day_idx += 1

        ax3.plot(day_actual_list, Rs, marker='o')
        ax4.plot(day_actual_list, Rct, marker='o')
        ax5.plot(day_actual_list, C, marker='o')

        ax1.legend(loc='upper right', fontsize = 15)
        ax2.legend(loc='upper right', fontsize = 15)
        plt.show()
        return None

    def getRC(self, df, value):
        """
        Get the table of R_s over time
        """
        data = []
        idx = 0

        if value == "Rs":
            idx = 3
        if value == "Rct":
            idx = 4
        if value == "C":
            idx = 5
        # remove strings

        j = 1
        while j <= len(df):
            data.append(float(df.iloc[j,idx]))

            j = j + 26
        return data

    def getActualDates(self, day_diff, room_temp, device_temp):
        # Accelerated Aging Test Formula
        exp = (room_temp - device_temp)/10.0
        factor = 2**(exp)
        day_real = day_diff * factor
        return int(day_real)

    def getDatetime(self, m_d_y):
        """
        m_d_y is a string in month, day, year format
        """
        time_list = m_d_y.split("/")
```



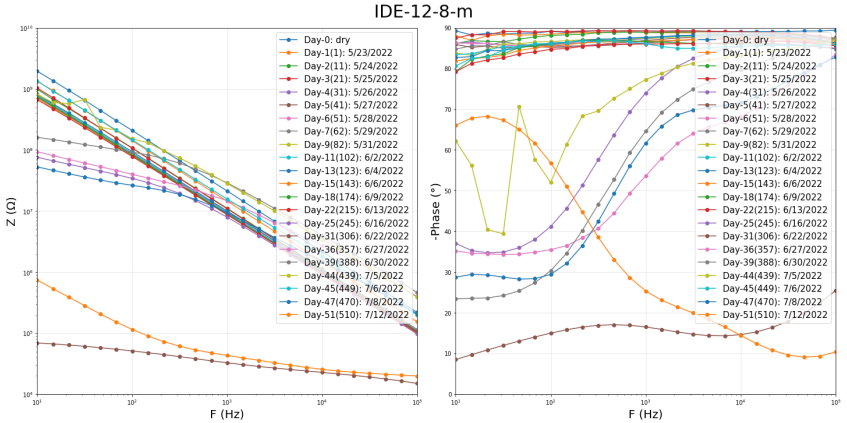
```
        date = datetime.date(2022, int(time_list[0]), int(time_list[1]))
        return date


def addNewIDE(start, end):
    """
        Create a list of new IDE with names.
        start: the start number of IDE
        end: the end number of IDE
    """
    L  = []
    for i in range(start, end):
        L.append(str(i) + "-2-m")
        L.append(str(i) + "-2-s")
        L.append(str(i) + "-4-m")
        L.append(str(i) + "-4-s")
        L.append(str(i) + "-8-m")
        L.append(str(i) + "-8-s")
        L.append(str(i) + "-16-m")
        L.append(str(i) + "-16-s")

    df_new_IDE = pd.DataFrame(L, columns=['new IDE name'])

    #Export a csv file with new IDEs
    df_new_IDE.to_csv("new_IDE.csv", index=False)
    return df_new_IDE
```

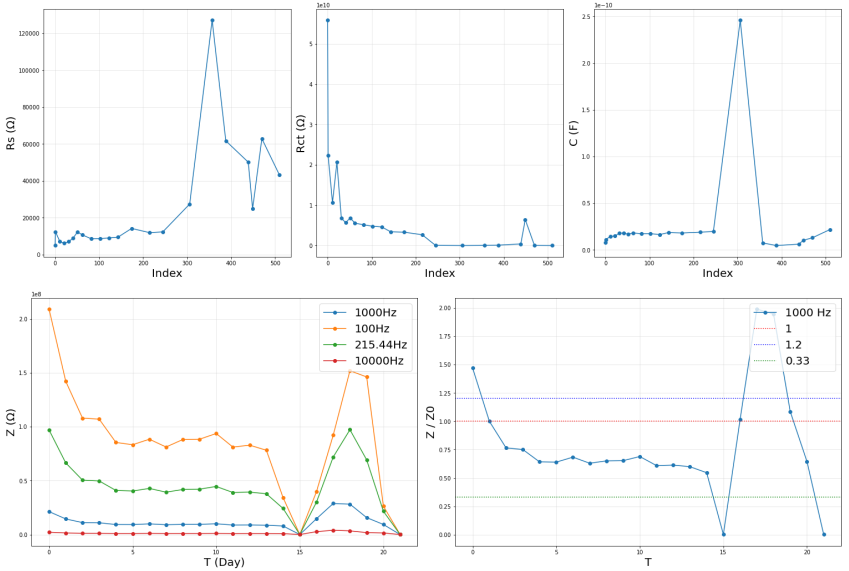
```
Matplotlib Version 3.5.1
Seaborn Version 0.11.2
```

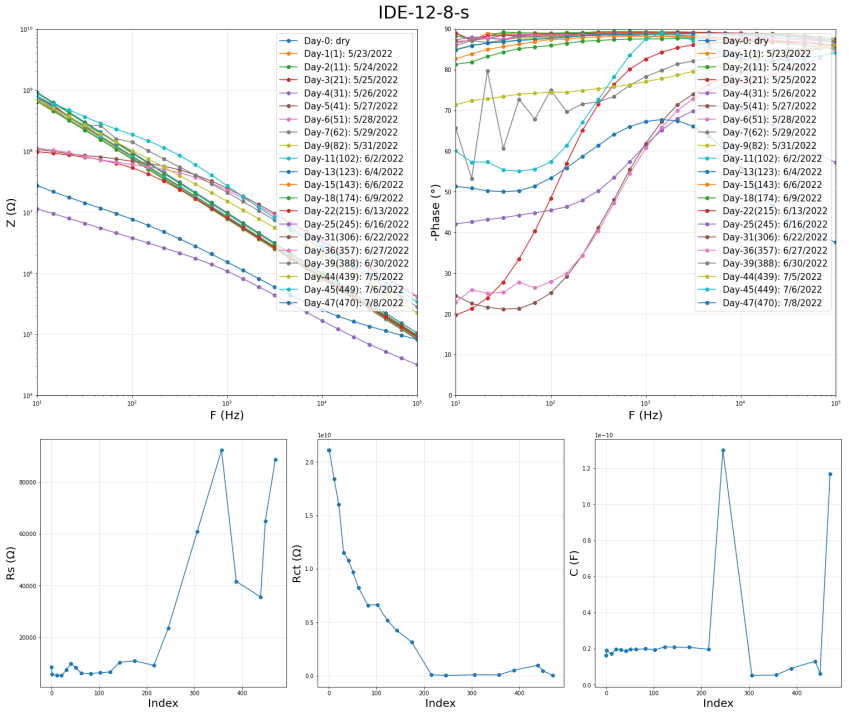
In [10]:

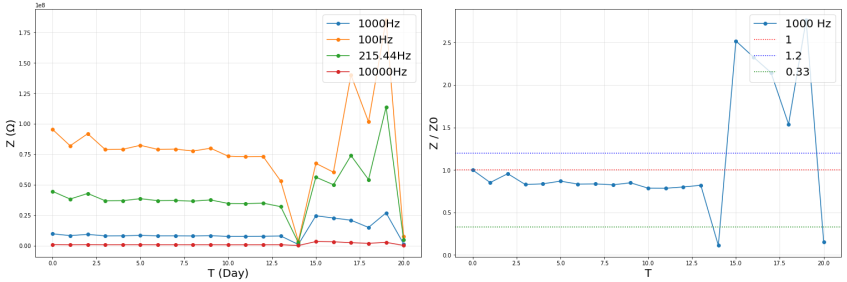
```
# Step 2: Initialize tested IDEs

# Read experiment date file.
date = "date.csv"
df_date = pd.read_csv(date)

# Initialize IDEs
#Old Devices
IDE_12 = IDE(12, [8], ["m","s"], "csv")
#IDE_14 = IDE(14, [16], ["m","s"], "csv")
IDE_16 = IDE(16, [2,4,8,16],["m","s"], "csv")
IDE_20 = IDE(20, [2,16], ["m","s"], "csv")

#New Devices
IDE_22 = IDE(22, [2,4,8,16],["m","s"], "csv")
IDE_26 = IDE(26, [2,4,8,16],["m","s"], "csv")
IDE_27 = IDE(27, [2,4,8,16],["m","s"], "csv")
IDE_28 = IDE(28, [2,4,8,16],["m","s"], "csv")
IDE_31 = IDE(31, [2,4,8,16],["m","s"], "csv")

# Track device results
total_channels = 0
num_failed = 0
num_good_2 = 0
num_good_4 = 0
num_good_8 = 0
num_good_16 = 0

# List of all IDEs
IDE_list = [IDE_12, IDE_16, IDE_20, IDE_22, IDE_26, IDE_27, IDE_28, IDE_31]

# IDE_12 as an example
```

```
# Iterate through one IDE
date_idx = 0

# Graph Device Data
for ide in IDE_list:
    ide.setData()
    for file in ide.getDataFile():
        df = pd.read_csv(file)

        #First clean the data to only include the 25 items
        ide.cleanData(df)

        #Read the cleaned data
        df = pd.read_csv(file)

        #Extract Rs, Rct, and C
        Rs = ide.getRC(df, "Rs")
        Rct = ide.getRC(df, "Rct")
        C = ide.getRC(df, "C")

        #Get the summary graph for each IDE
        ide.getGraph(file, df, df_date, date_idx, Rs, Rct, C)

        ide.plotImpeFreq(file, df, [1000, 100,  215.44, 10000])
        #Extract the impedance based on frequency

#Graph IDE failure mode - wisker plot

# Read IDE life span file.
life = "IDE_life_span.csv"
df_life = pd.read_csv(life)


# def graphLifeSpan(df):
#     fig1, ax1 = plt.subplots()
#     ax1.set_title('IDE life span')
#     ax1.boxplot(df)
#     return None

