overview

August 24, 2025

Dark-Fiber Charakterisierung für entanglement polarisierter QKD

Übersicht und Aufbereitung von Messverfahren und Messdaten

Autor: Laura Komma
Datensatz: Erfurt - Sundhausen

1 Einleitung: Kenngrößen, Messgerät und Datengrundlage

1.1 Ressourcen und Literatur

- Messdaten
- Messgerät
- Abbildung: Poincaré-Kugel

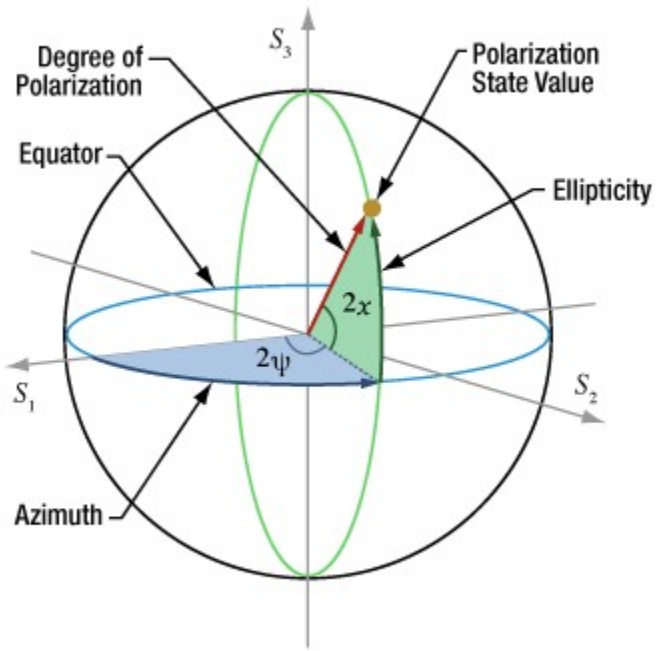
1.2 Kenngrößen: Bedeutung und Einheiten

Kenngöße	Einheit	Bedeutung	Wertebereiche
Time	date hh:mm:ss	absoluter Messzeitpunkt	-
Elapsed Time	hh:mm:ss:ms	relativer Messzeitpunkt	-
Normalized s1, s2, s3	-	Normierte Stokes-Komponenten	-1 x 1
S0	mW	Gesamtleistung	-
S1, S2, S3	mW	Stokes-Komponenten	-
Azimuth	°	Winkel in der Poincaré-Kugel (horizontaler Winkel)	-90° x 90°
Ellipticity	°	Maß für elliptische Polarisation (vertikaler Winkel)	-45° x 45°

Kenngöße	Einheit	Bedeutung	Wertebereiche
DOP	%	Degree of Polarization	0% x 100%
DOCP	%	Degree of Circular Polarization (Zirkularitätsmaß)	0% x 100%
DOLP	%	Degree of Linear Polarization (Linearitätsmaß)	0% x 100%
Power	mW / dBm	Gesamtleistung	-60 dBm x +10 dBm
Pol Power	mW / dBm	Polarisierter Anteil (= DOP × Gesamtleistung)	-60 dBm x +10 dBm
Unpol Power	mW / dBm	Unpolarisierter Anteil (= (1–DOP) × Gesamtleistung)	-60 dBm x +10 dBm
Phase Difference	°	Phasenunterschied zw. Polarisationsmoden	-180° x 180°
Power-Split-Ratio	-	Leistungsverhältnis zweier Polarisation-srichtungen	0 x 1
Warning	-	Hinweis für fehlerhafte Messung	-

[1]:
```
from IPython.display import Image
Image(filename="./img/poincare.jpg")
```

[1]:



1.3 Messgerät und Messverfahren

Kenngöße	Info
Device	PAX1000IR2/M
Serial Number	M00773008
Firmware Version	1.2.1
Software Version	1.4.2002.183
Wavelength [nm]	1560
Basic Sample Rate [Hz]	60
Operating Mode	1 revolution for one measurement, 1024 points for FFT

2 Aufbereitung der Messdaten

2.1 Verwendete Libraries / Softwaretools

[1]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import io
import datetime
import requests

from prettytable import PrettyTable
```

2.2 Eigene Hilfsfunktionen

[2]:
```
def fast_parse_elapsed(s):
    try:
        d, h, m, s, ms = s.replace('.', ':').split(':')
        return pd.Timedelta(days=int(d), hours=int(h), minutes=int(m),␣
 ↪seconds=int(s), milliseconds=int(ms))
    except:
        return pd.NaT
```

2.3 Datenaufbereitungsschritte

[3]:
```
filename ='20_02_to_26_02_Sundhausen to FZE port 2.csv'
skip = 8
sep = ";"
```

[4]:
```
```

```
columns = ['Time[date hh:mm:ss] ', ' Elapsed Time [hh:mm:ss:ms]', ' Normalized␣
 ↪s 1 ', ' Normalized s 2 ', ' Normalized s 3 ', ' S 0 [mW]', ' S 1 [mW]', ' S␣
 ↪2 [mW]', ' S 3 [mW]', ' Azimuth[°] ', ' Ellipticity[°] ', ' DOP[%] ', '␣
 ↪DOCP[%] ', ' DOLP[%] ', ' Power[mW] ', ' Pol Power[mW] ', ' Unpol Power[mW]␣
 ↪', ' Power[dBm] ', ' Pol Power[dBm] ', ' Unpol Power[dBm] ', '␣
 ↪Power-Split-Ratio ', ' Phase Difference[°] ', ' Warning']
for c in range(len(columns)):
    print(c, ': ', columns[c])
```

```
0 :  Time[date hh:mm:ss]
1 :   Elapsed Time [hh:mm:ss:ms]
2 :   Normalized s 1
3 :   Normalized s 2
4 :   Normalized s 3
5 :   S 0 [mW]
6 :   S 1 [mW]
7 :   S 2 [mW]
8 :   S 3 [mW]
9 :   Azimuth[°]
10 :   Ellipticity[°]
11 :   DOP[%]
12 :   DOCP[%]
13 :   DOLP[%]
14 :   Power[mW]
15 :   Pol Power[mW]
16 :   Unpol Power[mW]
17 :   Power[dBm]
18 :   Pol Power[dBm]
19 :   Unpol Power[dBm]
20 :   Power-Split-Ratio
21 :   Phase Difference[°]
22 :   Warning
```

3 Analyse der Messdaten

3.1 Fehler (Warning)

[5]:
```
warning = pd.read_csv(filename,skiprows=skip, usecols=[columns[22]], sep=sep)
```

```
C:\Users\laura\AppData\Local\Temp\ipykernel_17264\1864455350.py:1: DtypeWarning:
Columns (22) have mixed types. Specify dtype option on import or set
low_memory=False.
  warning = pd.read_csv(filename,skiprows=skip, usecols=[columns[22]], sep=sep)
```

[6]:
```
warning.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 2369654 entries, 0 to 2369653
```

```
Data columns (total 1 columns):
 #   Column    Dtype
---  ------    -----
 0    Warning  object
dtypes: object(1)
memory usage: 18.1+ MB
```

[7]:
```
warning.isnull().sum()
```

[7]:
```
Warning    2368270
dtype: int64
```

[8]:
```
len(warning)- warning.isnull().sum()
```

[8]:
```
Warning    1384
dtype: int64
```

3.2 Zeitwerte (Time, Elapsed Time)

[9]:
```
time = pd.read_csv(filename,skiprows=skip, usecols=[columns[0], columns[1]],␣
↪sep=sep)
```

[10]:
```
time.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 2369654 entries, 0 to 2369653
Data columns (total 2 columns):
 #   Column                        Dtype
---  ------                        -----
 0   Time[date hh:mm:ss]           object
 1    Elapsed Time [hh:mm:ss:ms]  object
dtypes: object(2)
memory usage: 36.2+ MB
```

[11]:
```
time.isnull().sum()
```

[11]:
```
Time[date hh:mm:ss]            0
 Elapsed Time [hh:mm:ss:ms]    0
dtype: int64
```

[12]:
```
time[columns[0]] = pd.to_datetime(time[columns[0]])
time['time_difference'] = time[columns[0]].diff()
time['time_frequency'] =  1 / time['time_difference'].dt.total_seconds()
time['time_difference']
```

[12]:
```
0                          NaT
1         0 days 00:00:00.250000
2         0 days 00:00:00.250000
```

```
3          0 days 00:00:00.240000
4          0 days 00:00:00.250000
                      …
2369649    0 days 00:00:00.250000
2369650    0 days 00:00:00.250000
2369651    0 days 00:00:00.250000
2369652    0 days 00:00:00.240000
2369653    0 days 00:00:00.250000
Name: time_difference, Length: 2369654, dtype: timedelta64[ns]
```

[13]:
```
time[columns[1]] = time[columns[1]].apply(fast_parse_elapsed)
time['elapsed_time_difference'] = time[columns[1]].diff()
time['elapsed_time_frequency'] =  1 / time['elapsed_time_difference'].dt.
 ↪total_seconds()
time['elapsed_time_difference']
```

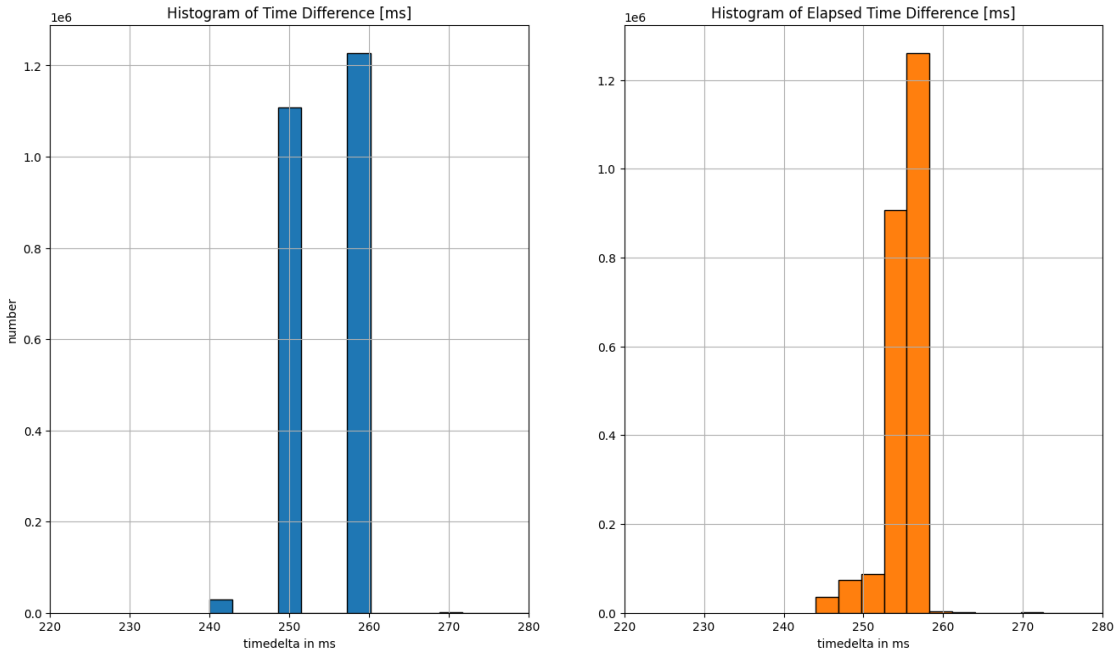
[13]:
```
0                          NaT
1          0 days 00:00:00.253000
2          0 days 00:00:00.245000
3          0 days 00:00:00.249000
4          0 days 00:00:00.250000
                      …
2369649    0 days 00:00:00.246000
2369650    0 days 00:00:00.248000
2369651    0 days 00:00:00.249000
2369652    0 days 00:00:00.245000
2369653    0 days 00:00:00.248000
Name: elapsed_time_difference, Length: 2369654, dtype: timedelta64[ns]
```

[14]:
```
t = PrettyTable([' ', 'Time', 'Elapsed Time'])
t.add_row(['Max', time['time_difference'].max(),␣
 ↪time['elapsed_time_difference'].max()])
t.add_row(['Min', time['time_difference'].min(), ␣
 ↪time['elapsed_time_difference'].min()])
t.add_row(['Mean', time['time_difference'].mean(), ␣
 ↪time['elapsed_time_difference'].mean()])
t.add_row(['Std', time['time_difference'].std(), ␣
 ↪time['elapsed_time_difference'].std()])
t.add_row(['Most', time['time_difference'].value_counts(dropna=True).idxmax(),␣
 ↪time['elapsed_time_difference'].value_counts(dropna=True).idxmax()])
t.add_row(['Mean Frequency', time['time_frequency'].mean(), ␣
 ↪time['elapsed_time_frequency'].mean()])

t
```

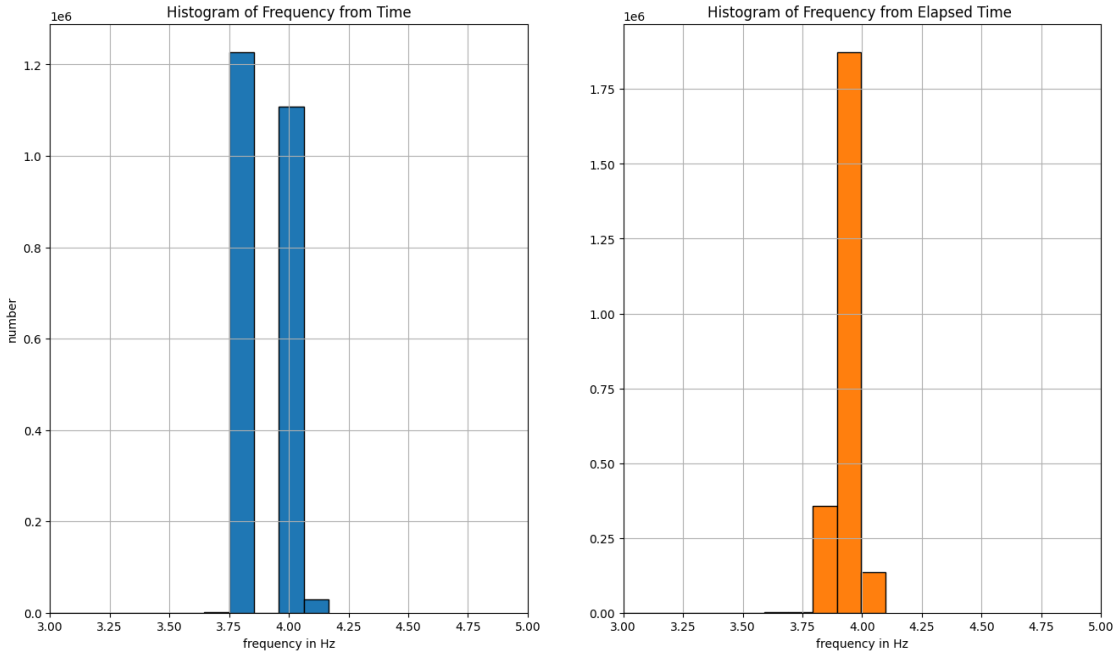
[14]:
```
+----------------+---------------------------+---------------------------+
|                |            Time           |        Elapsed Time       |
```

```
+----------------+---------------------------+---------------------------+
|      Max       |   0 days 00:00:00.960000  |   0 days 00:00:00.958000  |
|      Min       |   0 days 00:00:00.240000  |   0 days 00:00:00.244000  |
|      Mean      | 0 days 00:00:00.255231293 | 0 days 00:00:00.255231293 |
|      Std       | 0 days 00:00:00.008582554 | 0 days 00:00:00.007129904 |
|      Most      |   0 days 00:00:00.260000  |   0 days 00:00:00.256000  |
| Mean Frequency |     3.9209356490794565    |     3.919556262116962     |
+----------------+---------------------------+---------------------------+
```

[16]:
```
time_difference = time['time_difference'].dt.total_seconds() * 1000
elapsed_time_difference = time['elapsed_time_difference'].dt.total_seconds() *␣
 ↪1000

plt.figure(figsize = (16,9))
plt.subplot(1, 2, 1)
plt.hist(time_difference, bins=250, color='tab:blue', edgecolor='black')
plt.xlim([220, 280])
plt.grid()
plt.xlabel('timedelta in ms')
plt.ylabel('number')
plt.title('Histogram of Time Difference [ms]')

plt.subplot(1, 2, 2)
plt.hist(elapsed_time_difference, bins=250, color='tab:orange',␣
 ↪edgecolor='black')
plt.xlim([220, 280])
plt.grid()
plt.xlabel('timedelta in ms')
plt.title('Histogram of Elapsed Time Difference [ms]')

plt.show()
```



[17]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 2, 1)
plt.hist(time['time_frequency'], bins=30, color='tab:blue', edgecolor='black')
plt.xlim([3, 5])
plt.grid()
plt.xlabel('frequency in Hz')
plt.ylabel('number')
plt.title('Histogram of Frequency from Time')

plt.subplot(1, 2, 2)
plt.hist(time['elapsed_time_frequency'], bins=30, color='tab:orange',␣
 ↪edgecolor='black')
plt.xlim([3, 5])
plt.grid()
plt.xlabel('frequency in Hz')
plt.title('Histogram of Frequency from Elapsed Time ')

plt.show()
```