# graphLifeSpan(df_life)

# Extract the data for only 10000, 1000, 215.44, 100 Hz
```

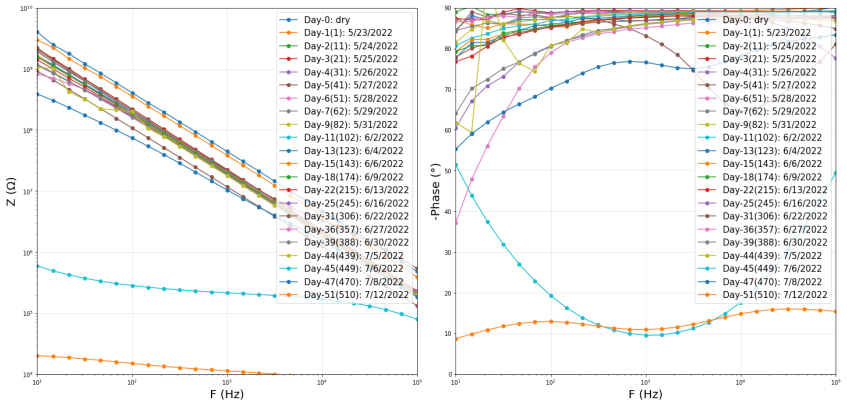


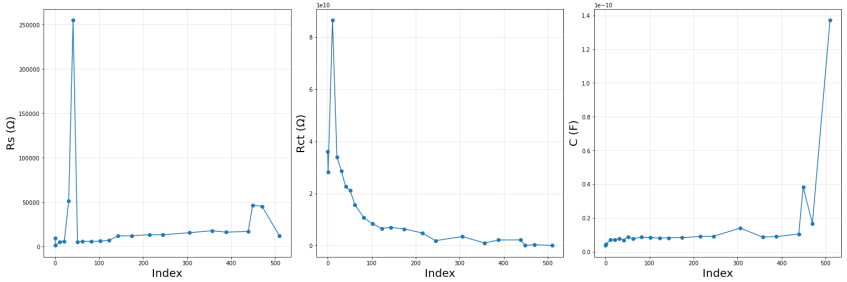


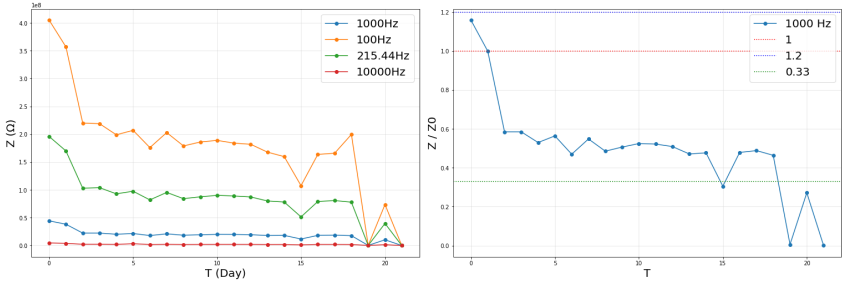




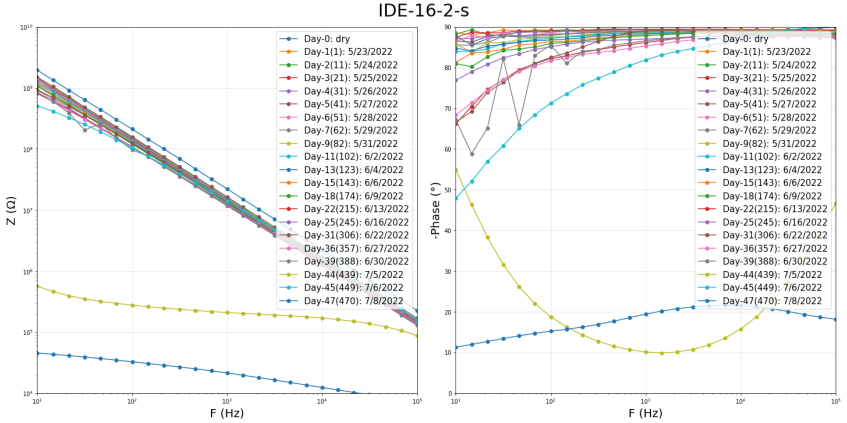
IDE-16-2-m

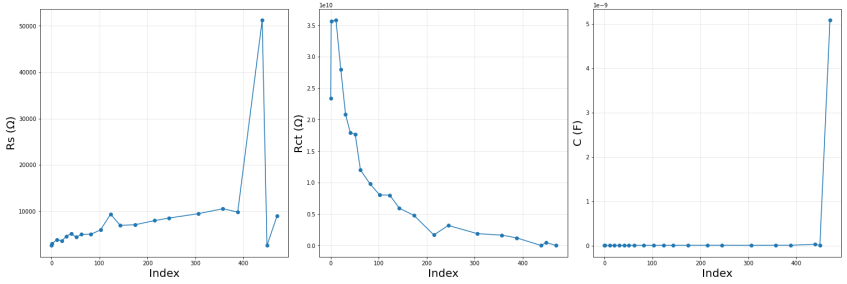


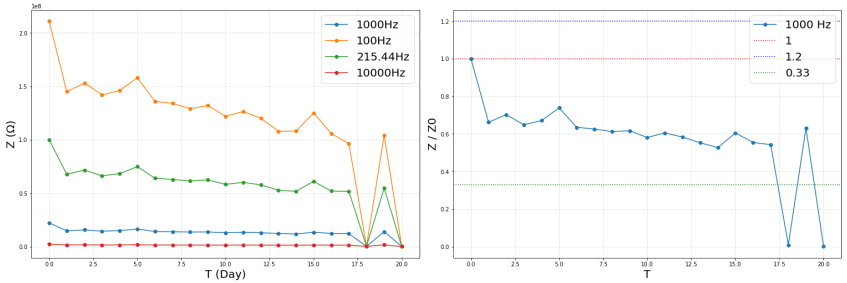




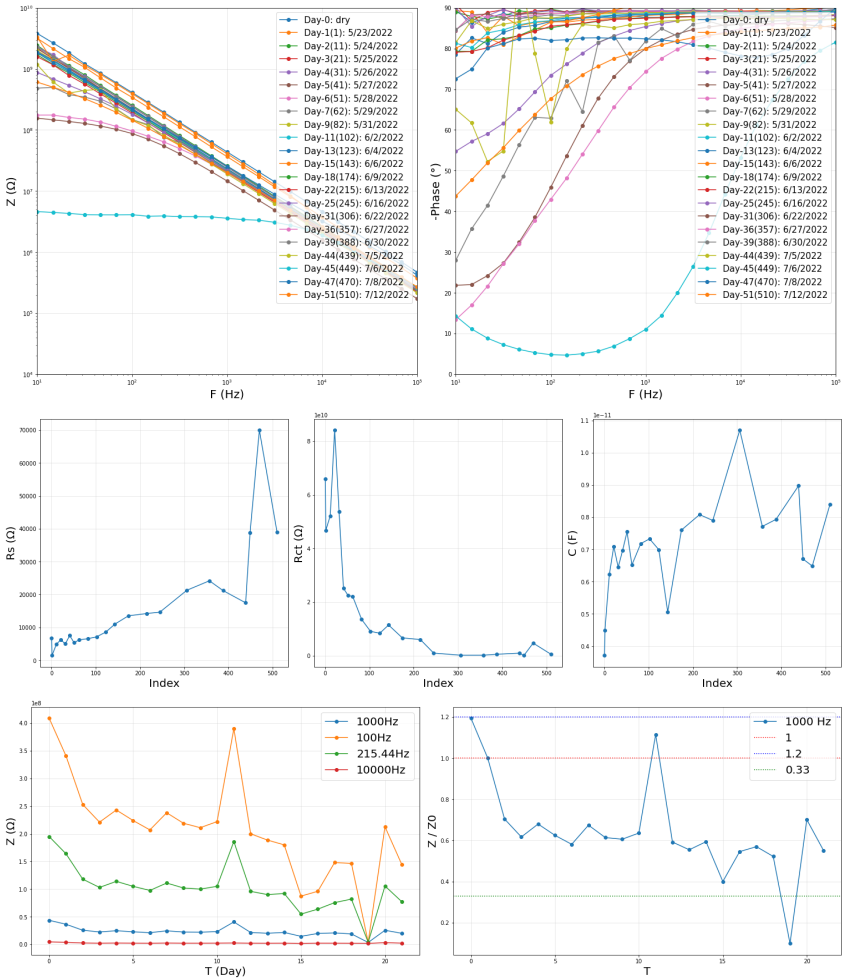
IDE-16-2-s



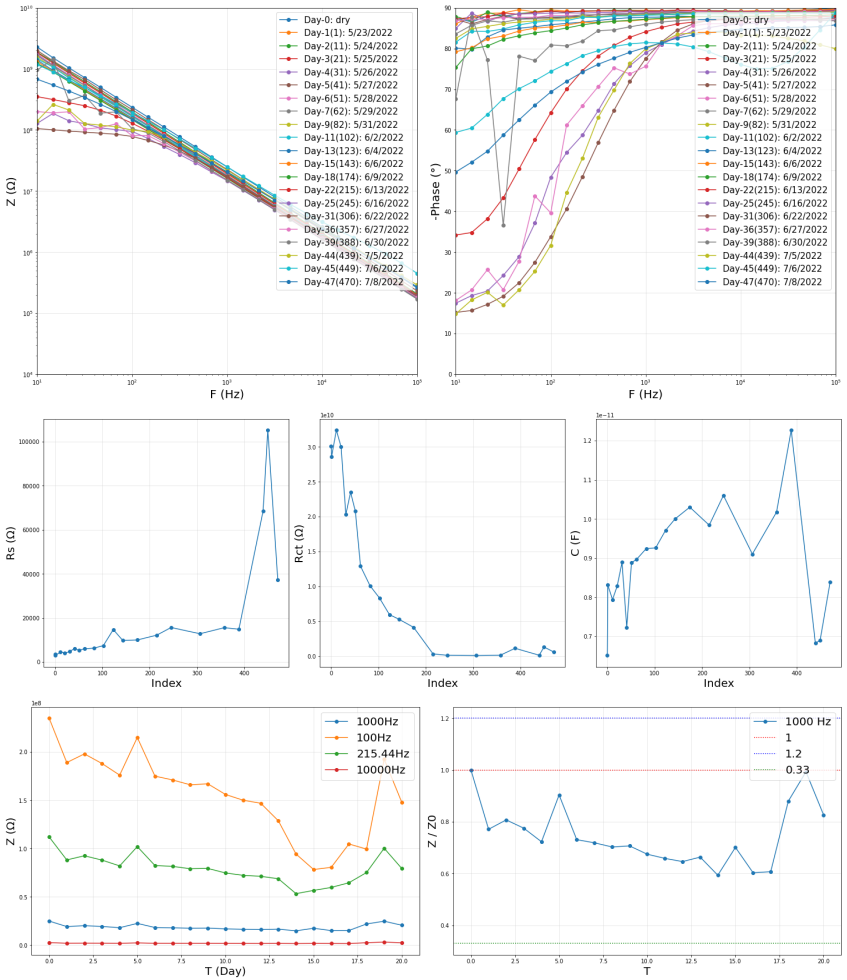




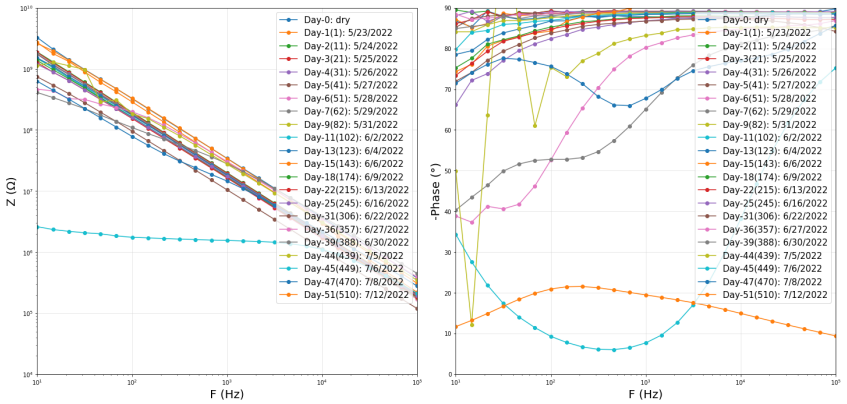
IDE-16-4-m

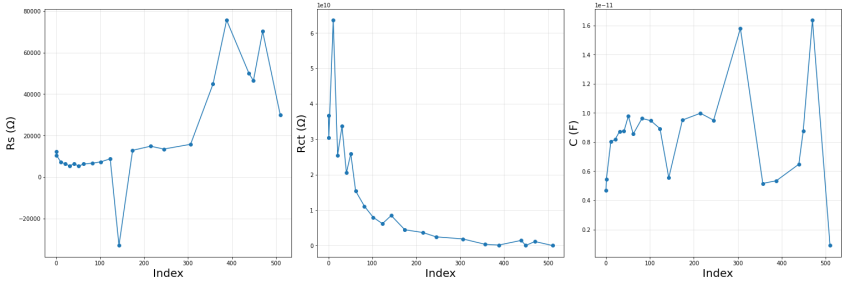


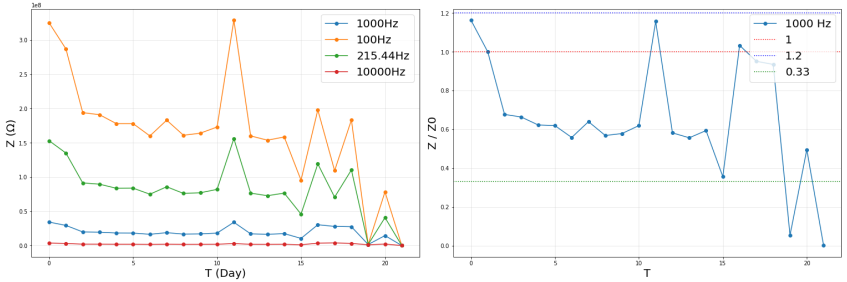
IDE-16-4-s



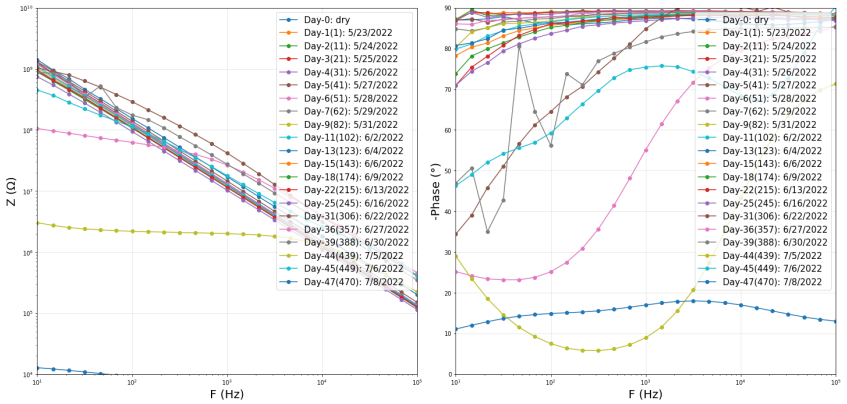
IDE-16-8-m

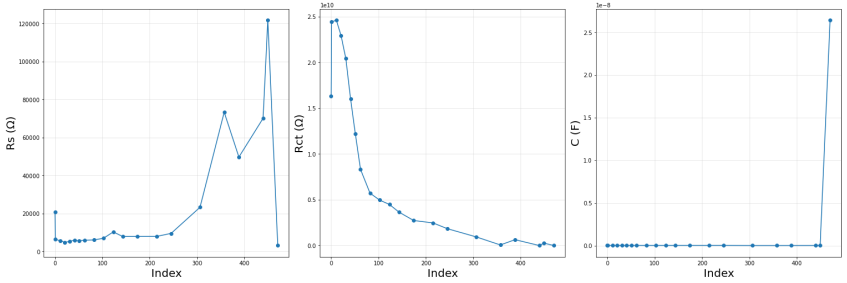


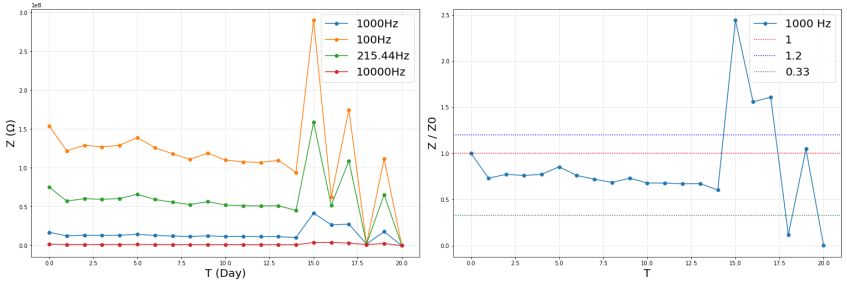




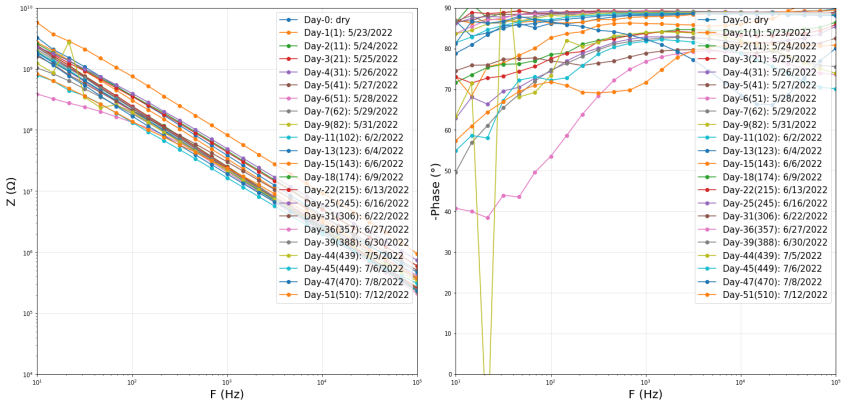
IDE-16-8-s

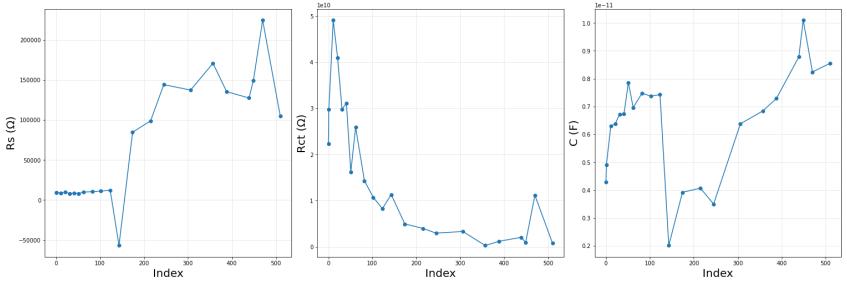


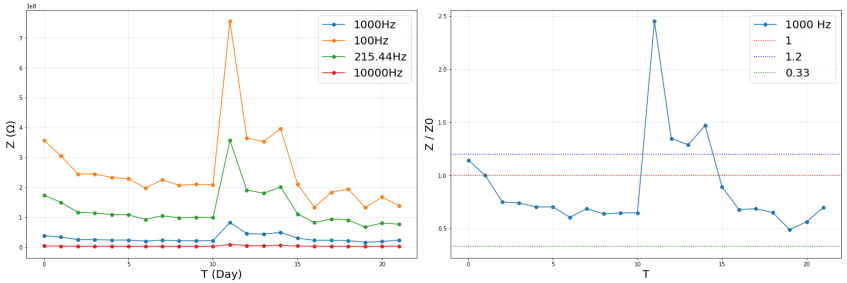




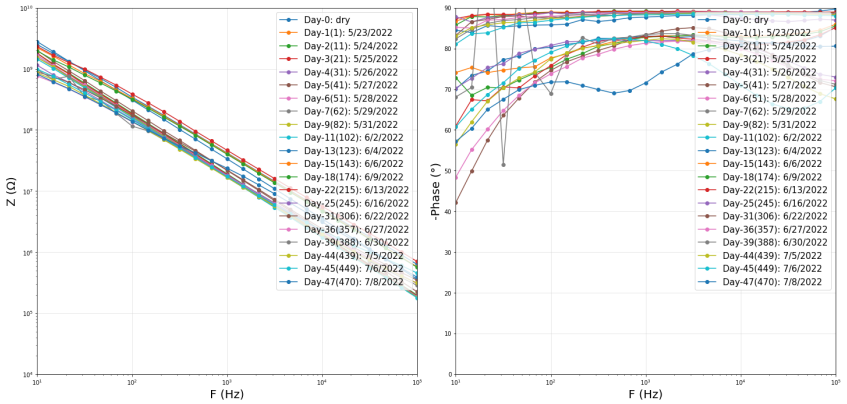
IDE-16-16-m