3.3 Polarisationsgrade (DOP, DOCP, DOLP)

[18]:
```
degree = pd.read_csv(filename,skiprows=skip, usecols=[columns[0], columns[11],␣
↪columns[12], columns[13]], sep=sep)
```

[19]:
```
degree[columns[0]] = pd.to_datetime(degree[columns[0]])
degree.set_index(columns[0], inplace=True)
```

[20]:
```
degree.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 3 columns):
 #   Column     Dtype
---  ------     -----
 0    DOP[%]    float64
 1    DOCP[%]   float64
 2    DOLP[%]   float64
dtypes: float64(3)
memory usage: 72.3 MB
```

[21]:
```
degree.isnull().sum()
```

[21]:
```
DOP[%]      0
DOCP[%]     0
```

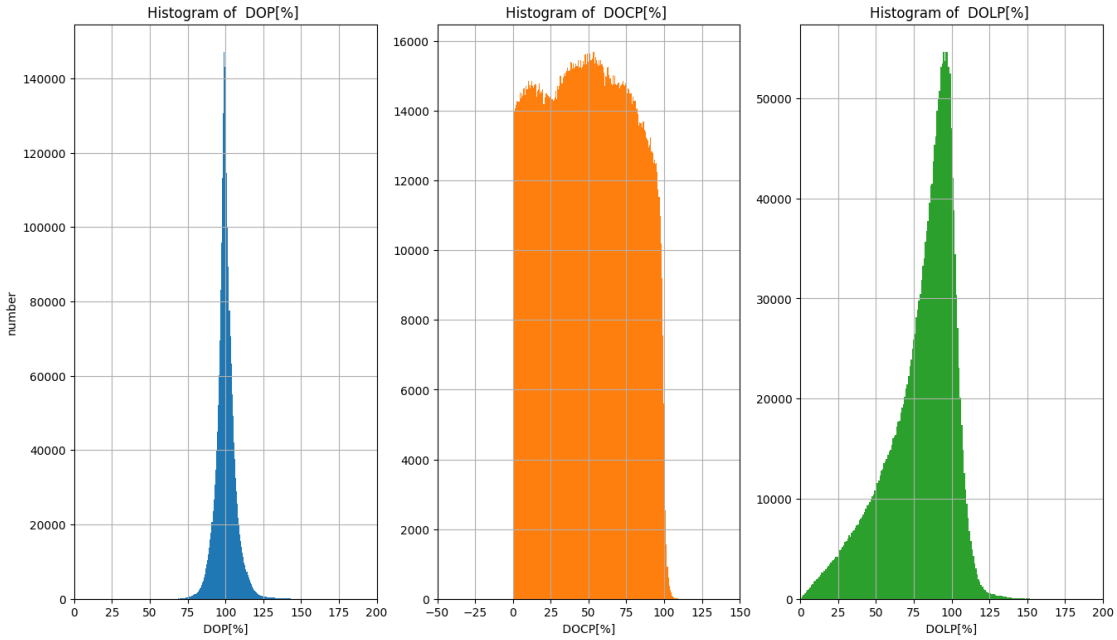
```
DOLP[%]     0
dtype: int64
```

[22]:
```
degree.describe()
```

[22]:

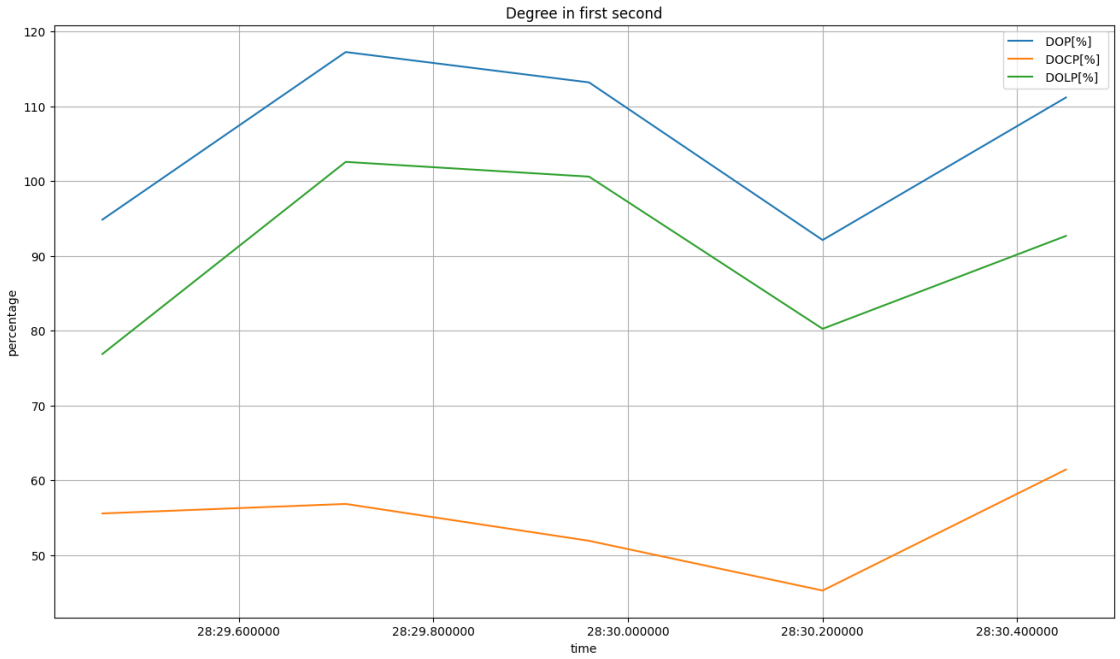
	DOP[%]	DOCP[%]	DOLP[%]
count	2.369654e+06	2.369654e+06	2.369654e+06
mean	1.000893e+02	4.901668e+01	7.972596e+01
std	6.368664e+00	2.815734e+01	2.251058e+01
min	5.856000e+01	0.000000e+00	5.000000e-02
25%	9.694000e+01	2.490000e+01	6.766000e+01
50%	9.974000e+01	4.894000e+01	8.564000e+01
75%	1.030100e+02	7.280000e+01	9.610000e+01
max	1.737000e+02	1.219400e+02	1.714200e+02

[25]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 3, 1)
plt.hist(degree[columns[11]], bins=200, color='tab:blue')
plt.xlim([0, 200])
plt.grid()
plt.xlabel(columns[11])
plt.ylabel('number')
plt.title(f'Histogram of {columns[11]}')

plt.subplot(1, 3, 2)
plt.hist(degree[columns[12]], bins=200, color='tab:orange')
plt.xlim([-50, 150])
plt.grid()
plt.xlabel(columns[12])
plt.title(f'Histogram of {columns[12]}')

plt.subplot(1, 3, 3)
plt.hist(degree[columns[13]], bins=200, color='tab:green')
plt.xlim([0, 200])
plt.grid()
plt.xlabel(columns[13])
plt.title(f'Histogram of {columns[13]}')

plt.show()
```

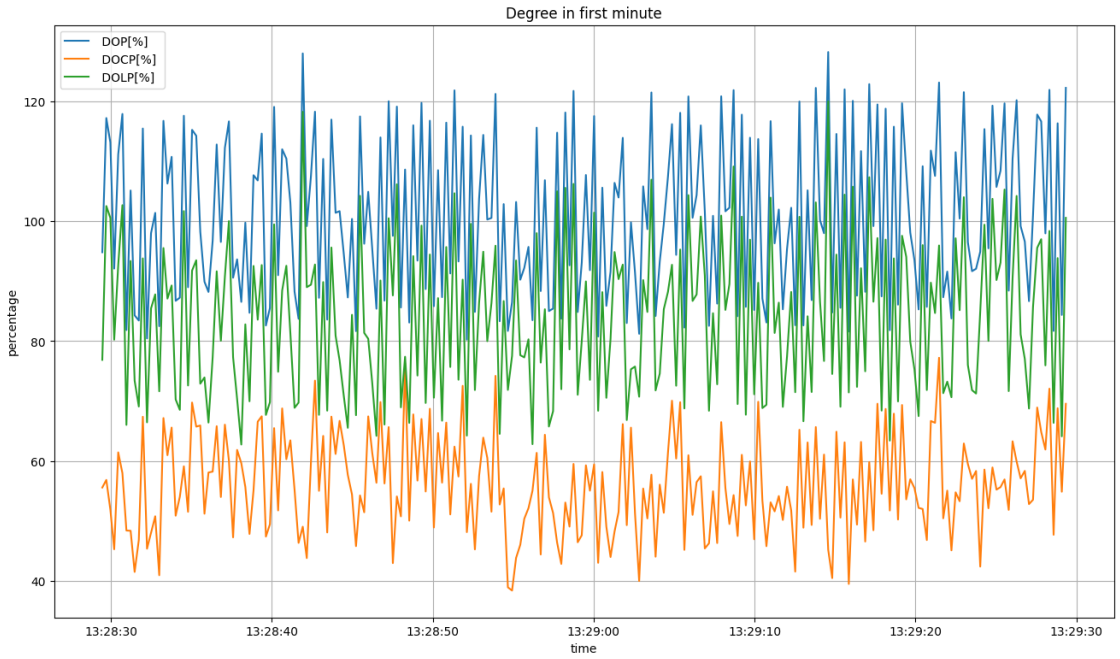


[26]:
```
one_second = datetime.timedelta(seconds=1)
one_minute = datetime.timedelta(minutes=1)
one_hour = datetime.timedelta(hours=1)
one_day = datetime.timedelta(days=1)