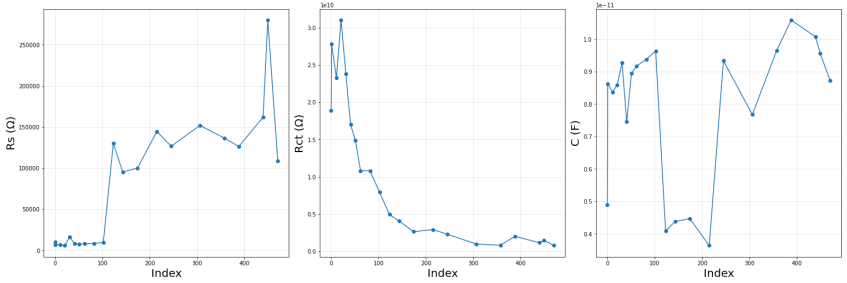


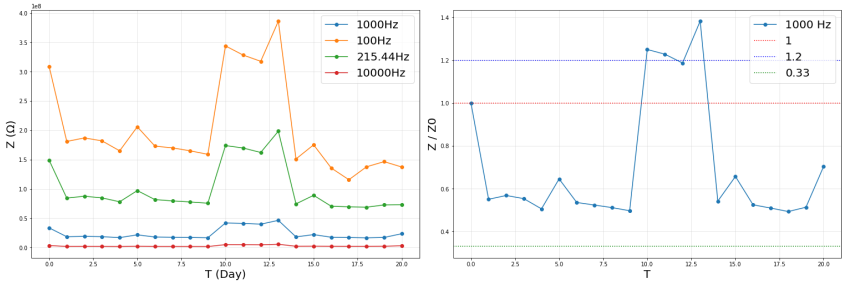




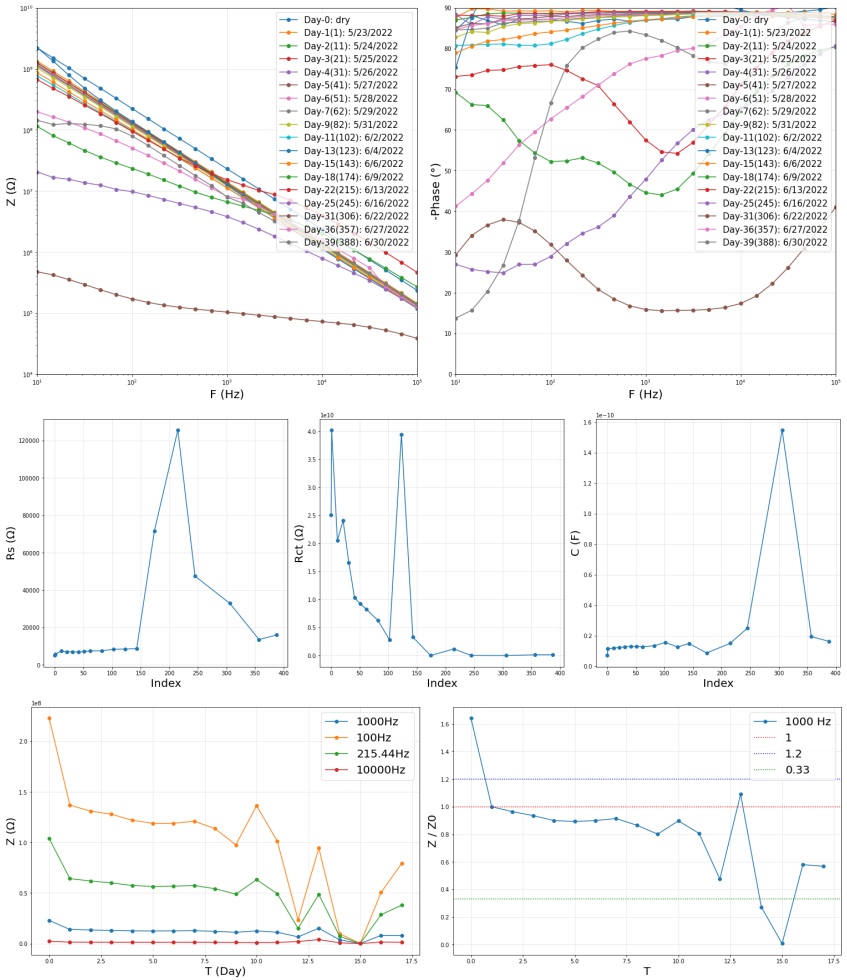
IDE-16-16-s



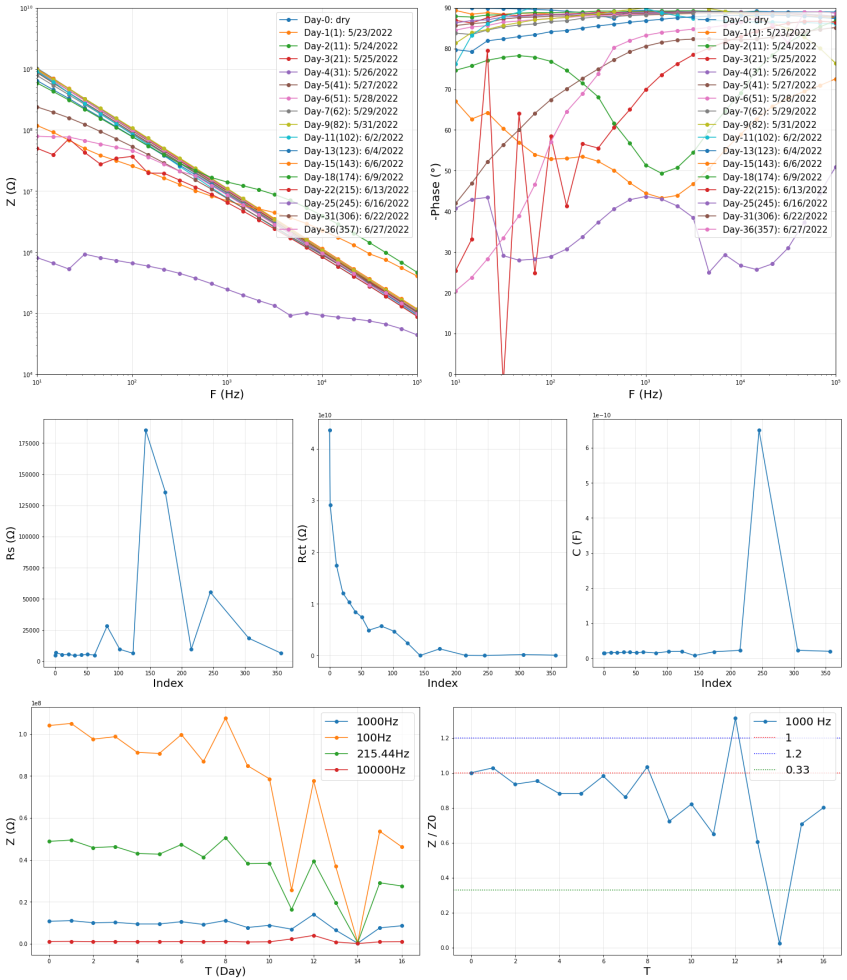




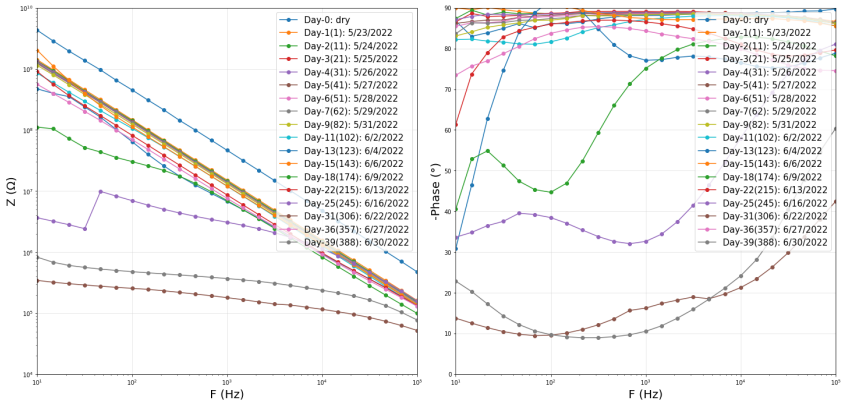
IDE-20-2-m

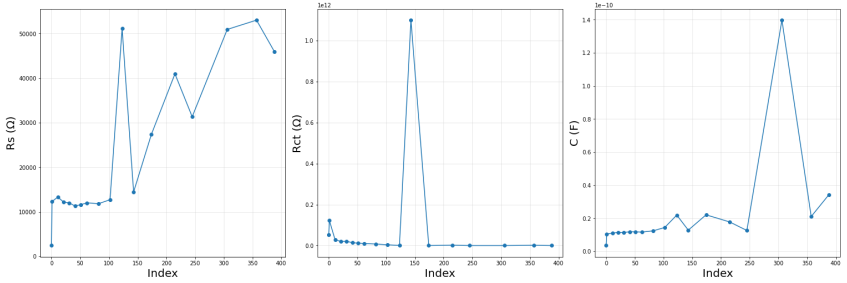


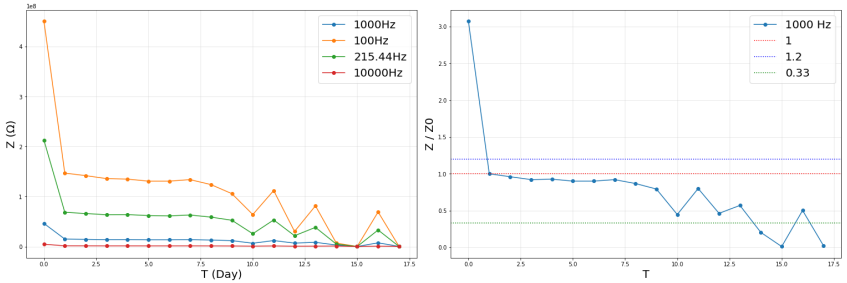
IDE-20-2-s



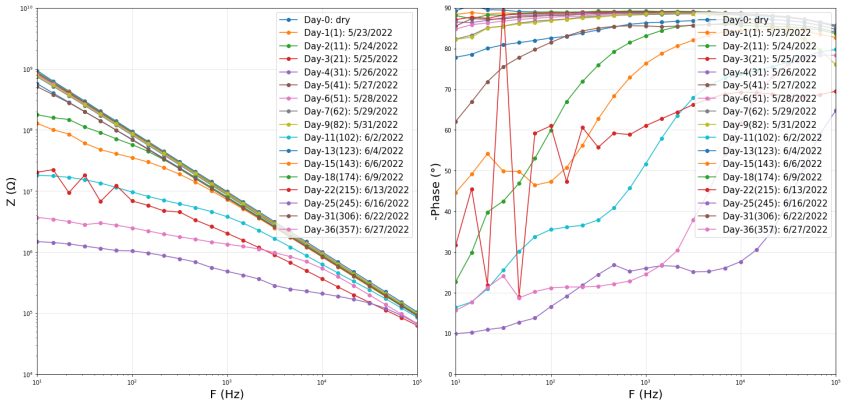
IDE-20-16-m

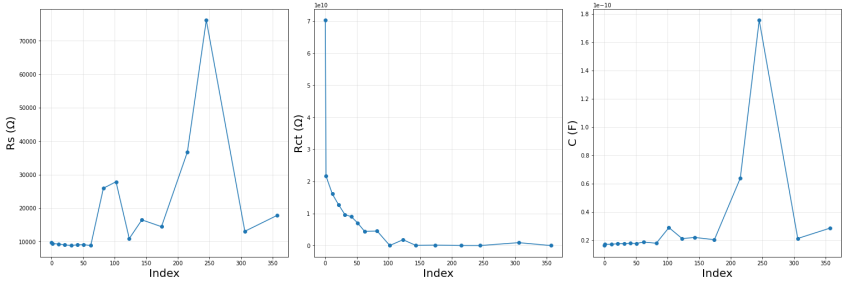


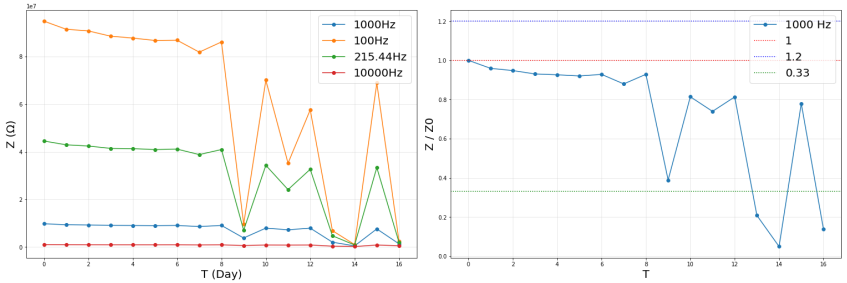




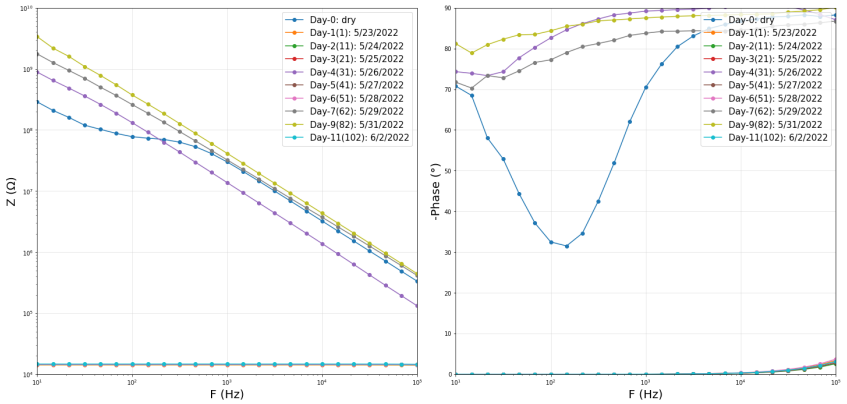
IDE-20-16-s

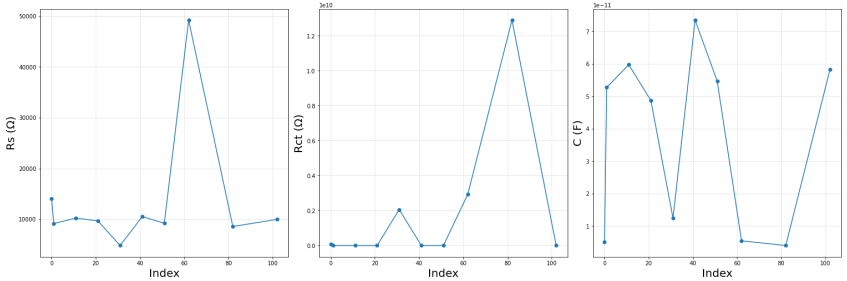


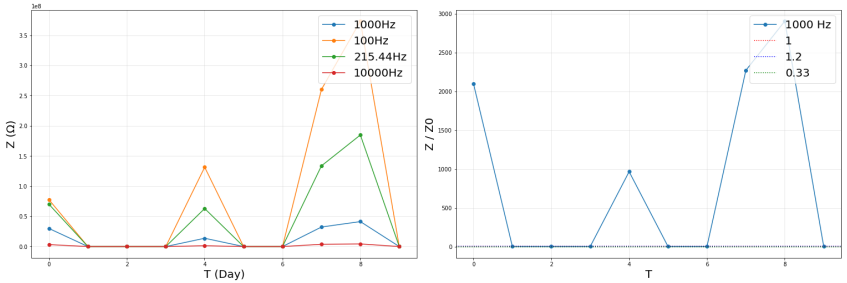




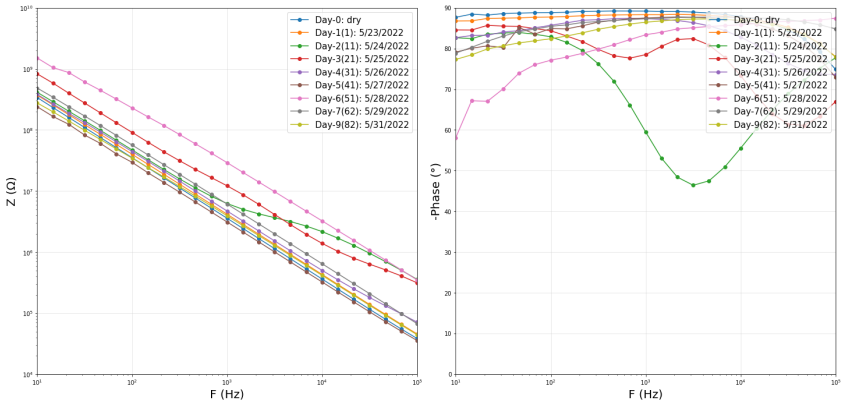
IDE-22-2-m

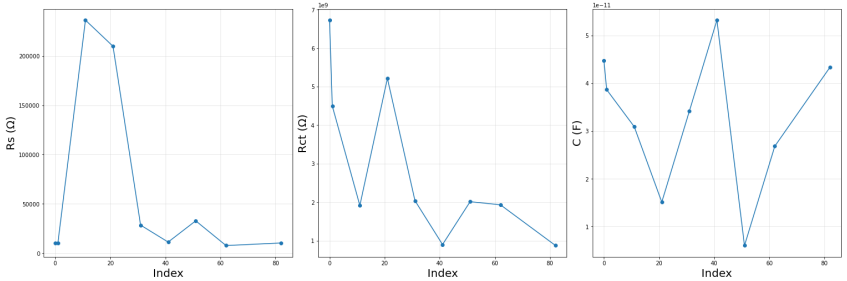


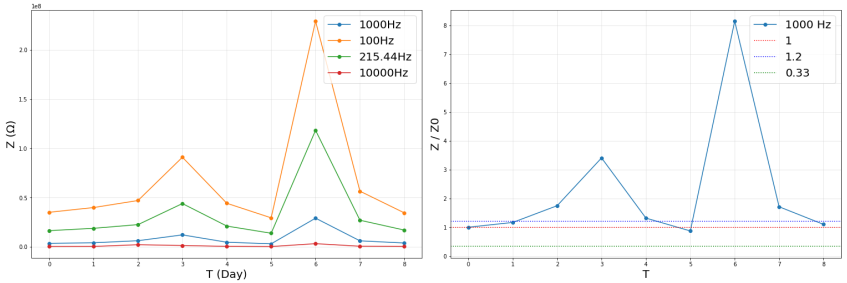




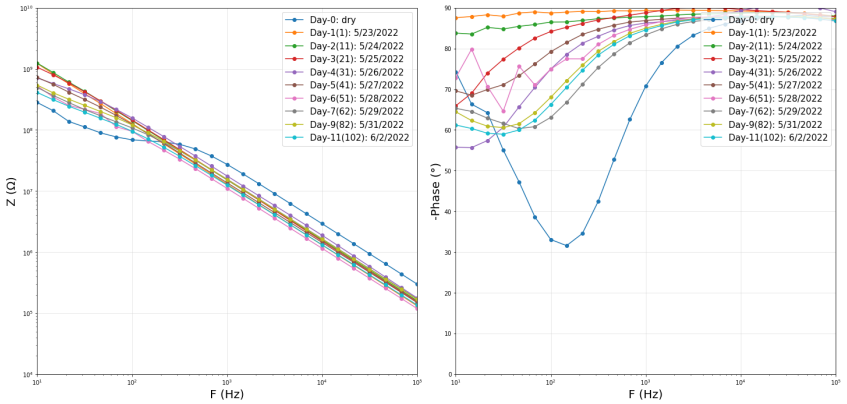
IDE-22-2-s

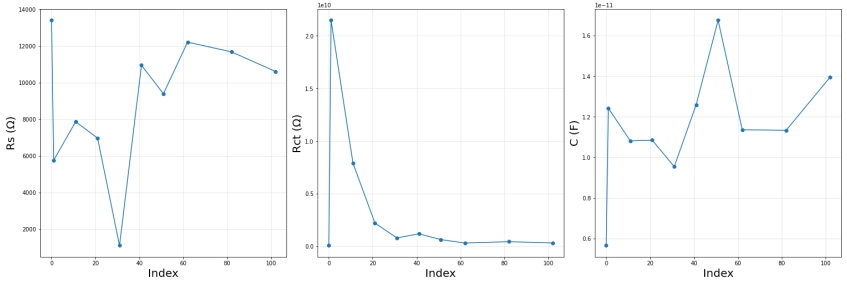


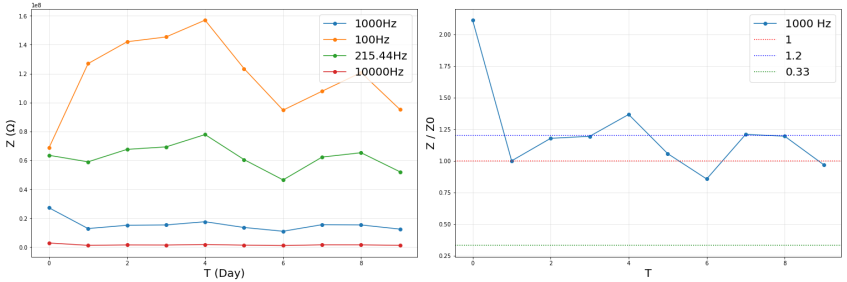




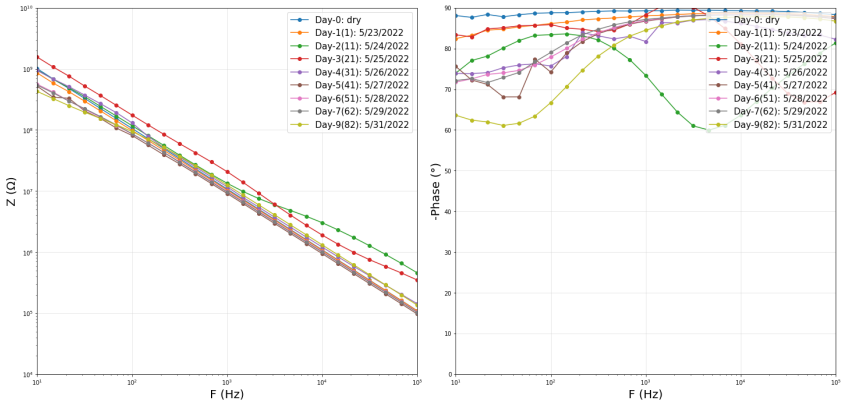
IDE-22-4-m