start_time = datetime.datetime.strptime(str(degree.index[0]), '%Y-%m-%d %H:%M:
 ↪%S.%f')
end_time_second = start_time + one_second
end_time_minute = start_time + one_minute
end_time_hour = start_time + one_hour
end_time_day = start_time + one_day
```

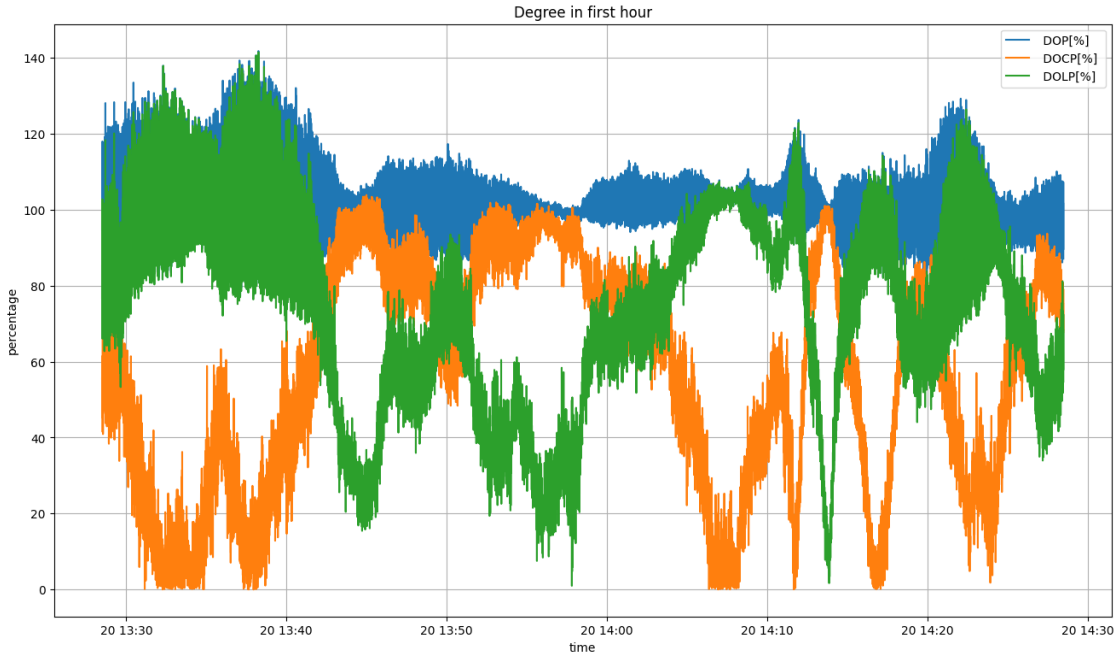
[27]:
```
first_second = degree.loc[(degree.index >= start_time) & (degree.index <␣
 ↪end_time_second)]

plt.figure(figsize = (16,9))
plt.plot(first_second.index, first_second[columns[11]], label = columns[11])
plt.plot(first_second.index, first_second[columns[12]], label = columns[12])
plt.plot(first_second.index, first_second[columns[13]], label = columns[13])
plt.grid()
plt.legend(loc = 'best')
plt.title('Degree in first second')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```



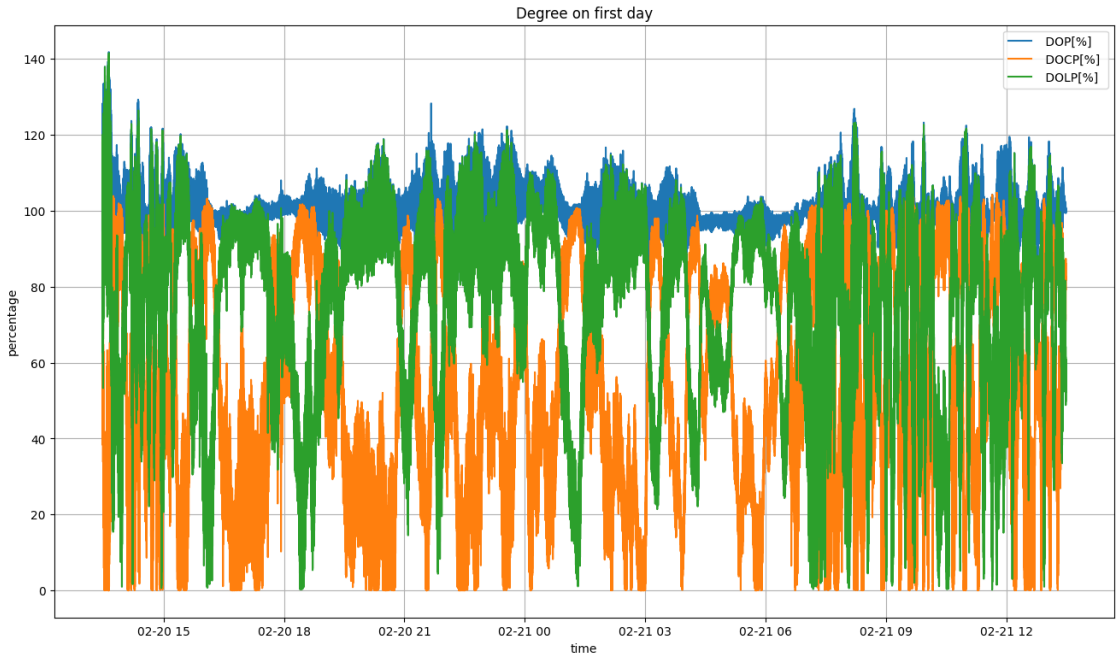
[28]:
```
first_minute = degree.loc[(degree.index >= start_time) & (degree.index <␣
↪end_time_minute)]

plt.figure(figsize = (16,9))
plt.plot(first_minute.index, first_minute[columns[11]], label = columns[11])
plt.plot(first_minute.index, first_minute[columns[12]], label = columns[12])
plt.plot(first_minute.index, first_minute[columns[13]], label = columns[13])
plt.grid()
plt.legend(loc = 'best')
plt.title('Degree in first minute')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```



[29]:
```
first_hour = degree.loc[(degree.index >= start_time) & (degree.index <␣
 ↪end_time_hour)]

plt.figure(figsize = (16,9))
plt.plot(first_hour.index, first_hour[columns[11]], label = columns[11])
plt.plot(first_hour.index, first_hour[columns[12]], label = columns[12])
plt.plot(first_hour.index, first_hour[columns[13]], label = columns[13])
plt.grid()
plt.legend(loc = 'best')
plt.title('Degree in first hour')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```