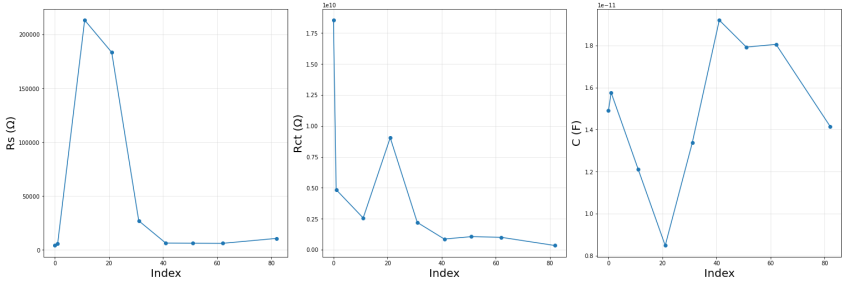


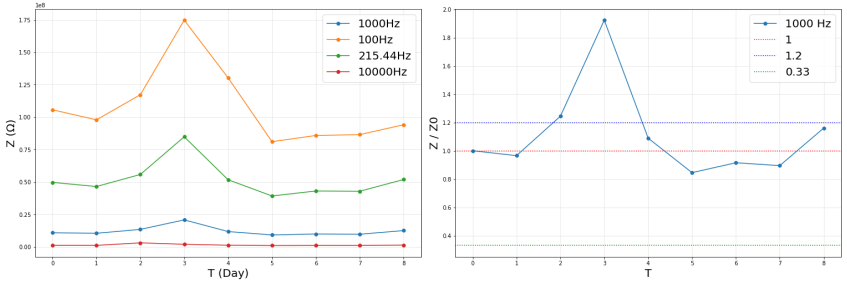




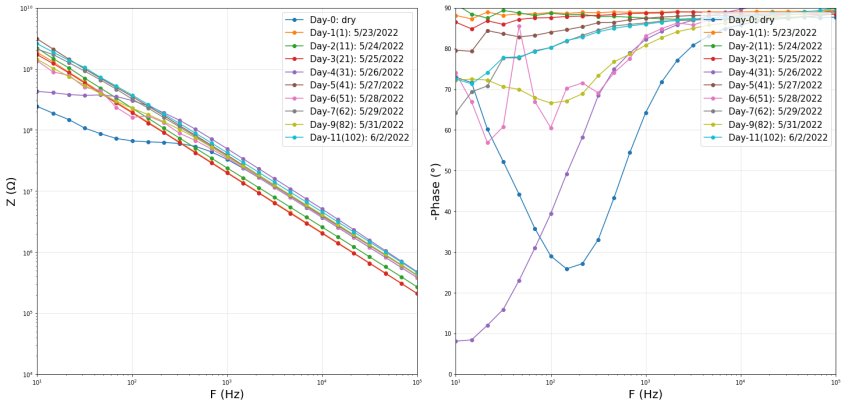
IDE-22-4-s

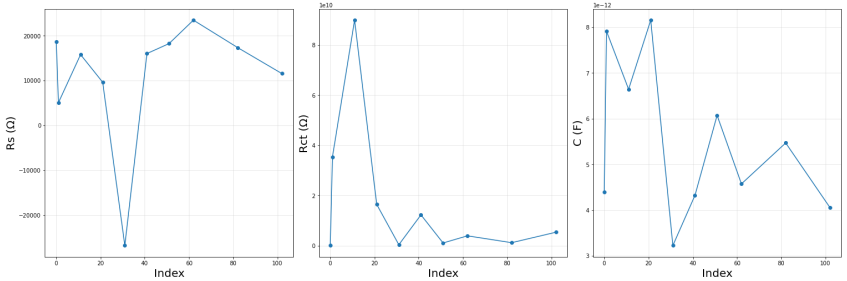


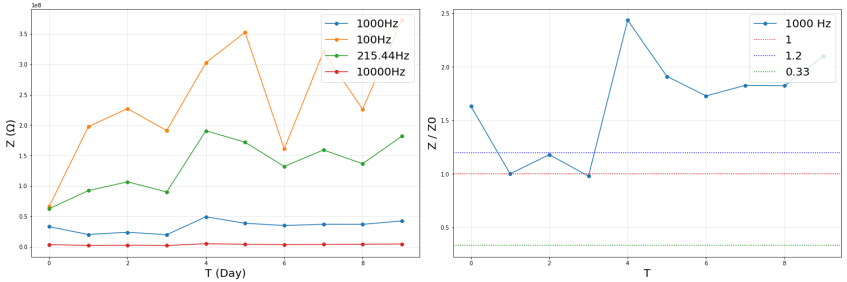




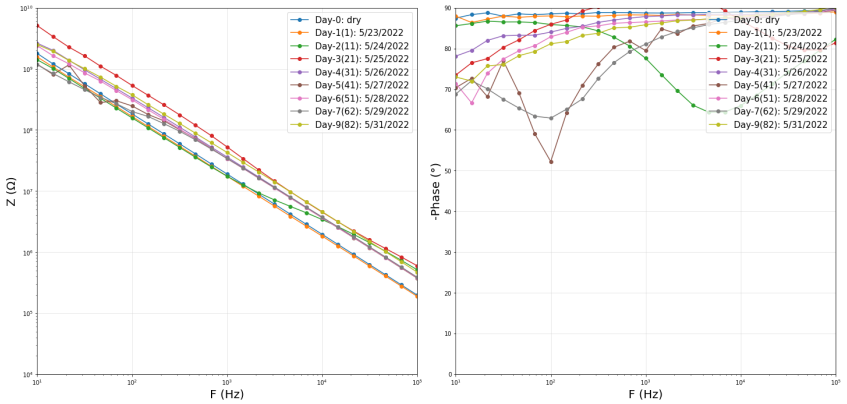
IDE-22-8-m

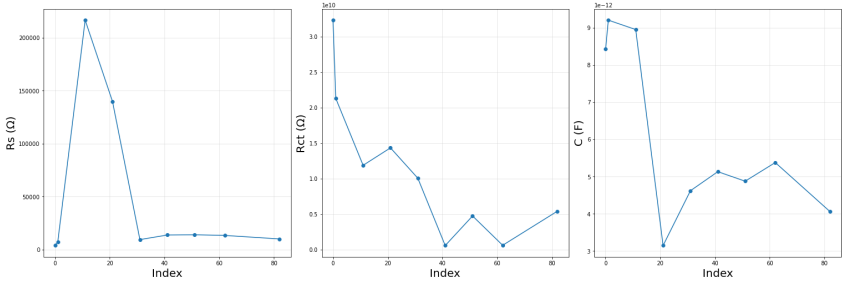


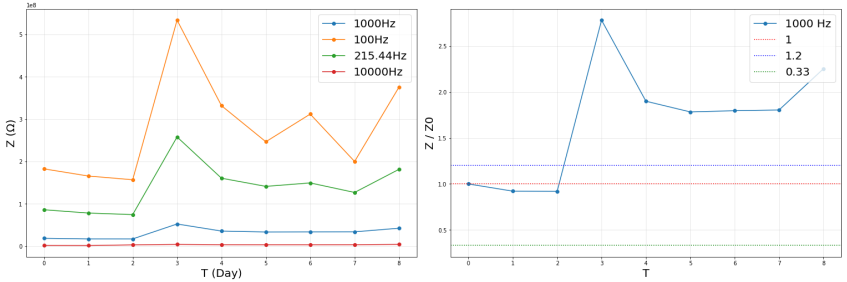




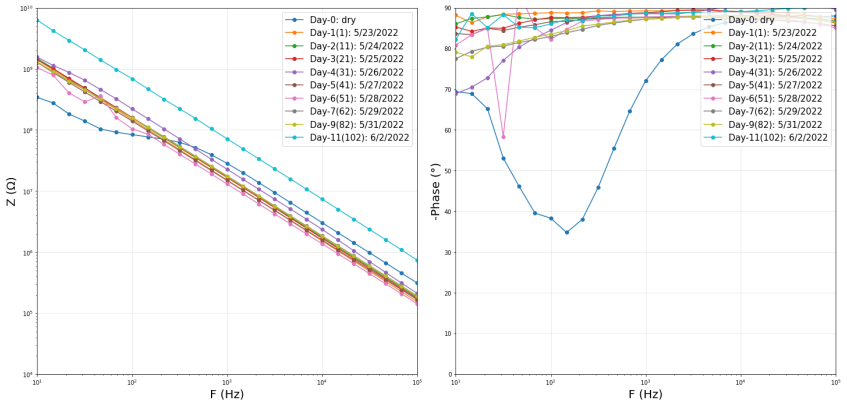
IDE-22-8-s

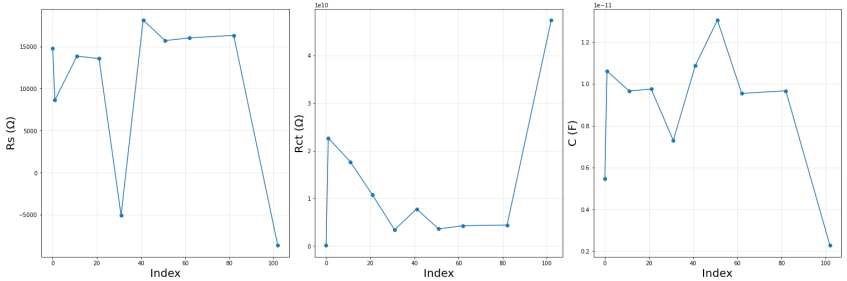


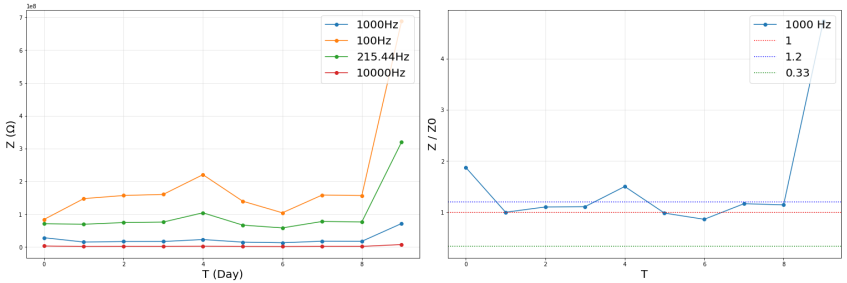




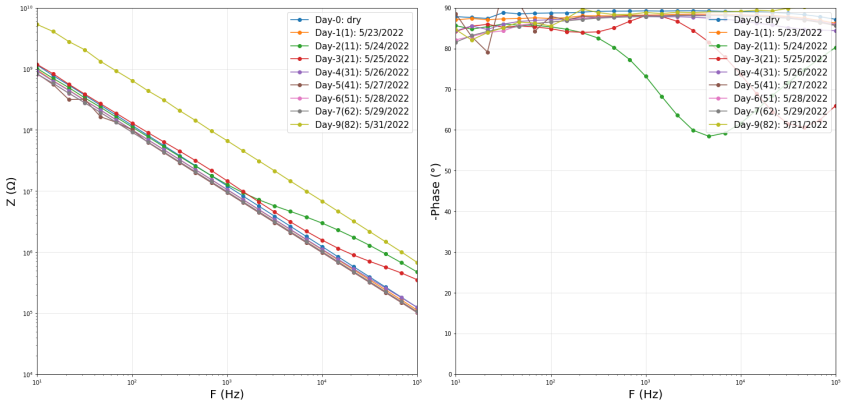
IDE-22-16-m

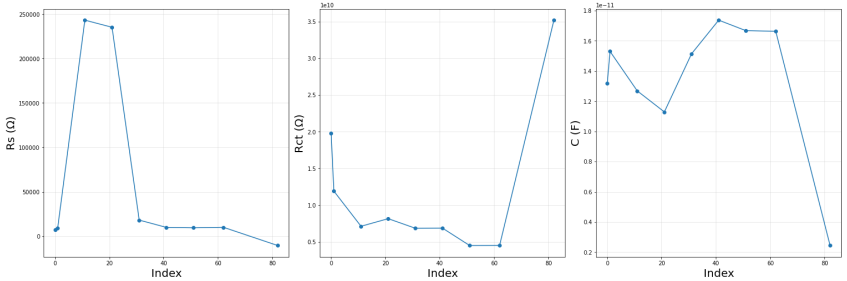


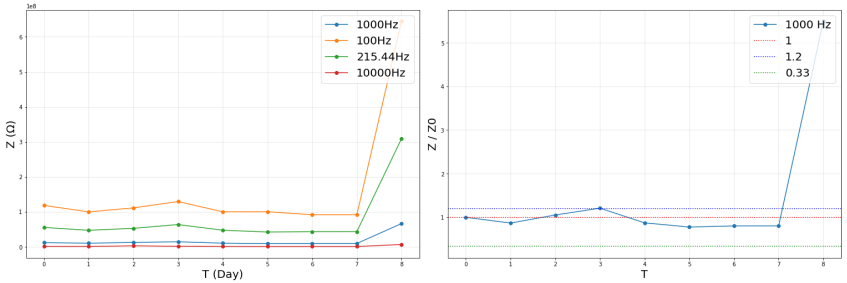




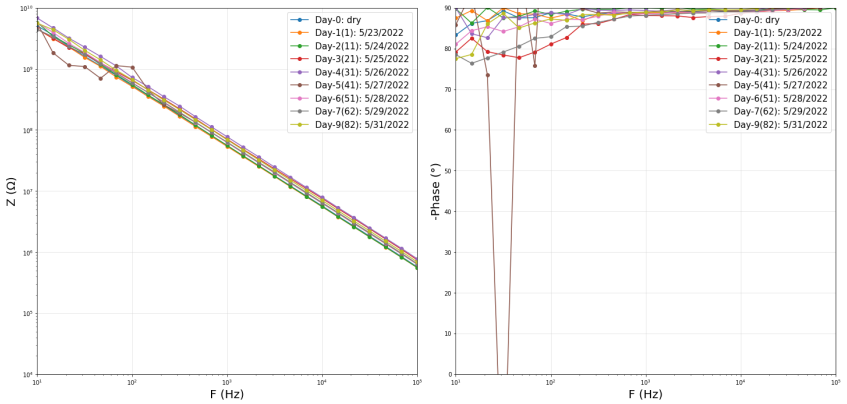
IDE-22-16-s

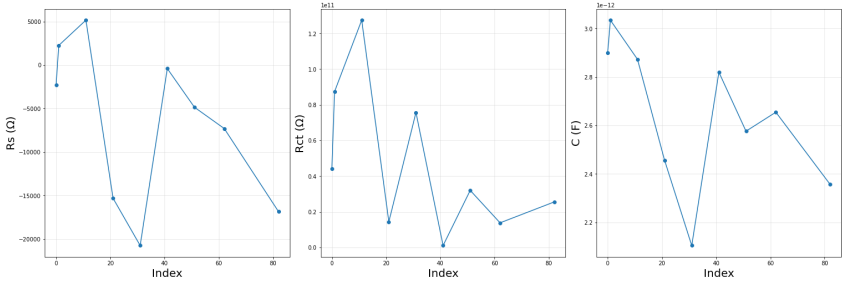


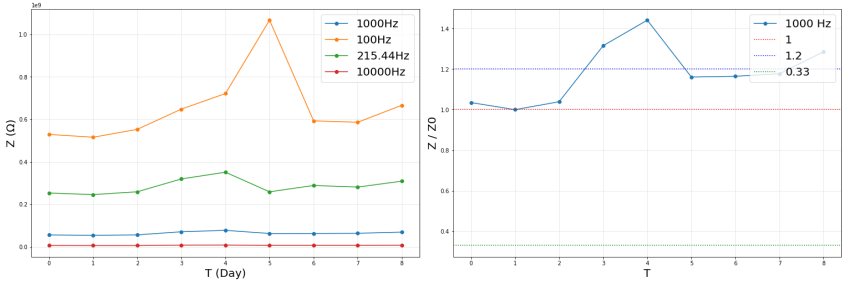




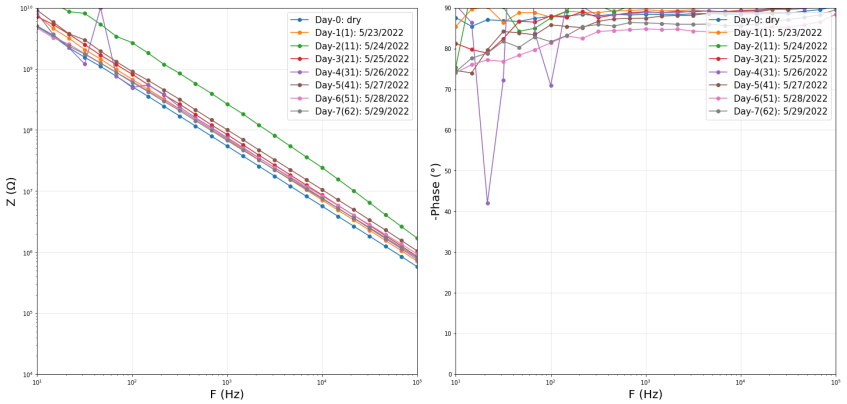
IDE-26-2-m

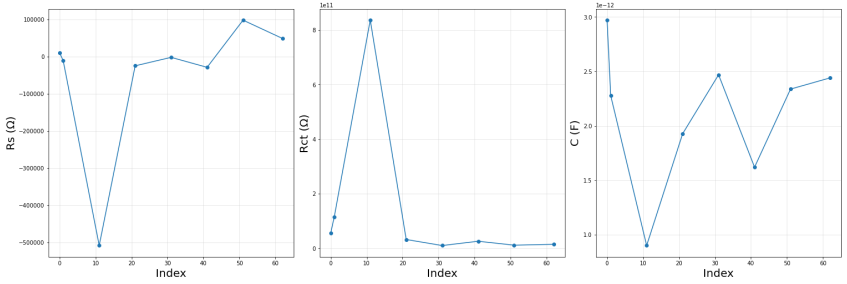


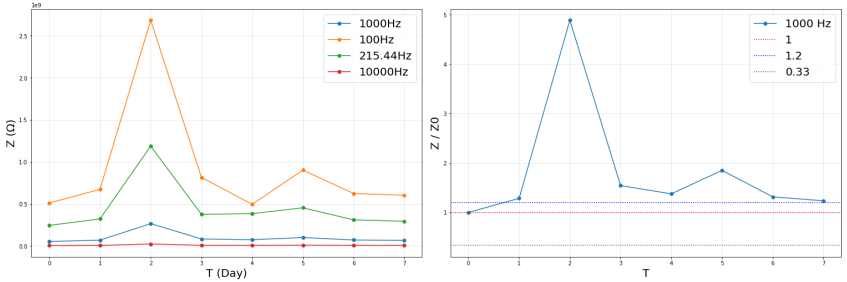




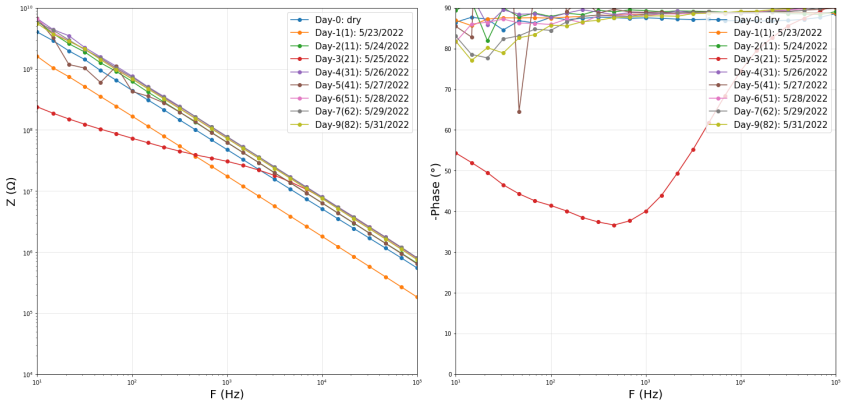
IDE-26-2-s

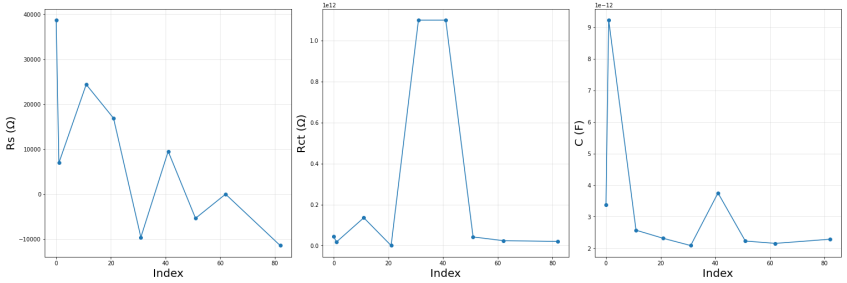


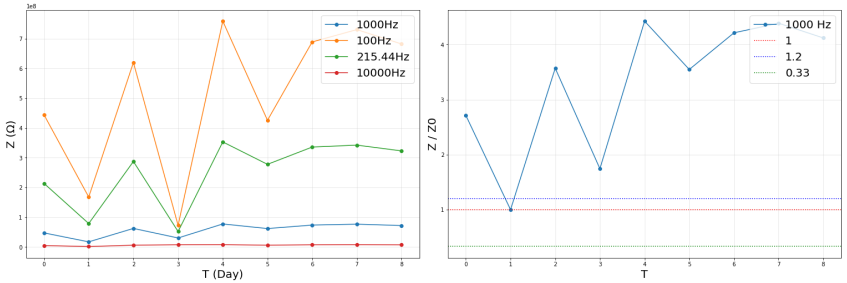




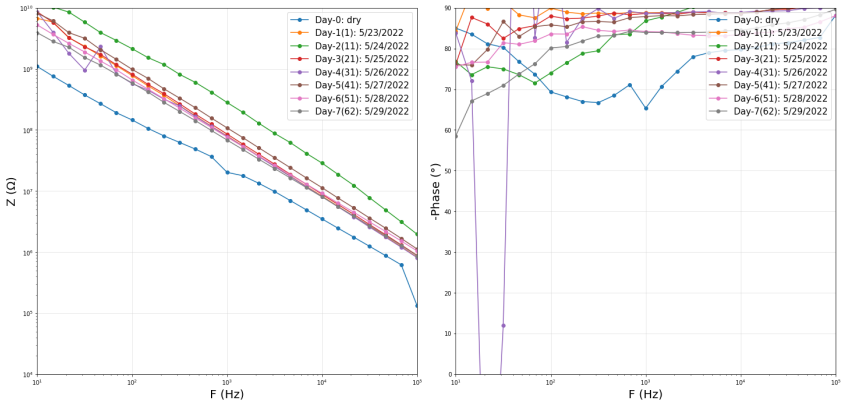
IDE-26-4-m

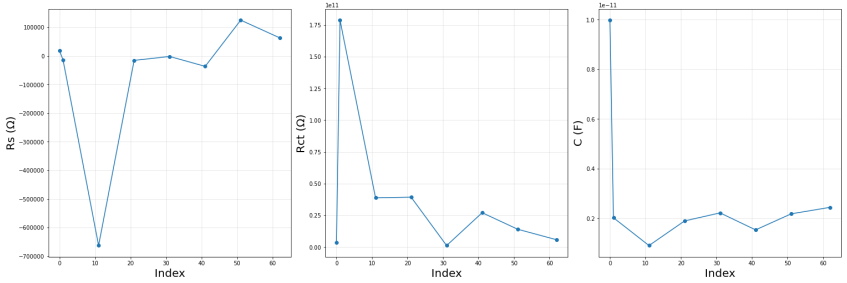


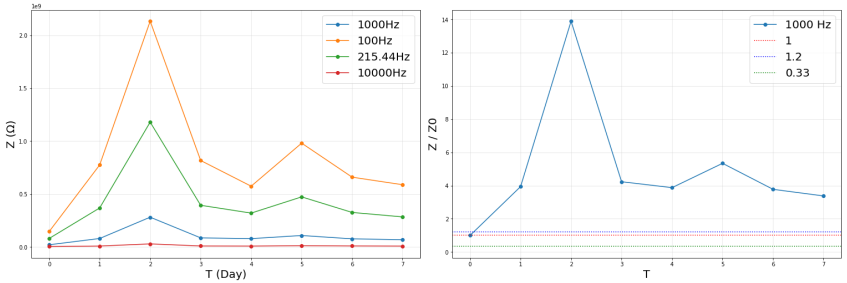




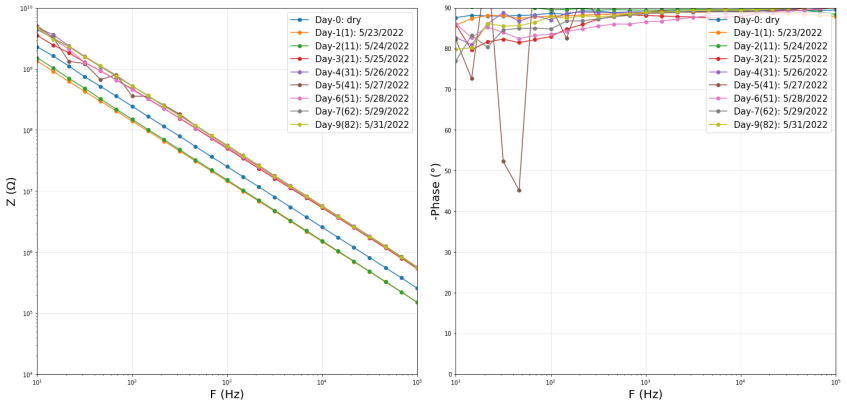
IDE-26-4-s

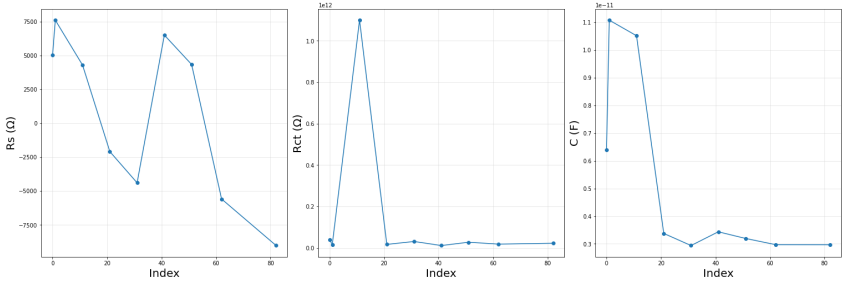


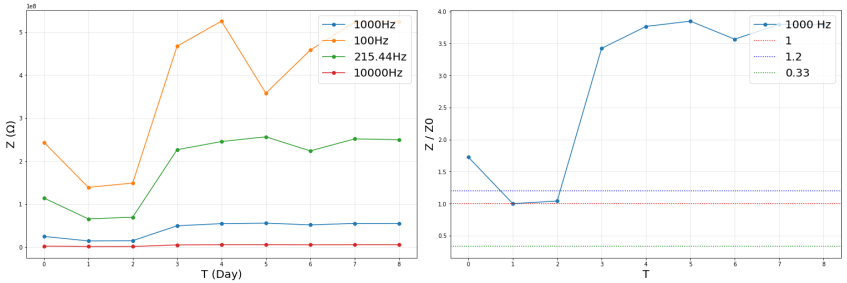




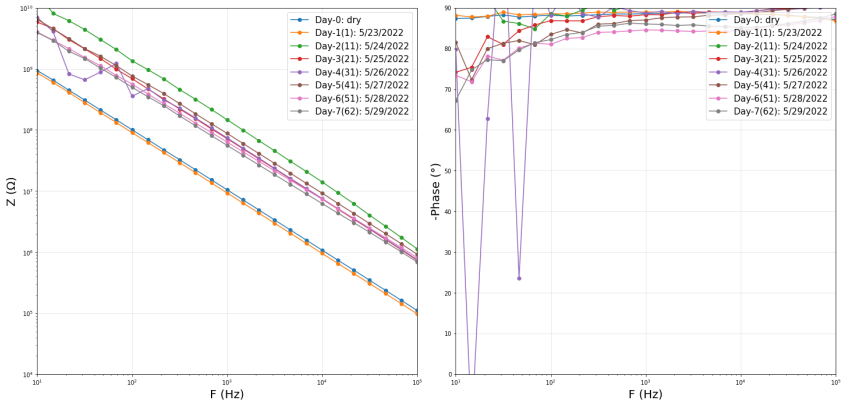
IDE-26-8-m

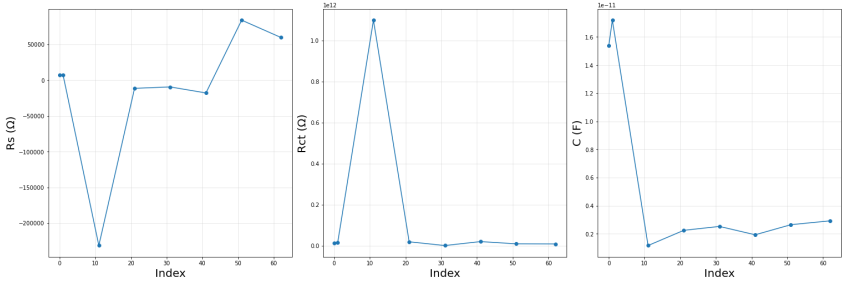


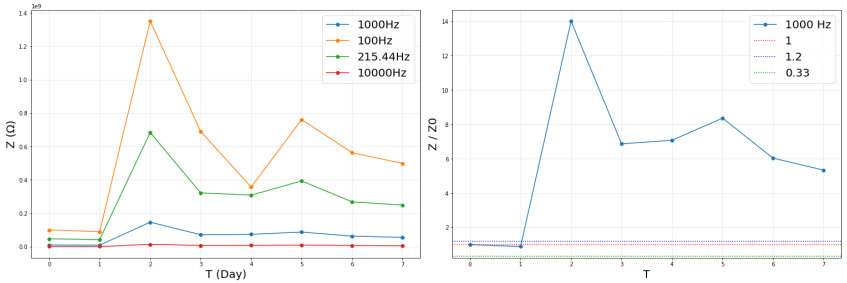




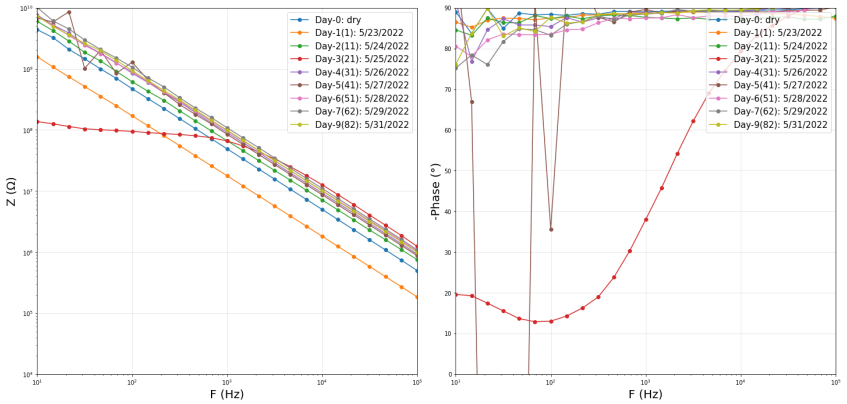
IDE-26-8-s

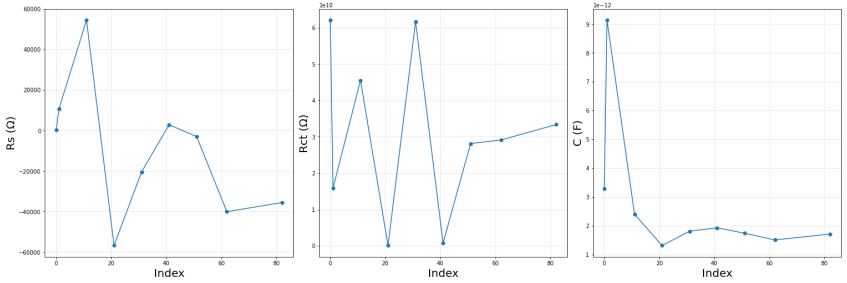


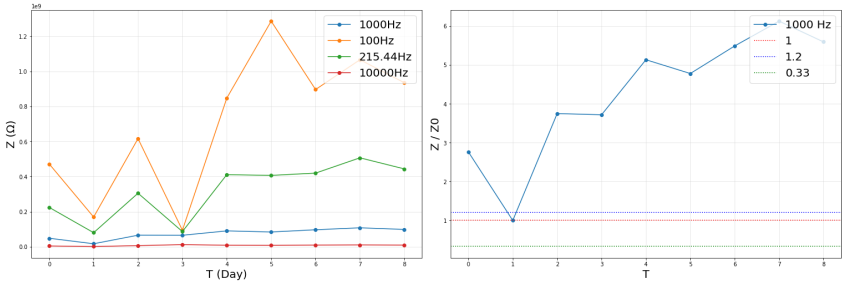




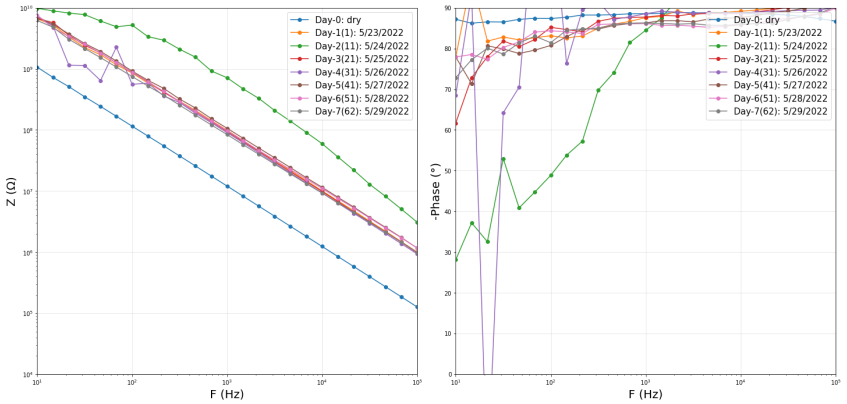
IDE-26-16-m

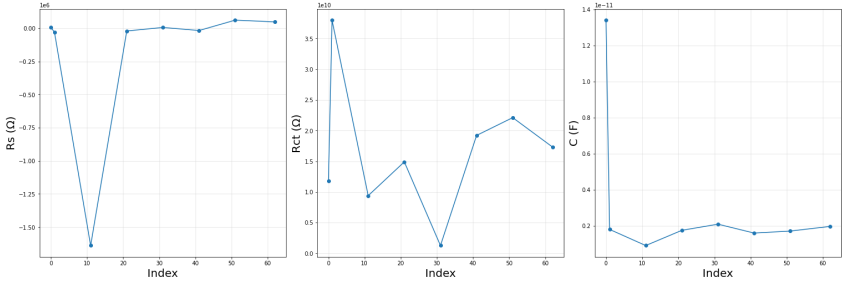


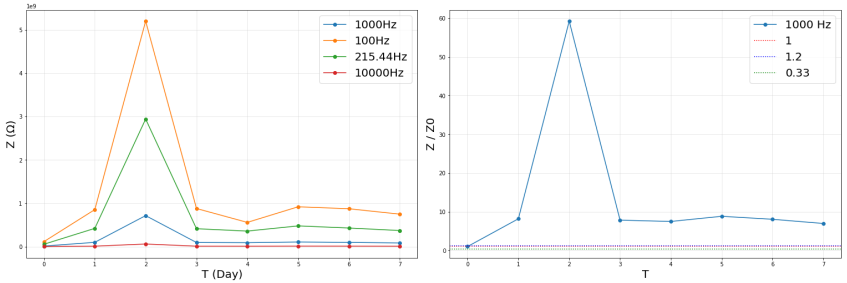




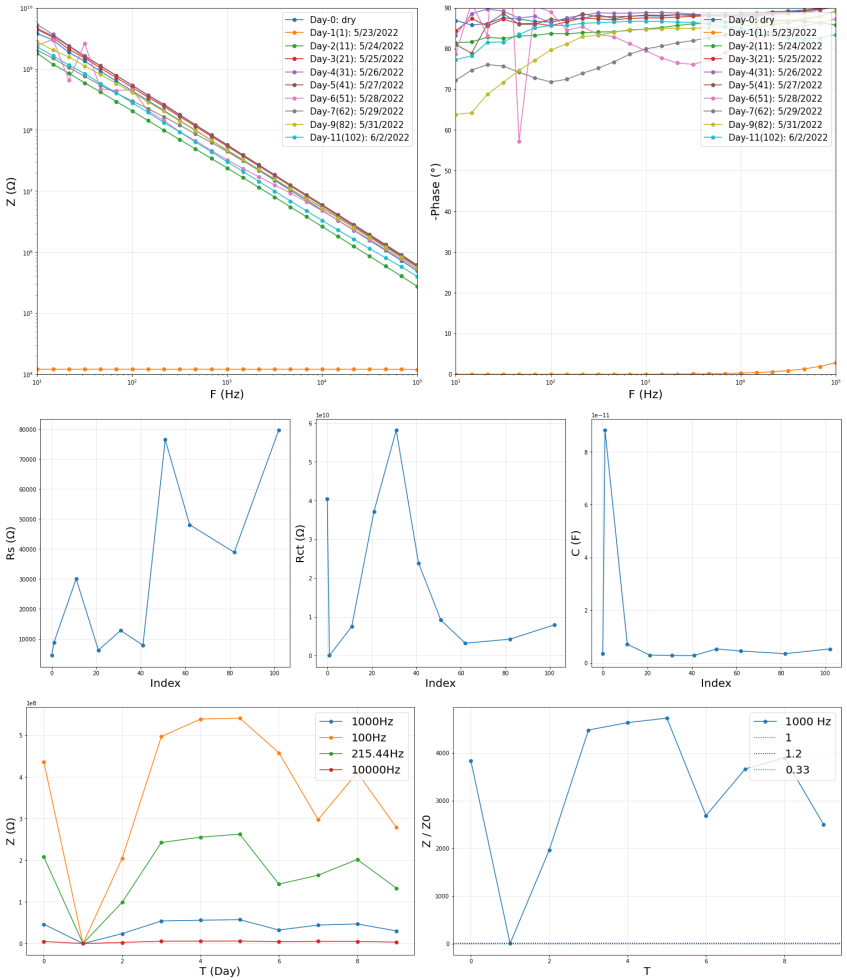
IDE-26-16-s



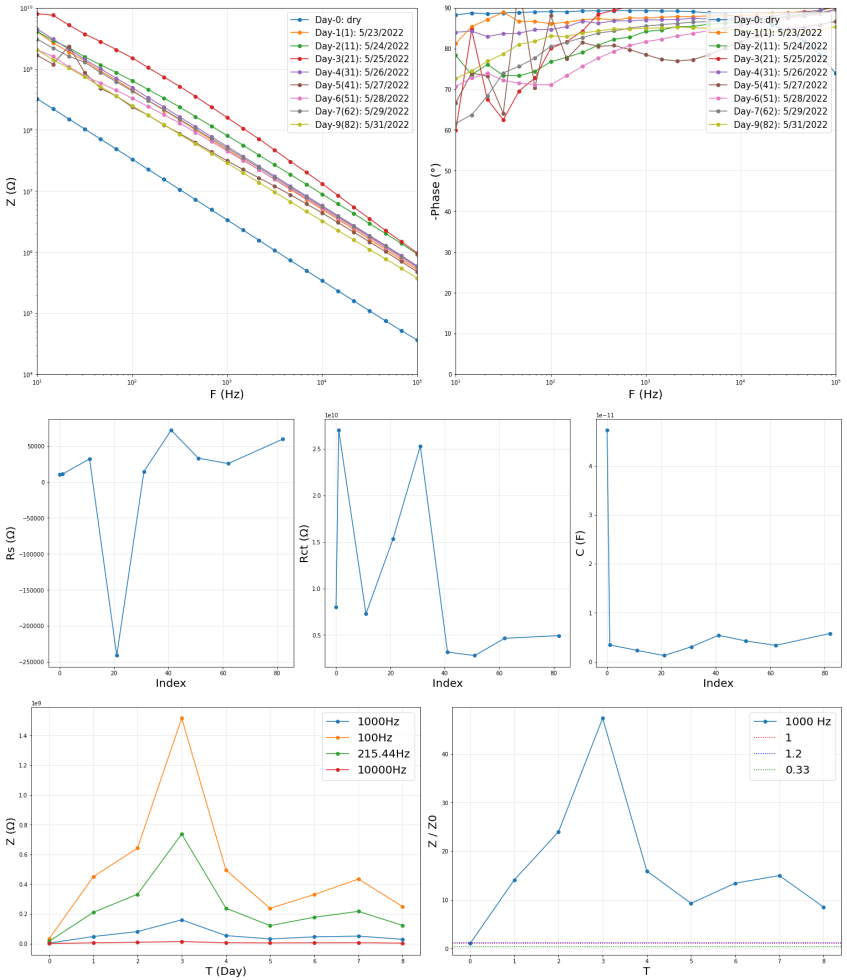




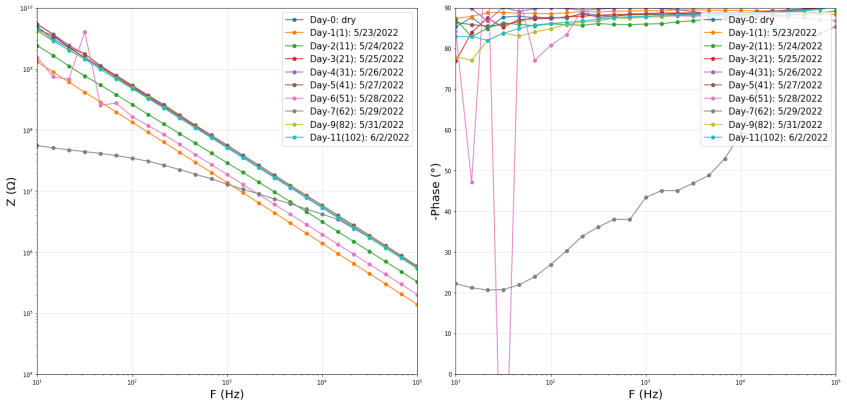