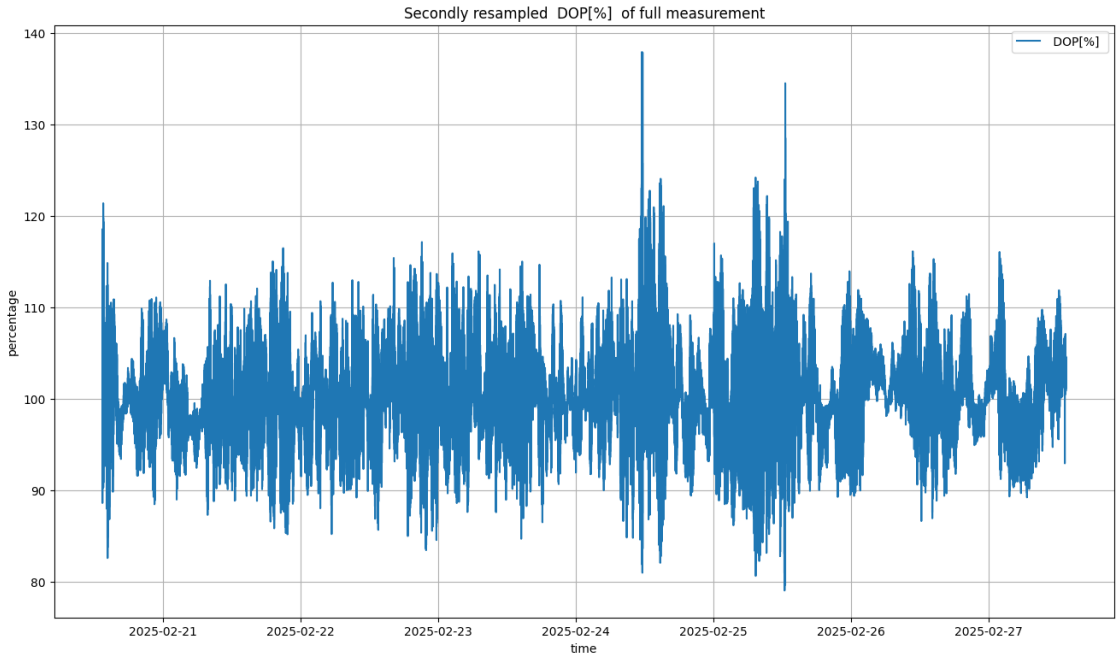


[30]:
```
first_day = degree.loc[(degree.index >= start_time) & (degree.index <␣
 ↪end_time_day)]

plt.figure(figsize = (16,9))
plt.plot(first_day.index, first_day[columns[11]], label = columns[11])
plt.plot(first_day.index, first_day[columns[12]], label = columns[12])
plt.plot(first_day.index, first_day[columns[13]], label = columns[13])
plt.grid()
plt.legend(loc = 'best')
plt.title('Degree on first day')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```

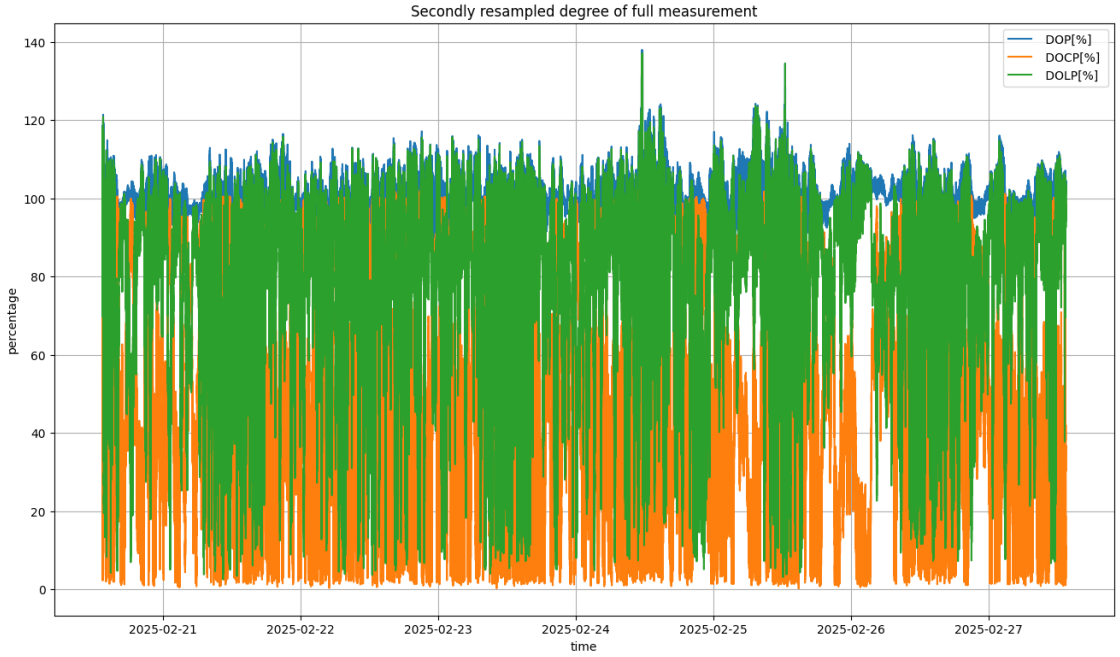


[31]:
```
degree_seconds_resample = degree.resample('s').mean()
```

[32]:
```
plt.figure(figsize = (16,9))
plt.plot(degree_seconds_resample.index, degree_seconds_resample[columns[11]],␣
↪label = columns[11])
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Secondly resampled {columns[11]} of full measurement')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```



[33]:
```
plt.figure(figsize = (16,9))
plt.plot(degree_seconds_resample.index, degree_seconds_resample[columns[11]],␣
 ↪label = columns[11])
plt.plot(degree_seconds_resample.index, degree_seconds_resample[columns[12]],␣
 ↪label = columns[12])
plt.plot(degree_seconds_resample.index, degree_seconds_resample[columns[13]],␣
 ↪label = columns[13])
plt.grid()
plt.legend(loc = 'best')
plt.title('Secondly resampled degree of full measurement')
plt.xlabel('time')
plt.ylabel('percentage')
plt.show()
```



3.4 Energie (Power, Pol Power, Unpol Power [mW/dBm])

[34]:
```
power_mw = pd.read_csv(filename,skiprows=skip, usecols=[columns[0],␣
↪columns[14], columns[15], columns[16]], sep=sep)
```

[35]:
```
power_mw[columns[0]] = pd.to_datetime(power_mw[columns[0]])
power_mw.set_index(columns[0], inplace=True)
```

[36]:
```
power_mw.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 3 columns):
 #   Column             Dtype
---  ------             -----
 0    Power[mW]         float64
 1    Pol Power[mW]     float64
 2    Unpol Power[mW]   float64
dtypes: float64(3)
memory usage: 72.3 MB
```

[37]:
```
power_mw.isnull().sum()
```

[37]:
```
Power[mW]           0
Pol Power[mW]       0
```

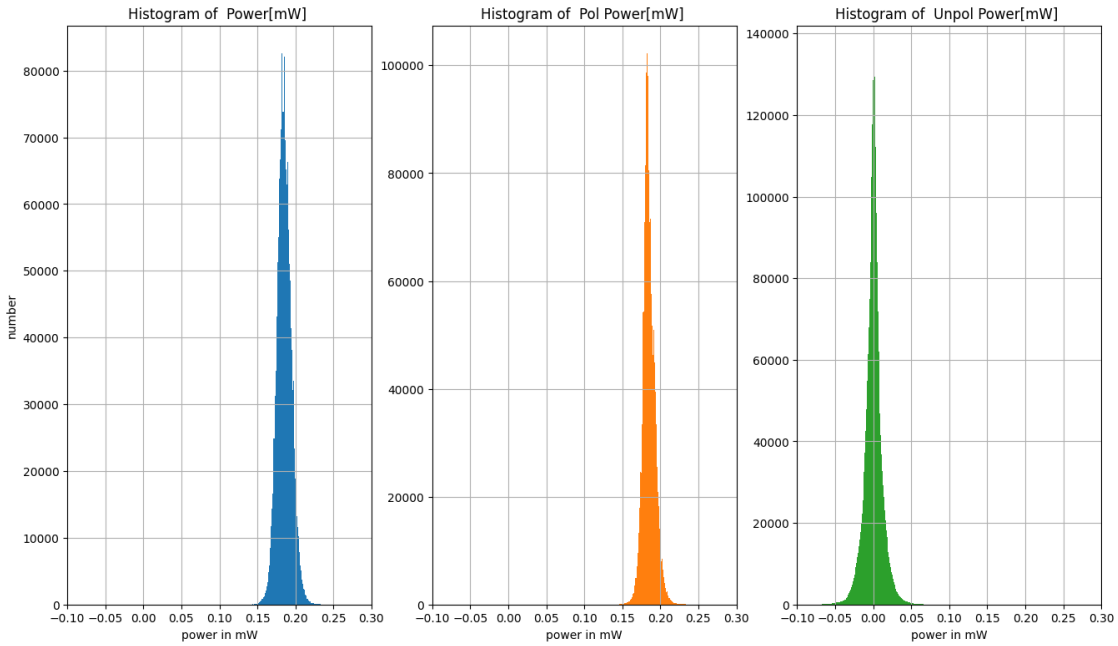
```
Unpol Power[mW]     0
dtype: int64
```

[38]:
```
power_mw.describe()
```

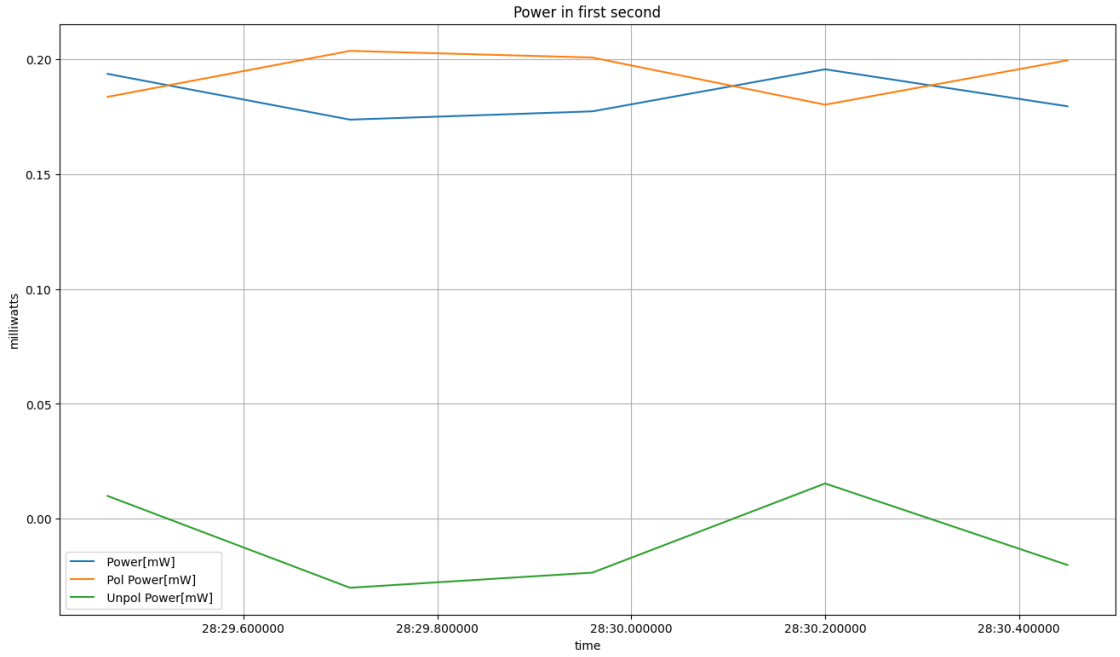
[38]:

	Power[mW]	Pol Power[mW]	Unpol Power[mW]
count	2.369654e+06	2.369654e+06	2.369654e+06
mean	1.853396e-01	1.850686e-01	2.709176e-04
std	9.411575e-03	8.015791e-03	1.166701e-02
min	9.761000e-02	1.111000e-01	-1.006000e-01
25%	1.791000e-01	1.800000e-01	-5.437000e-03
50%	1.849000e-01	1.842000e-01	4.901000e-04
75%	1.914000e-01	1.898000e-01	5.802000e-03
max	2.415000e-01	2.417000e-01	9.792000e-02

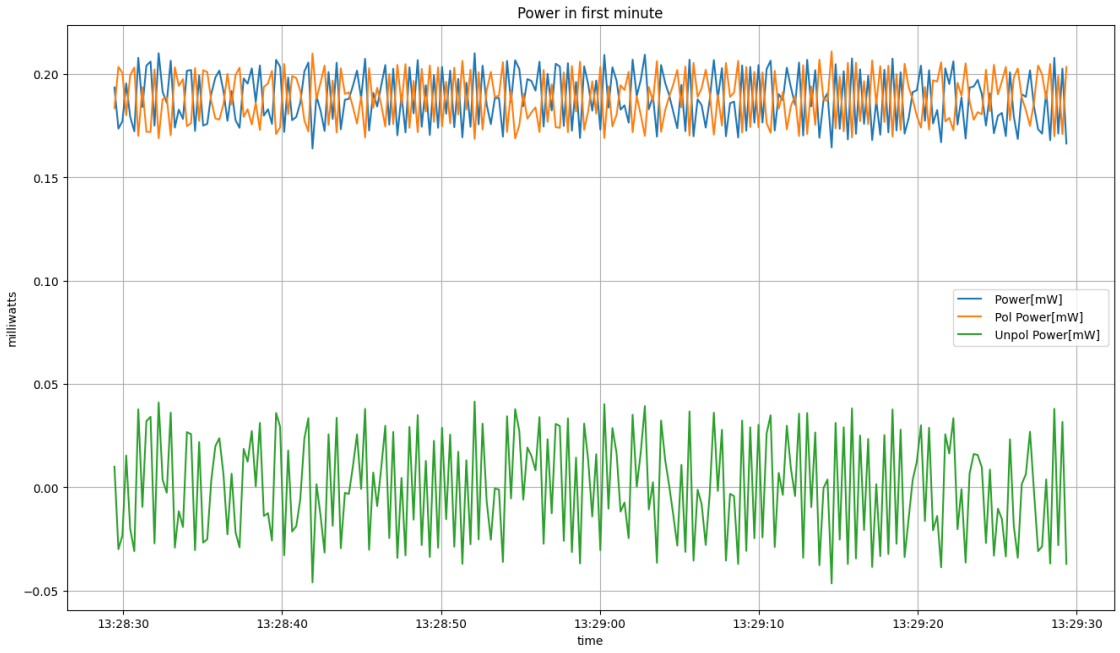
[39]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 3, 1)
plt.hist(power_mw[columns[14]], bins=200, color='tab:blue')
plt.xlim([-0.1, 0.3])
plt.grid()
plt.xlabel('power in mW')
plt.ylabel('number')
plt.title(f'Histogram of {columns[14]}')

plt.subplot(1, 3, 2)
plt.hist(power_mw[columns[15]], bins=200, color='tab:orange')
plt.xlim([-0.1, 0.3])
plt.grid()
plt.xlabel('power in mW')
plt.title(f'Histogram of {columns[15]}')

plt.subplot(1, 3, 3)
plt.hist(power_mw[columns[16]], bins=200, color='tab:green')
plt.xlim([-0.1, 0.3])
plt.grid()
plt.xlabel('power in mW')
plt.title(f'Histogram of {columns[16]}')

plt.show()
```



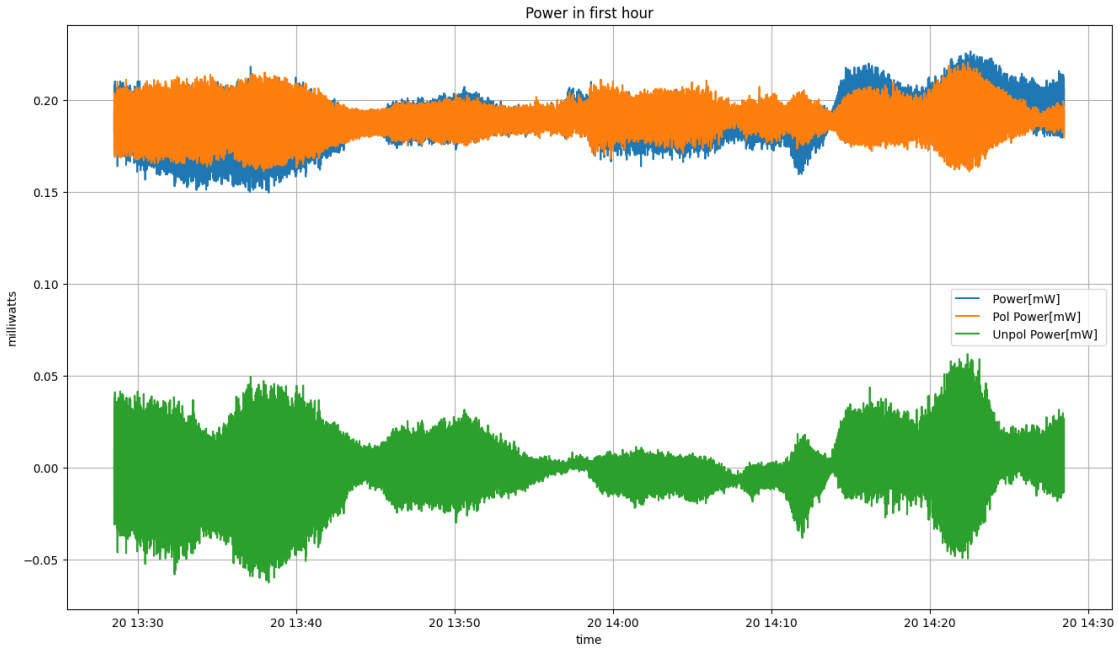
[40]:
```
first_second = power_mw.loc[(power_mw.index >= start_time) & (power_mw.index <␣
↪end_time_second)]