IDE-27-2-m

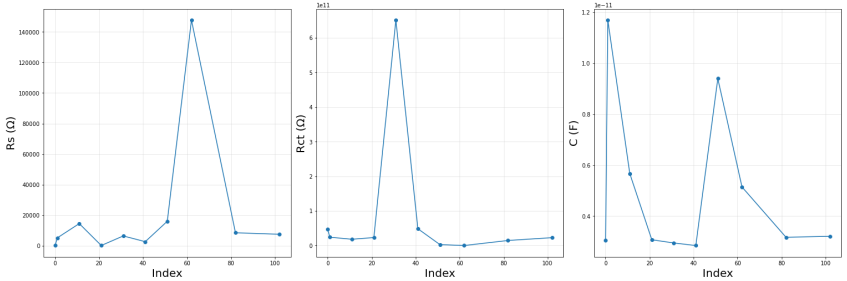


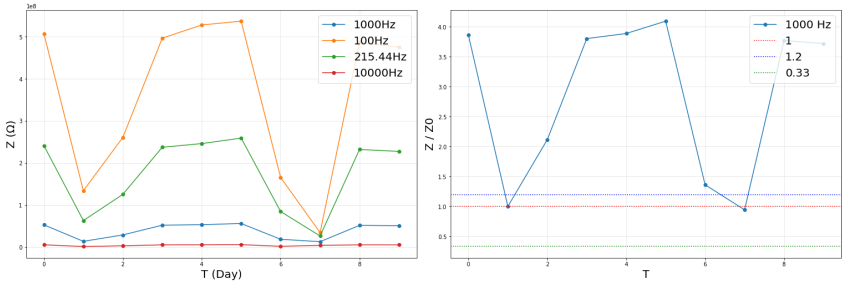
IDE-27-2-s



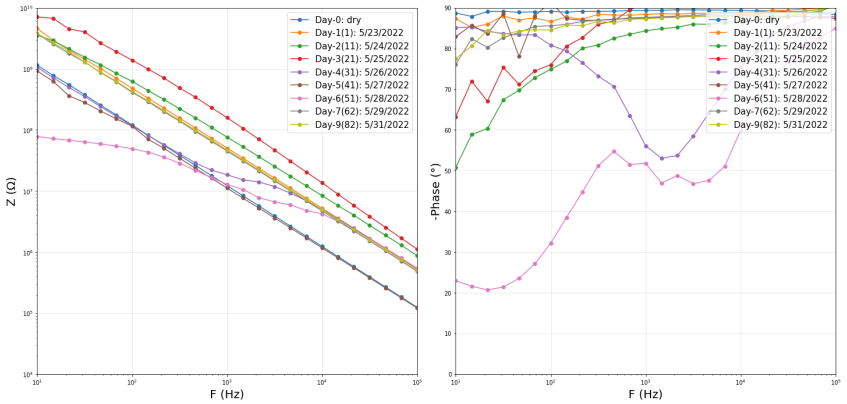
IDE-27-4-m

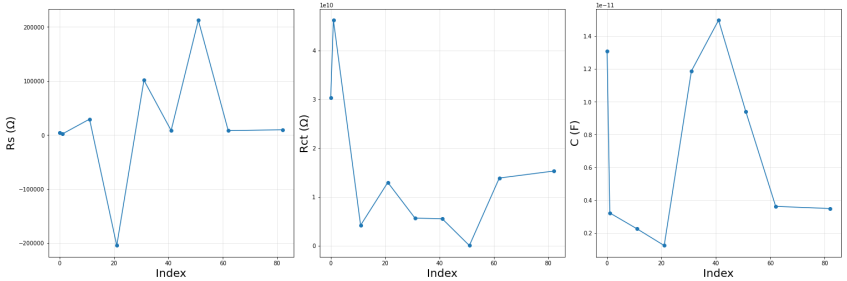


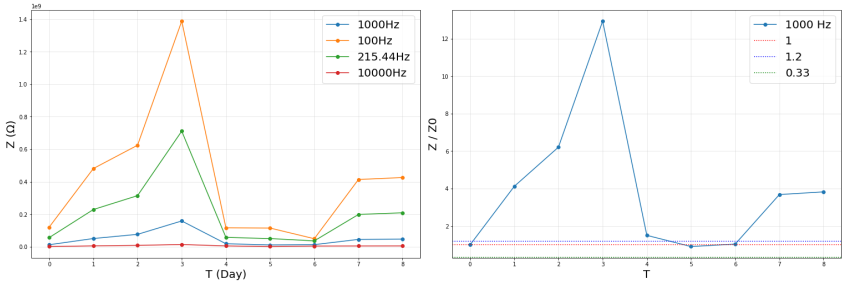




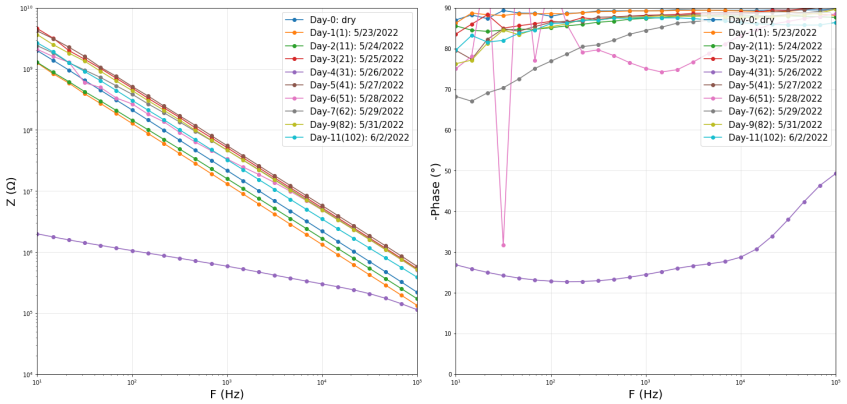
IDE-27-4-s

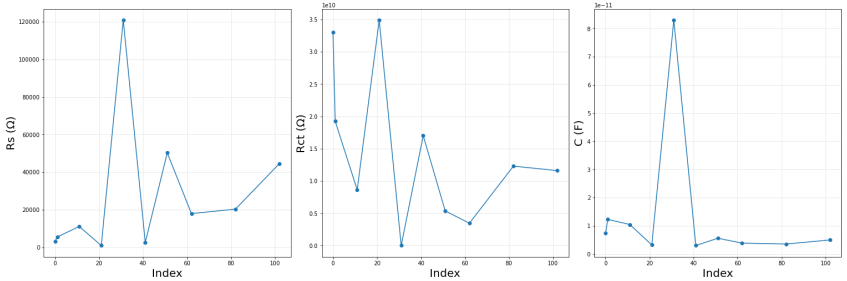


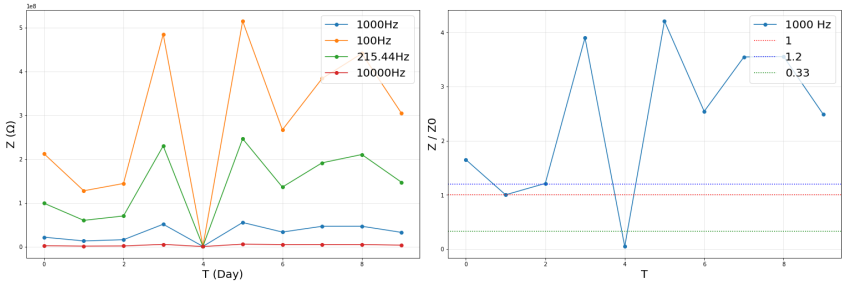




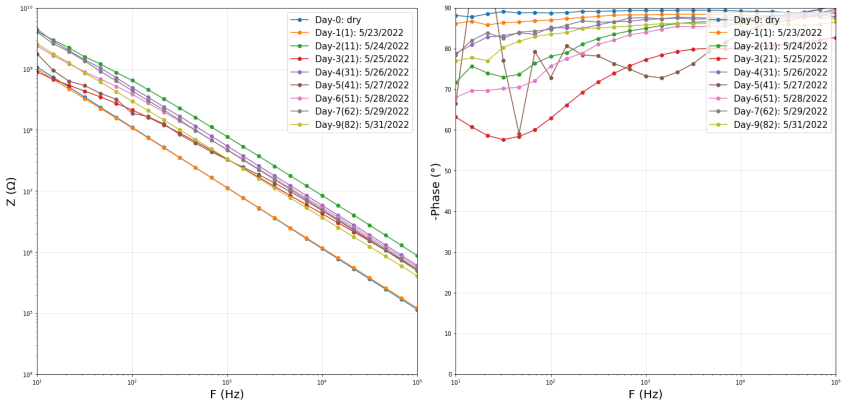
IDE-27-8-m

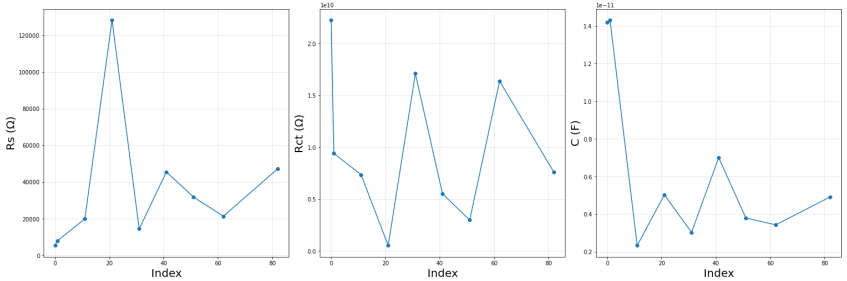


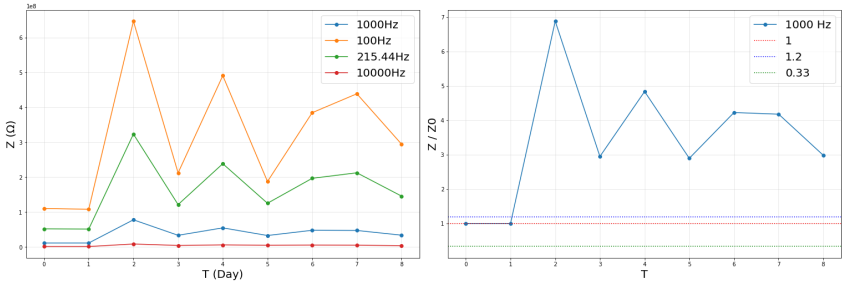




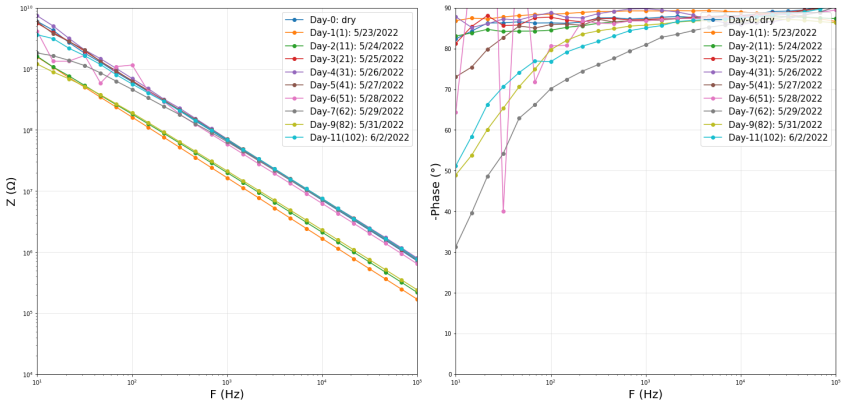
IDE-27-8-s

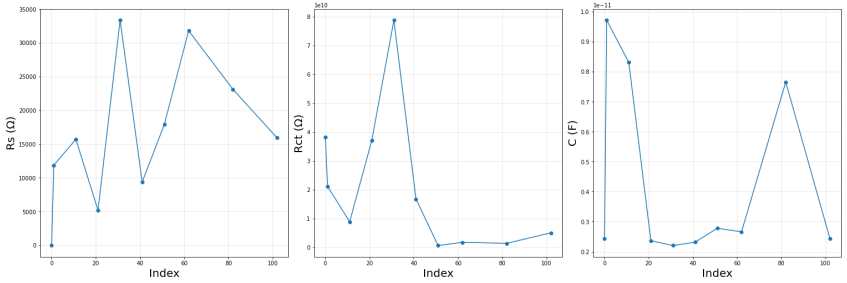


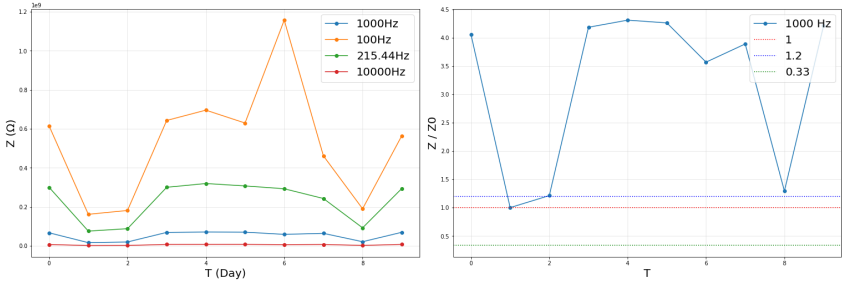




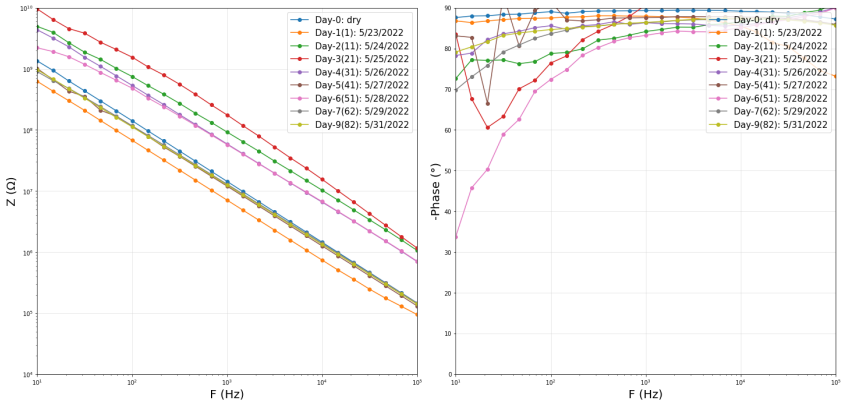
IDE-27-16-m

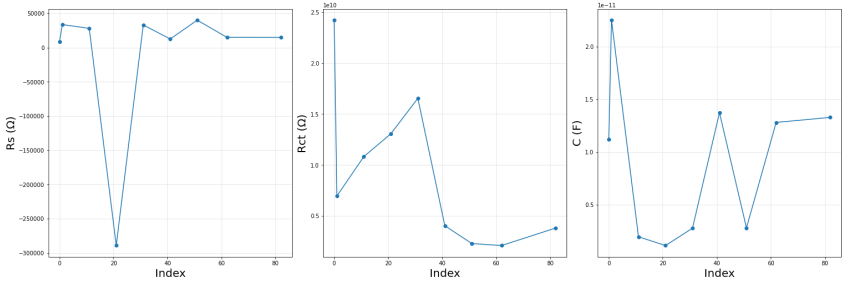


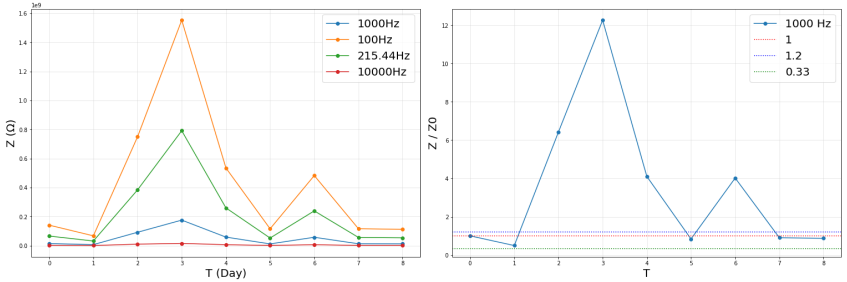




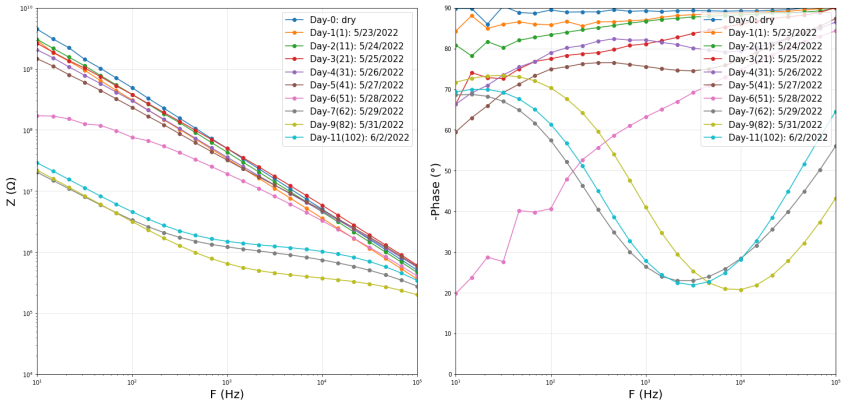
IDE-27-16-s

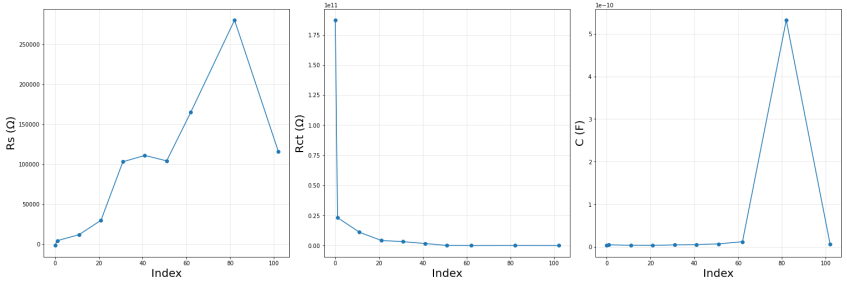


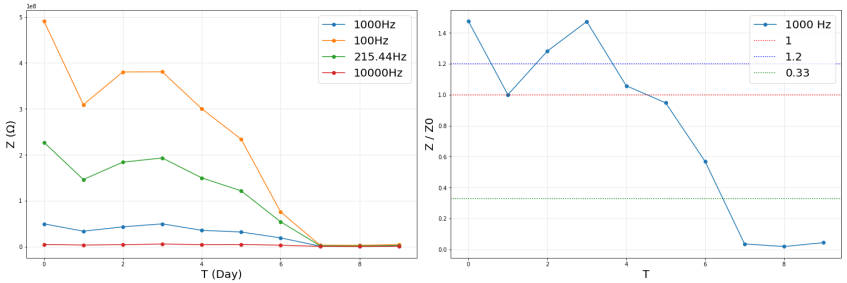