plt.figure(figsize = (16,9))
plt.plot(first_second.index, first_second[columns[14]], label = columns[14])
plt.plot(first_second.index, first_second[columns[15]], label = columns[15])
plt.plot(first_second.index, first_second[columns[16]], label = columns[16])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first second')
plt.xlabel('time')
plt.ylabel('milliwatts')
plt.show()
```



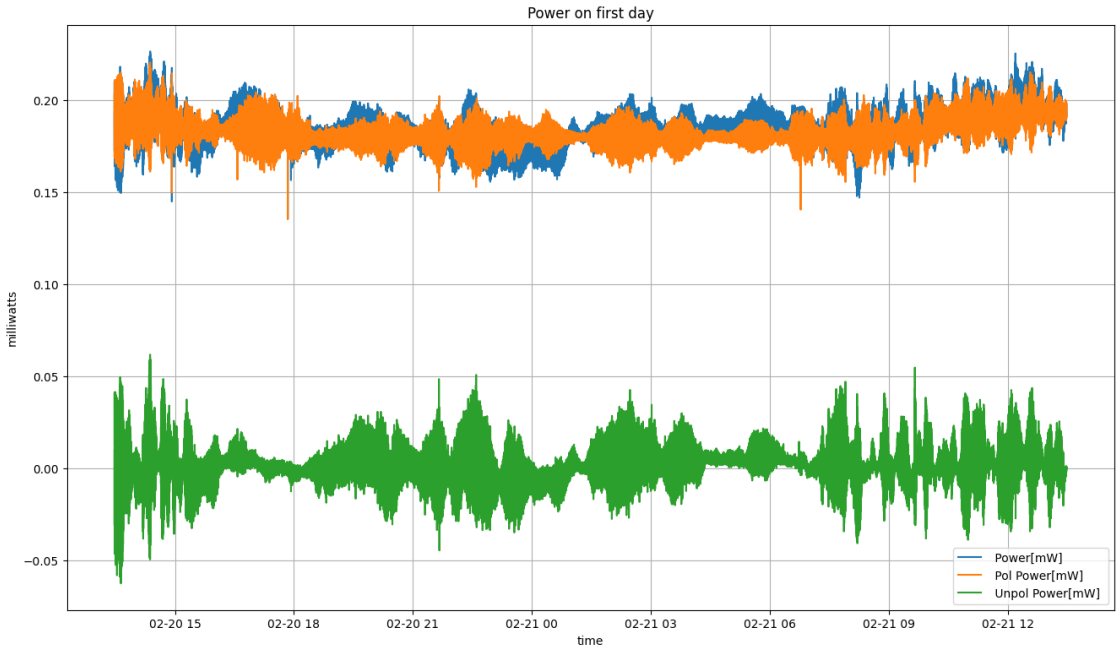
[41]:
```
first_minute = power_mw.loc[(power_mw.index >= start_time) & (power_mw.index <␣
↪end_time_minute)]

plt.figure(figsize = (16,9))
plt.plot(first_minute.index, first_minute[columns[14]], label = columns[14])
plt.plot(first_minute.index, first_minute[columns[15]], label = columns[15])
plt.plot(first_minute.index, first_minute[columns[16]], label = columns[16])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first minute')
plt.xlabel('time')
plt.ylabel('milliwatts')
plt.show()
```



[42]:
```
first_hour = power_mw.loc[(power_mw.index >= start_time) & (power_mw.index <␣
 ↪end_time_hour)]

plt.figure(figsize = (16,9))
plt.plot(first_hour.index, first_hour[columns[14]], label = columns[14])
plt.plot(first_hour.index, first_hour[columns[15]], label = columns[15])
plt.plot(first_hour.index, first_hour[columns[16]], label = columns[16])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first hour')
plt.xlabel('time')
plt.ylabel('milliwatts')
plt.show()
```

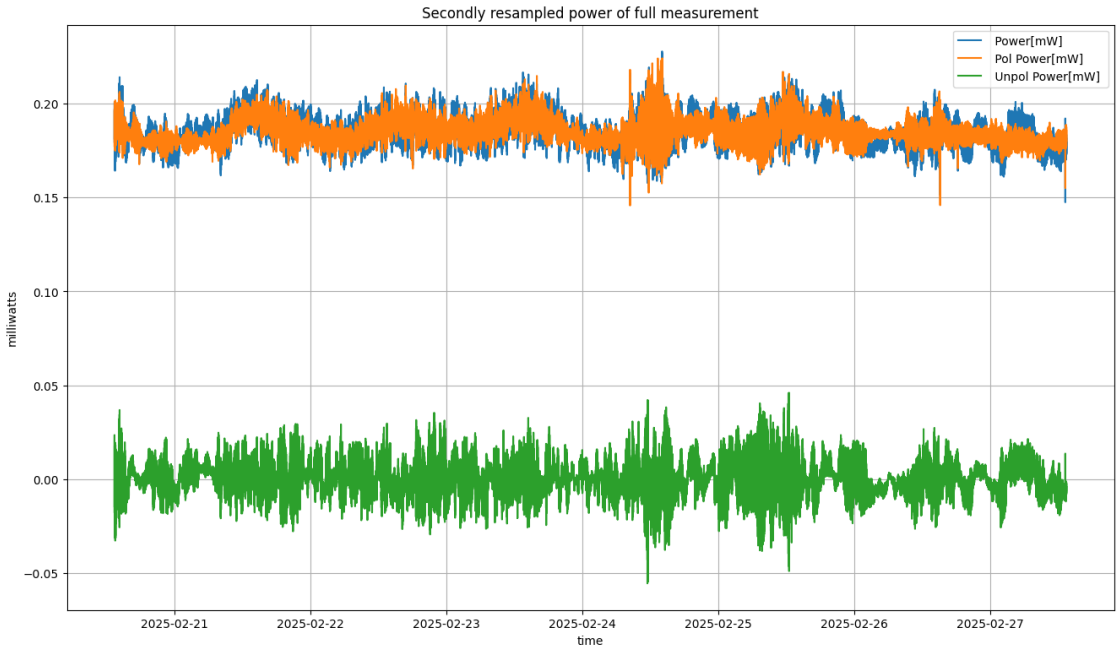


[43]:
```
first_day = power_mw.loc[(power_mw.index >= start_time) & (power_mw.index <␣
 ↪end_time_day)]