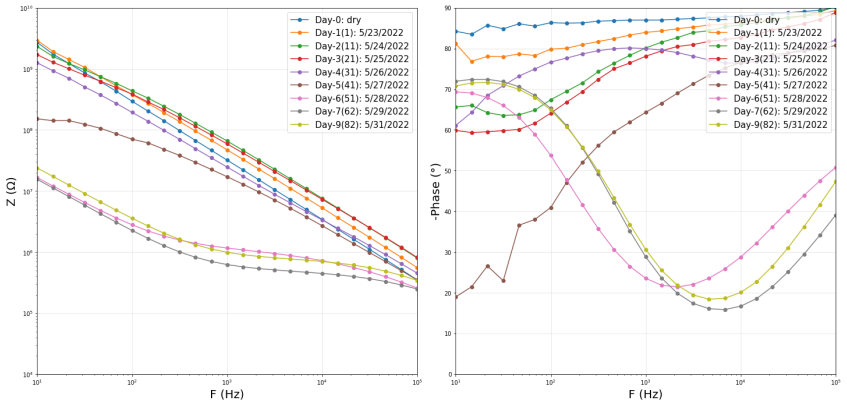
IDE-28-2-m

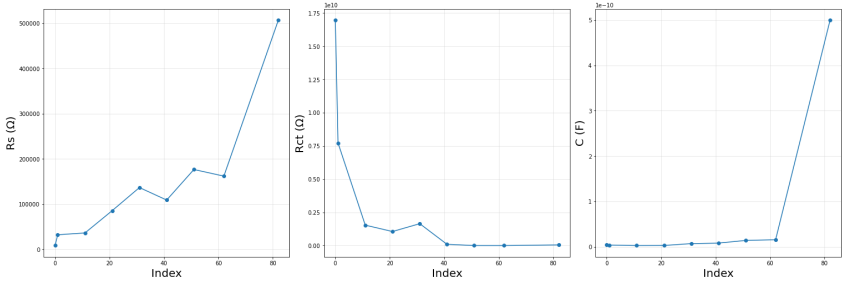


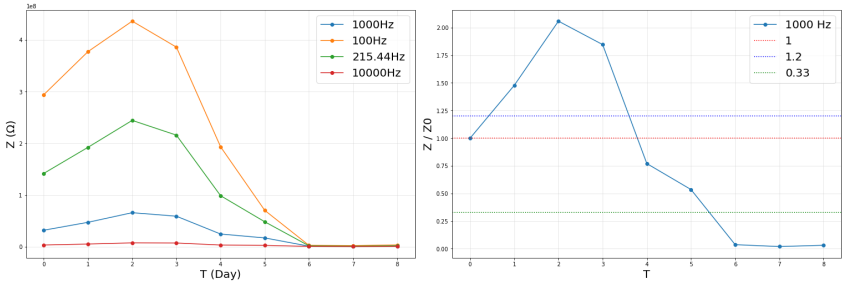




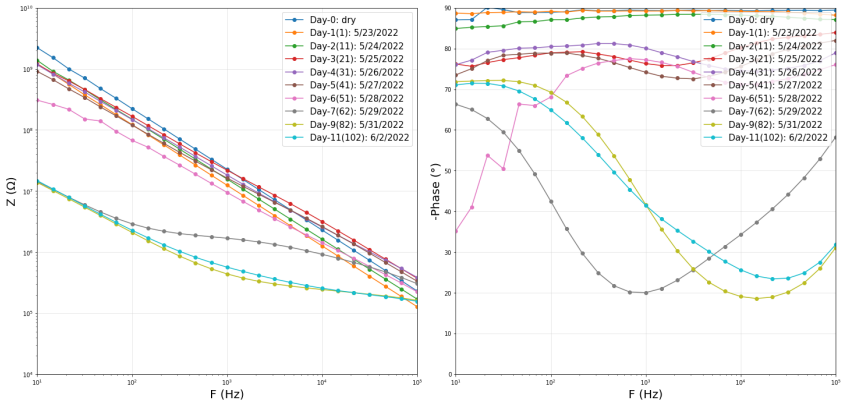
IDE-28-2-s

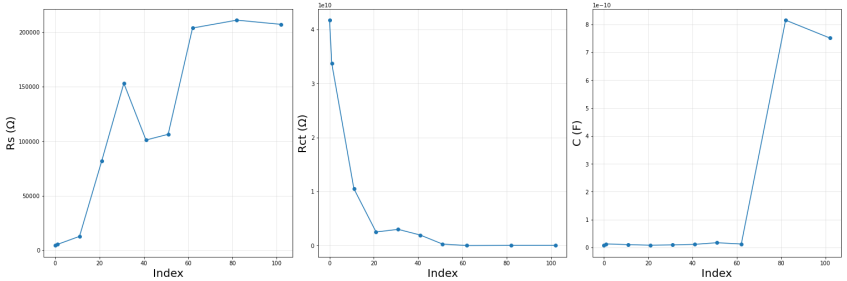


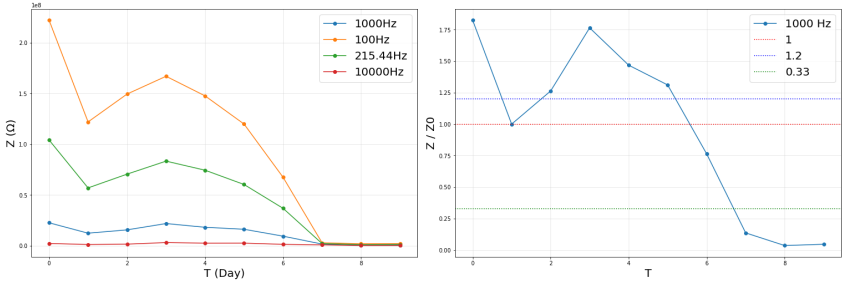




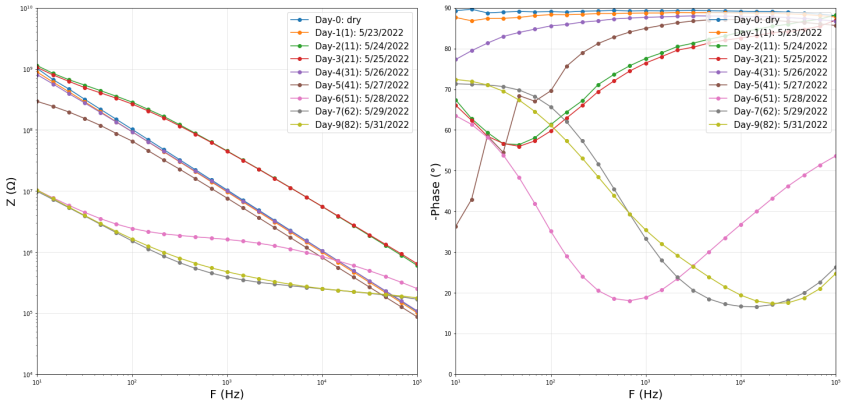
IDE-28-4-m

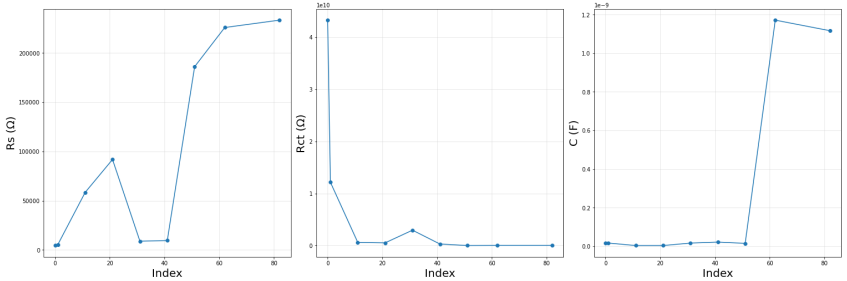


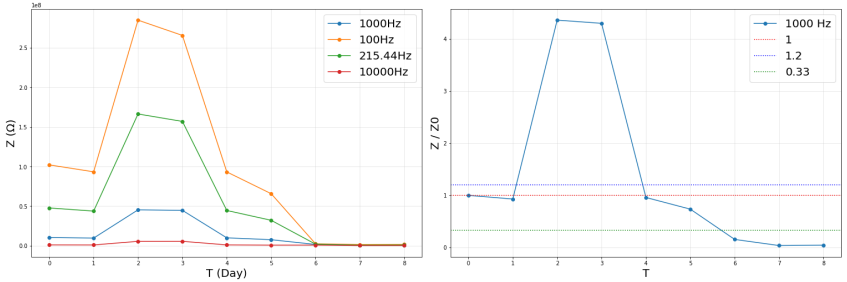




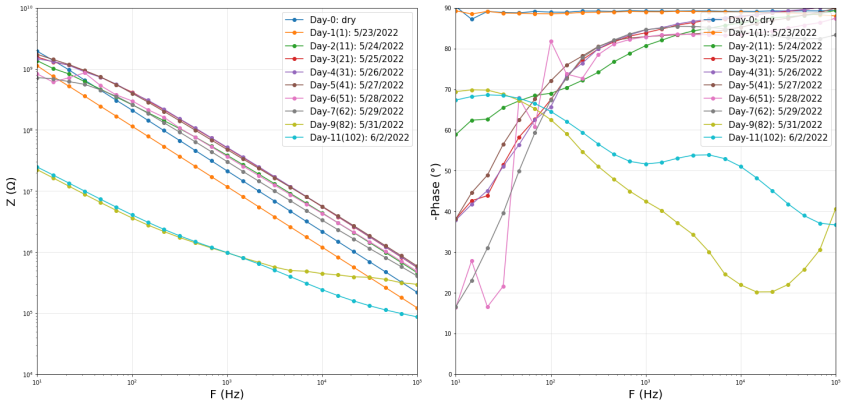
IDE-28-4-s

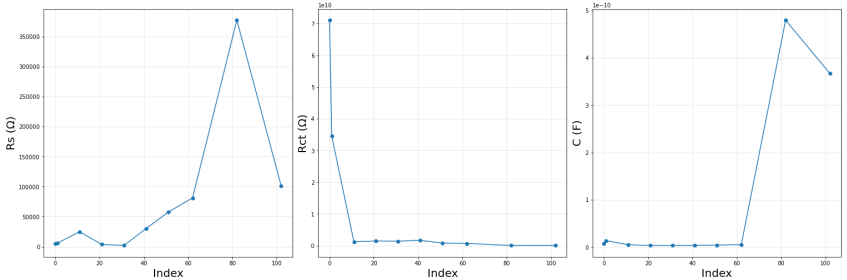


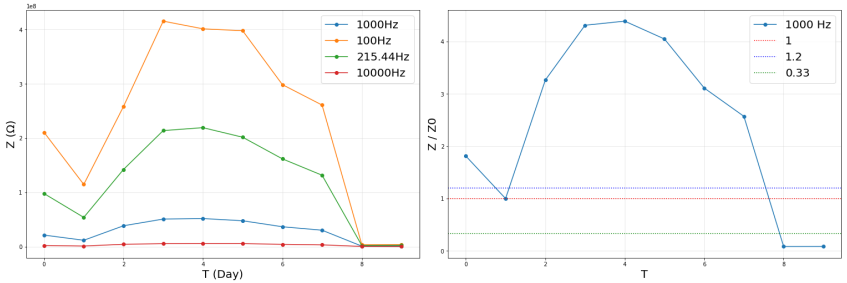




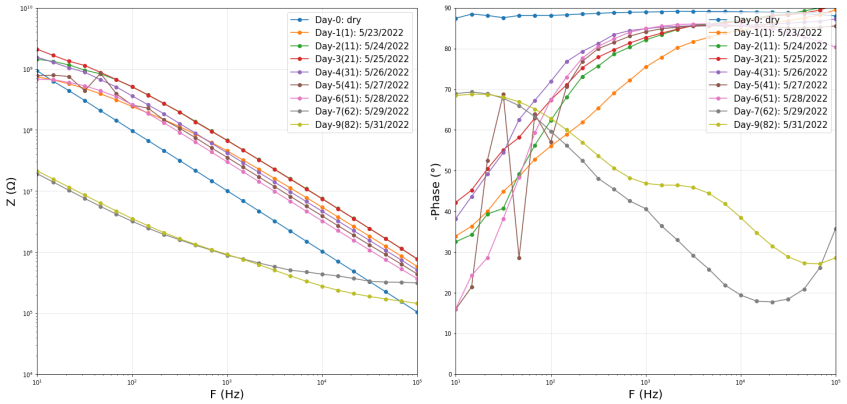
IDE-28-8-m

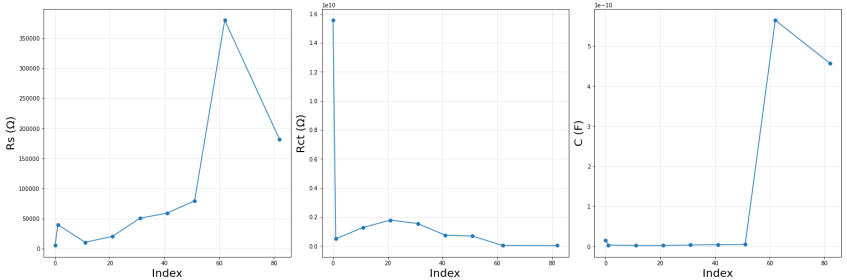


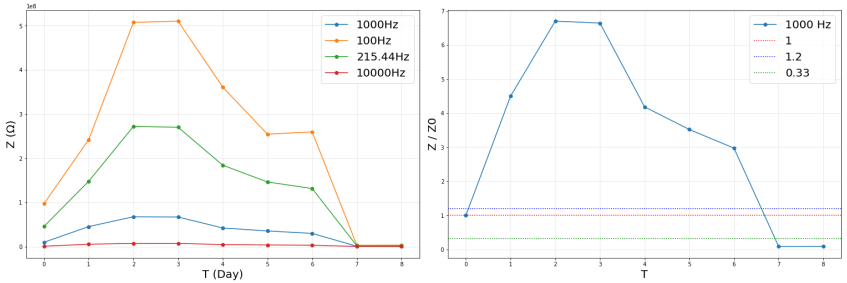




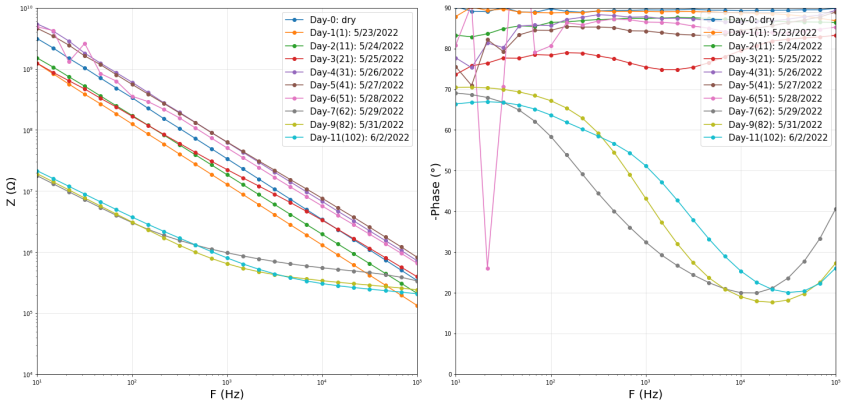
IDE-28-8-s

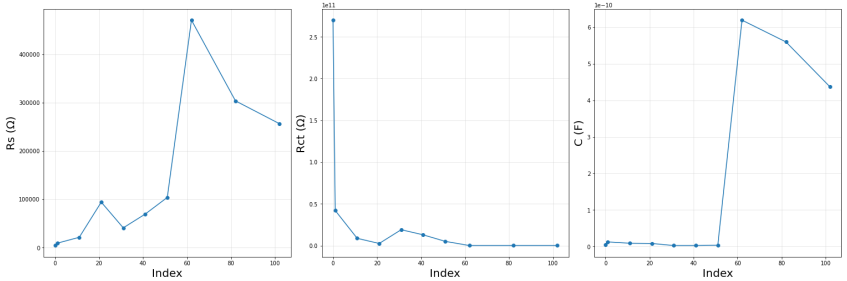


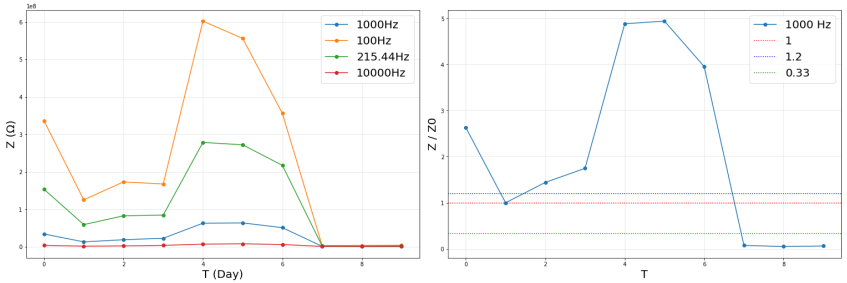




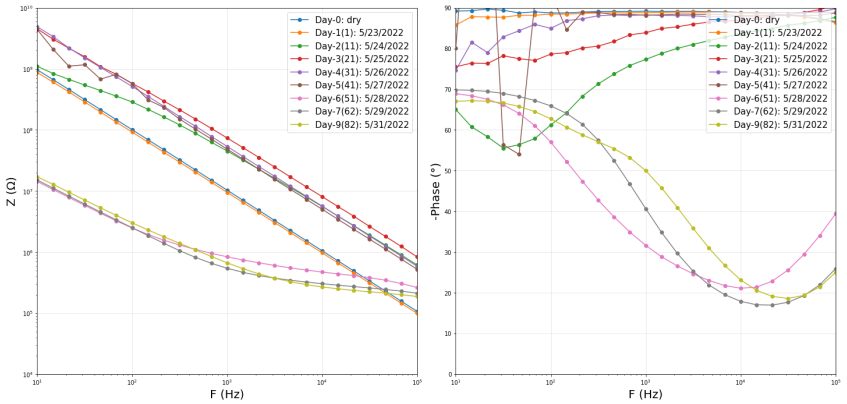
IDE-28-16-m

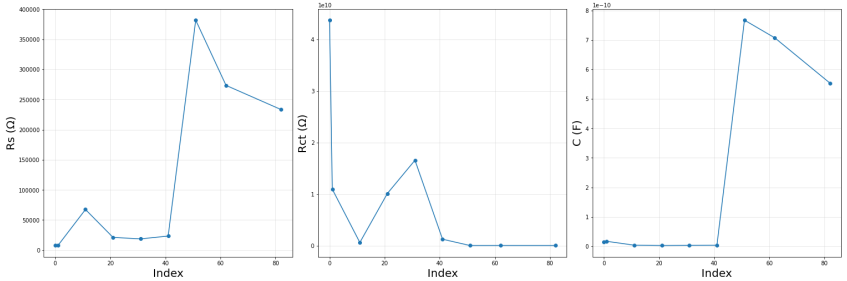


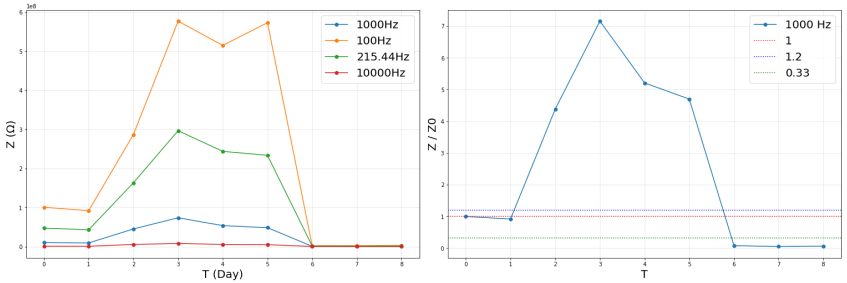




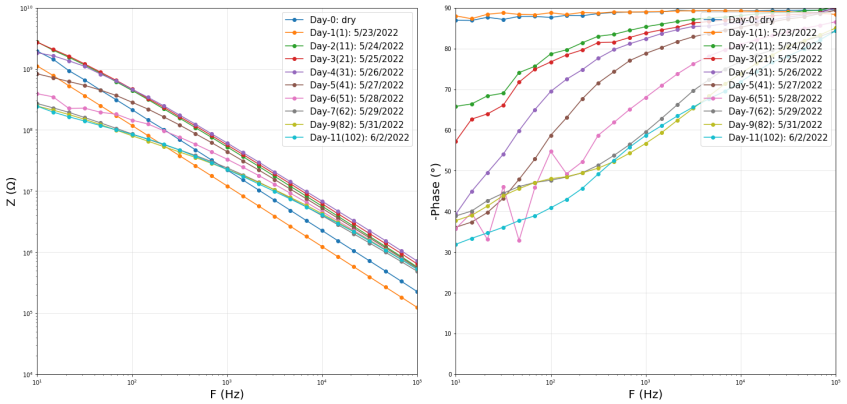
IDE-28-16-s

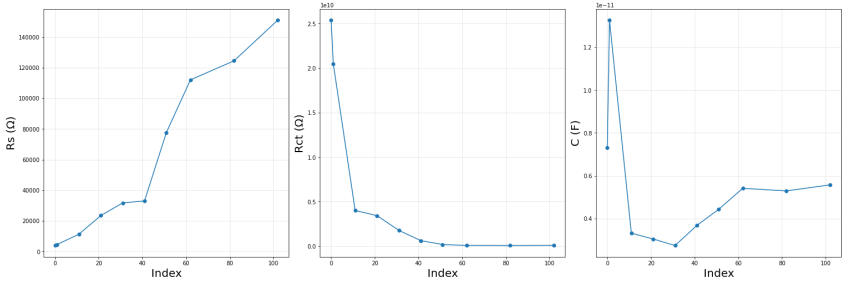


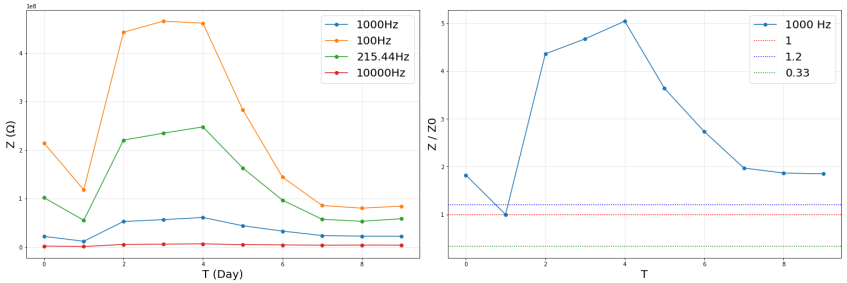




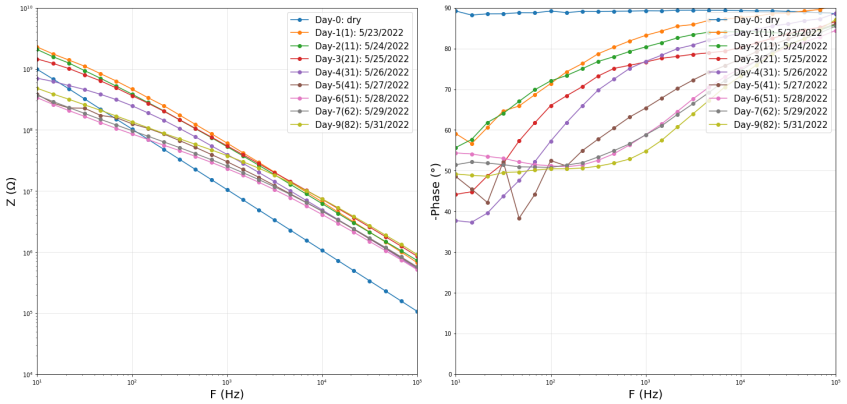
IDE-31-2-m

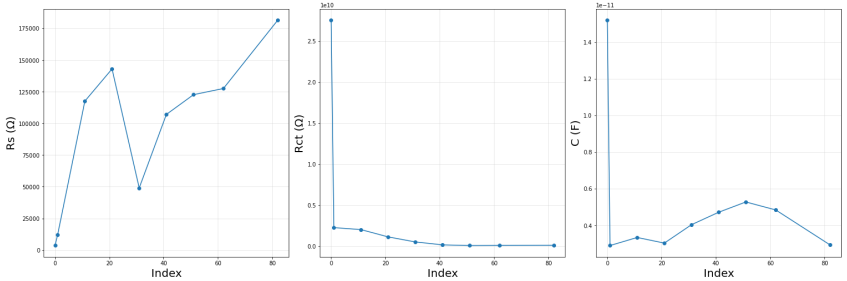


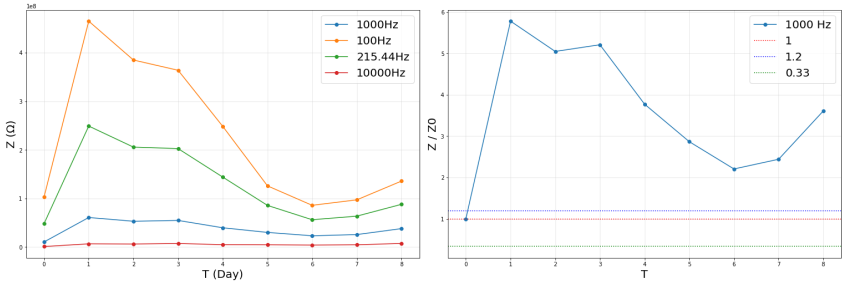




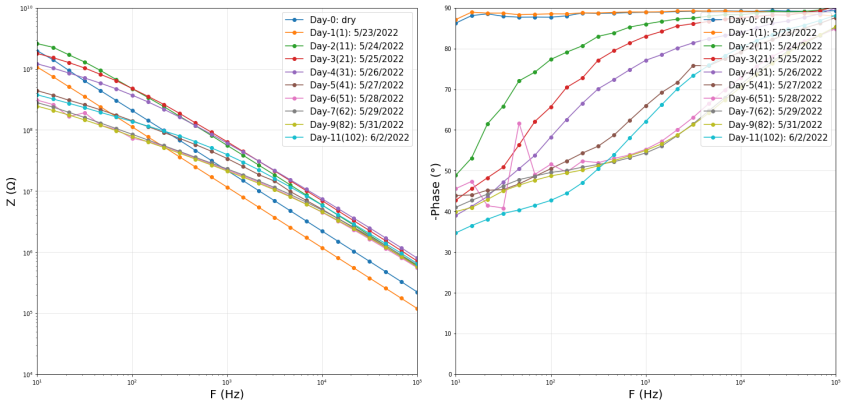
IDE-31-2-s

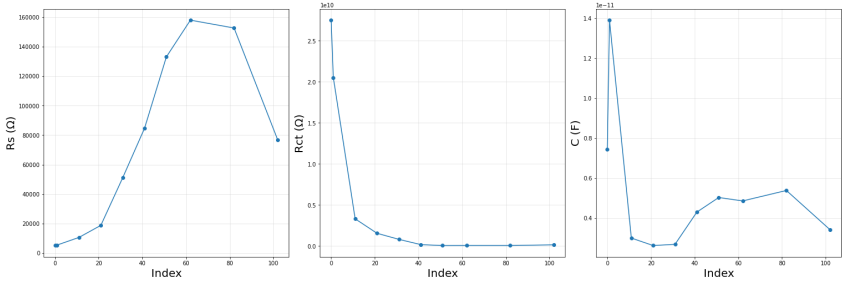


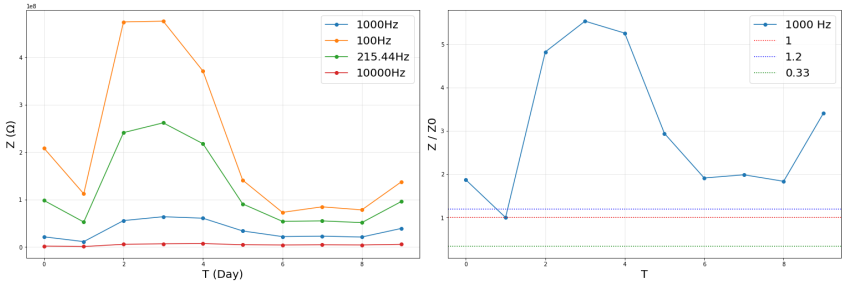




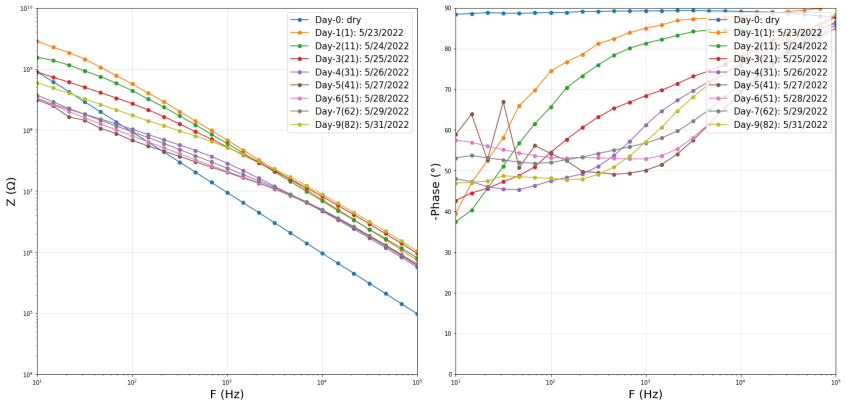
IDE-31-4-m

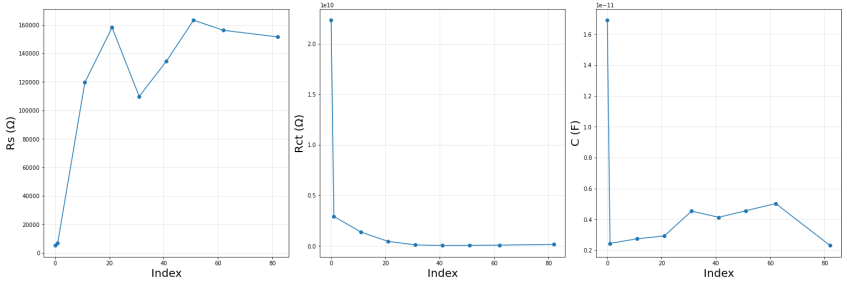


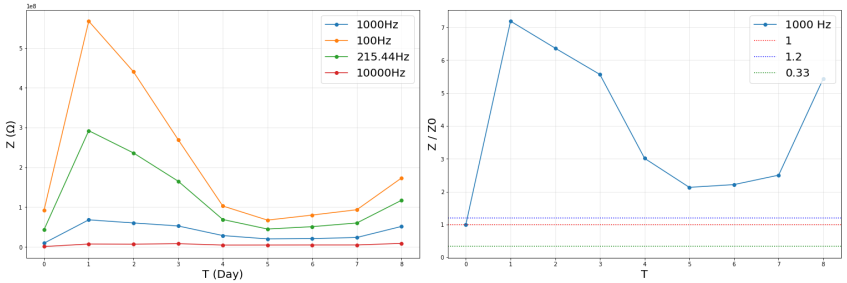




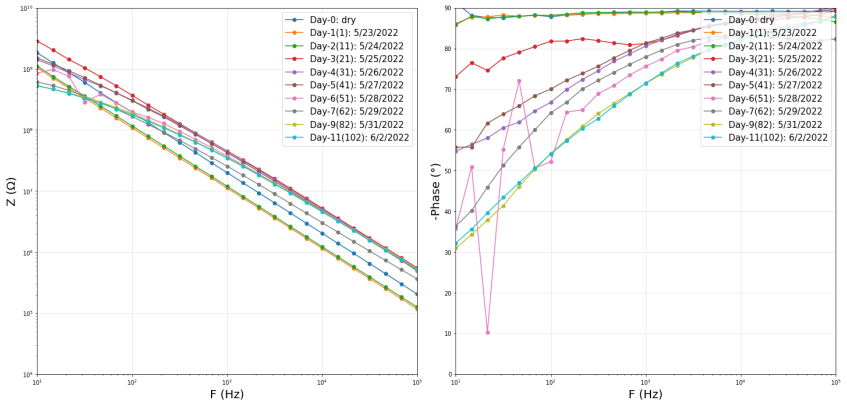
IDE-31-4-s

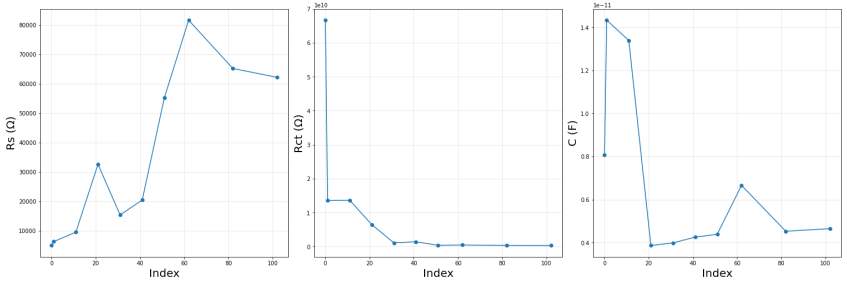


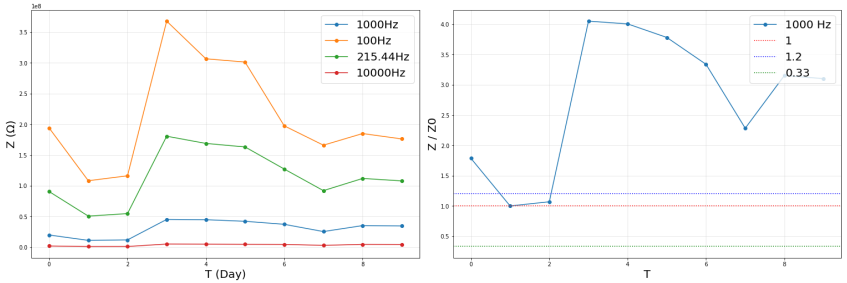




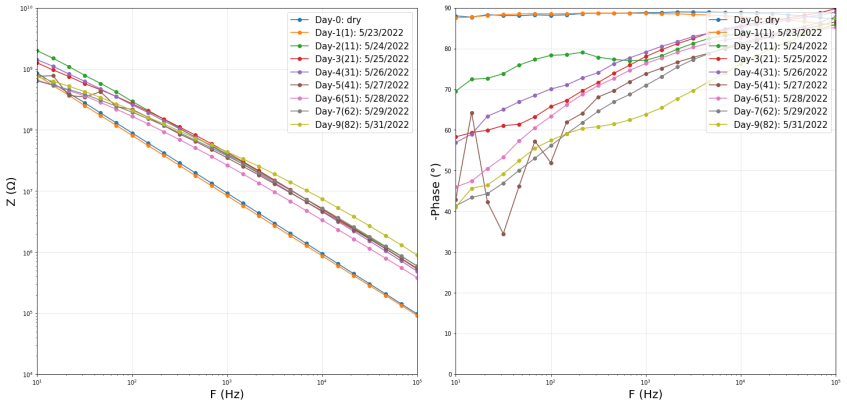
IDE-31-8-m

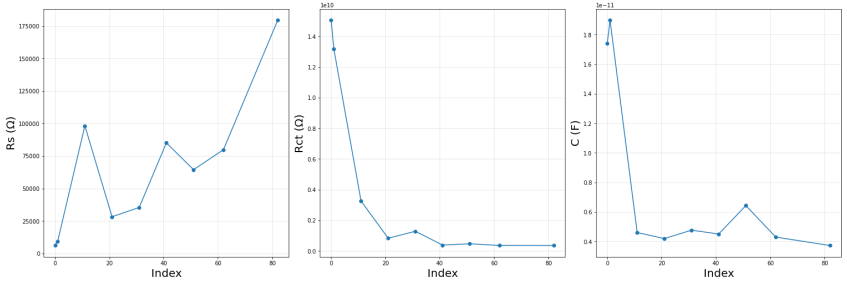


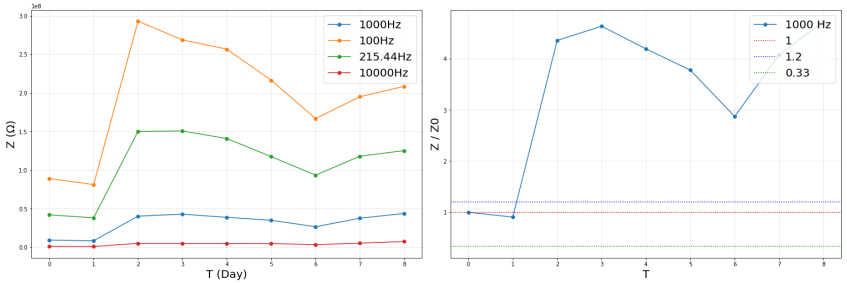




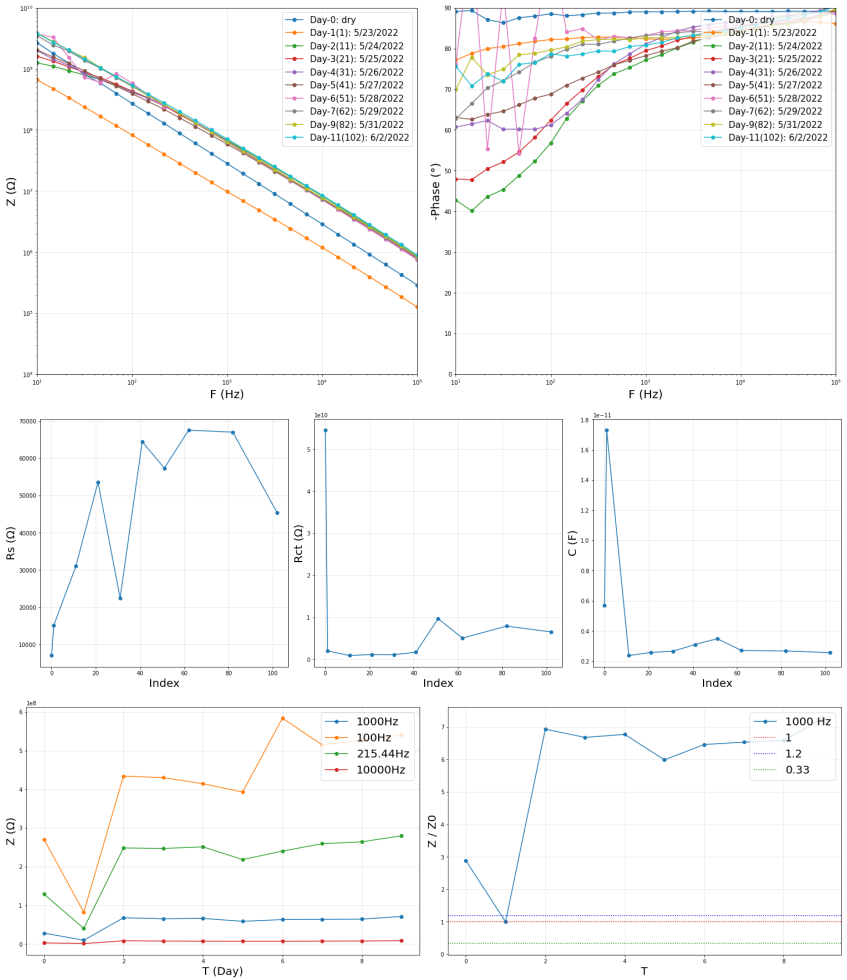
IDE-31-8-s







IDE-31-16-m



IDE-31-16-s