plt.figure(figsize = (16,9))
plt.plot(first_day.index, first_day[columns[14]], label = columns[14])
plt.plot(first_day.index, first_day[columns[15]], label = columns[15])
plt.plot(first_day.index, first_day[columns[16]], label = columns[16])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power on first day')
plt.xlabel('time')
plt.ylabel('milliwatts')
plt.show()
```



[44]:
```
power_mw_seconds_resample = power_mw.resample('s').mean()
```

[45]:
```
plt.figure(figsize = (16,9))
plt.plot(power_mw_seconds_resample.index,␣
 ↪power_mw_seconds_resample[columns[14]], label = columns[14])
plt.plot(power_mw_seconds_resample.index,␣
 ↪power_mw_seconds_resample[columns[15]], label = columns[15])
plt.plot(power_mw_seconds_resample.index,␣
 ↪power_mw_seconds_resample[columns[16]], label = columns[16])
plt.grid()
plt.legend(loc = 'best')
plt.title('Secondly resampled power of full measurement')
plt.xlabel('time')
plt.ylabel('milliwatts')
plt.show()
```



[46]:
```
power_dbm = pd.read_csv(filename,skiprows=skip, usecols=[columns[0],␣
↪columns[17], columns[18], columns[19]], sep=sep)
```

[47]:
```
power_dbm[columns[0]] = pd.to_datetime(power_dbm[columns[0]])
power_dbm.set_index(columns[0], inplace=True)
```

[48]:
```
power_dbm.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 3 columns):
 #   Column              Dtype
---  ------              -----
 0    Power[dBm]         float64
 1    Pol Power[dBm]     float64
 2    Unpol Power[dBm]   float64
dtypes: float64(3)
memory usage: 72.3 MB
```

[49]:
```
power_dbm.isnull().sum()
```

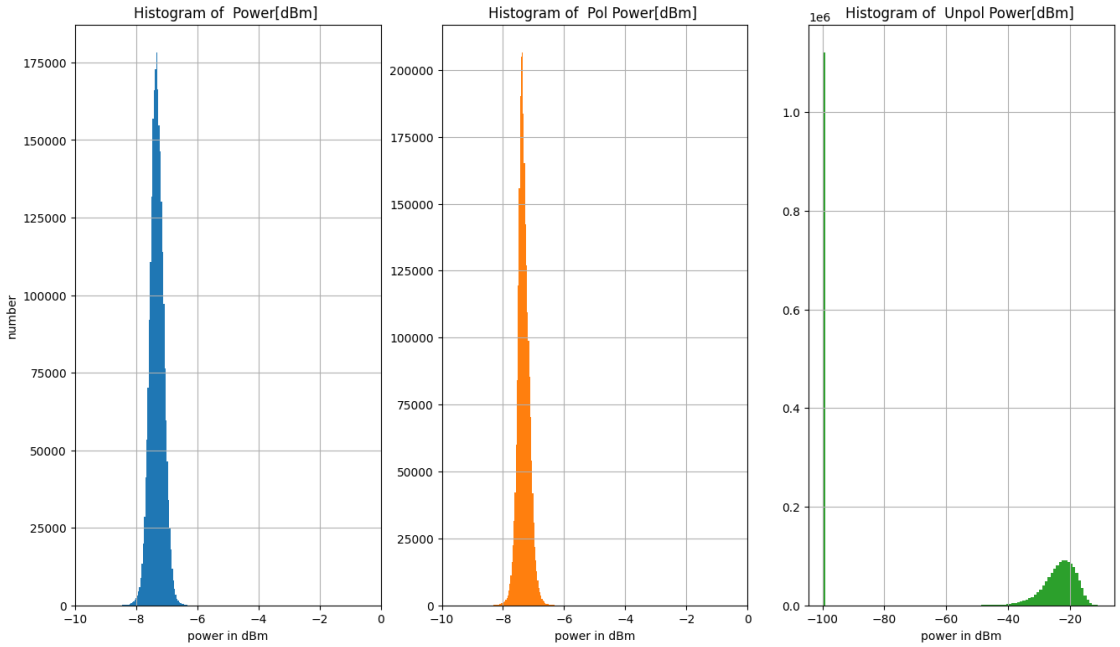
[49]:
```
Power[dBm]           0
Pol Power[dBm]       0
Unpol Power[dBm]     0
dtype: int64
```

[50]:
```
power_dbm.describe()
```

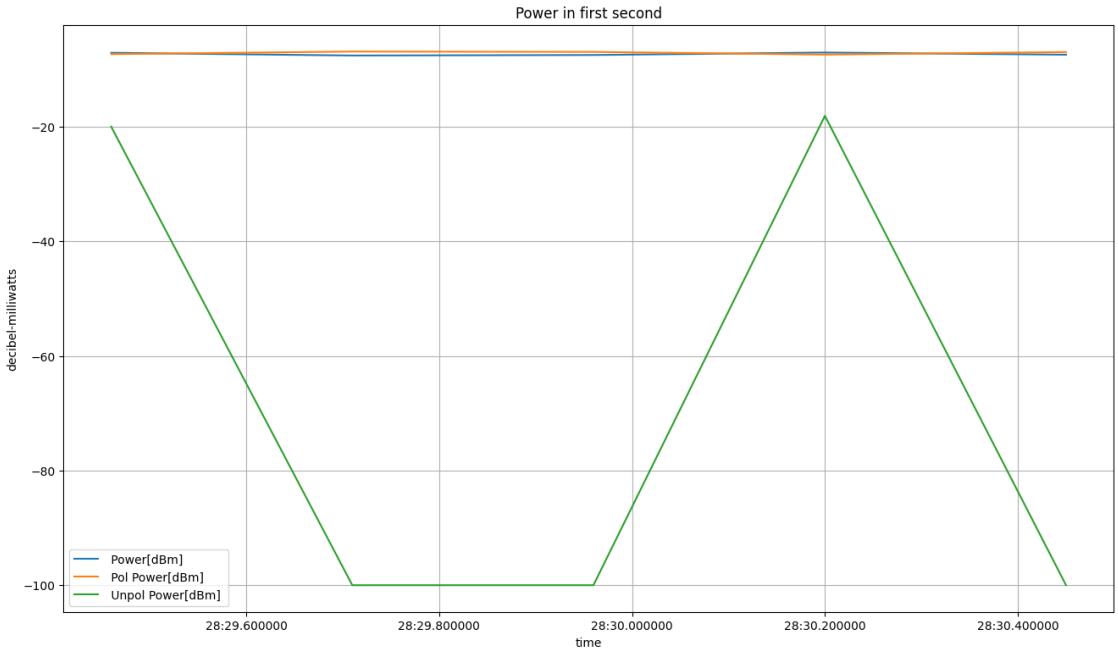
[50]:

	Power[dBm]	Pol Power[dBm]	Unpol Power[dBm]
count	2.369654e+06	2.369654e+06	2.369654e+06
mean	-7.325910e+00	-7.330714e+00	-5.963221e+01
std	2.203316e-01	1.870446e-01	3.844336e+01
min	-1.010500e+01	-9.542000e+00	-9.999000e+01
25%	-7.469000e+00	-7.447000e+00	-9.999000e+01
50%	-7.330000e+00	-7.347000e+00	-3.309700e+01
75%	-7.181000e+00	-7.218000e+00	-2.236400e+01
max	-6.171000e+00	-6.168000e+00	-1.009200e+01

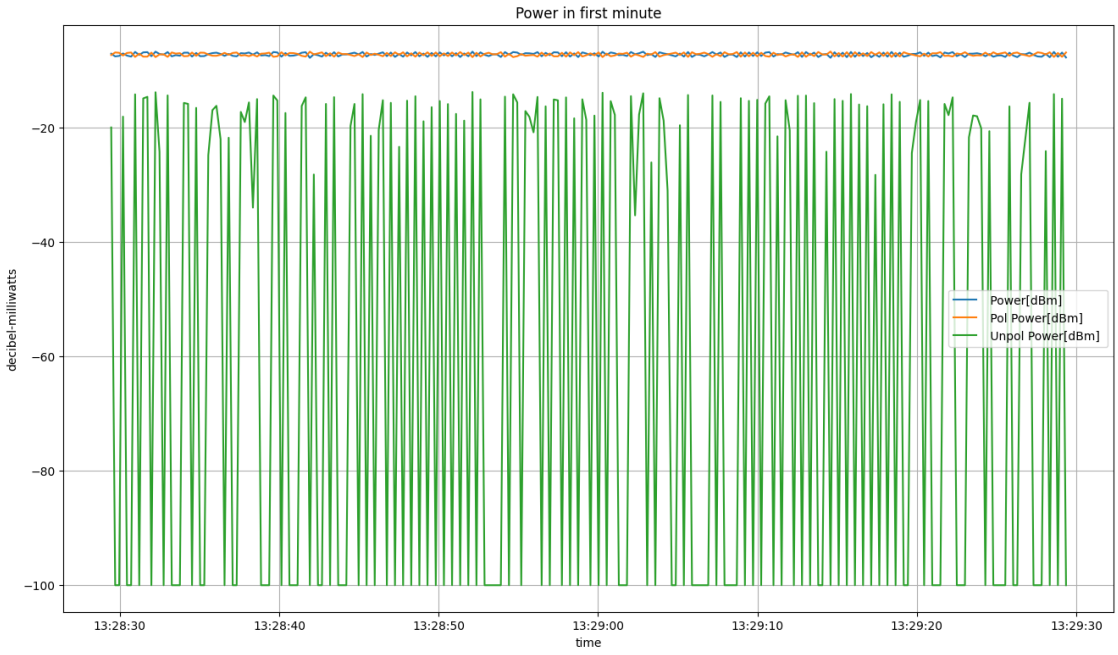
[51]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 3, 1)
plt.hist(power_dbm[columns[17]], bins=100, color='tab:blue')
plt.xlim([-10, 0])
plt.grid()
plt.xlabel('power in dBm')
plt.ylabel('number')
plt.title(f'Histogram of {columns[17]}')

plt.subplot(1, 3, 2)
plt.hist(power_dbm[columns[18]], bins=100, color='tab:orange')
plt.xlim([-10, 0])
plt.grid()
plt.xlabel('power in dBm')
plt.title(f'Histogram of {columns[18]}')

plt.subplot(1, 3, 3)
plt.hist(power_dbm[columns[19]], bins=100, color='tab:green')
plt.grid()
plt.xlabel('power in dBm')
plt.title(f'Histogram of {columns[19]}')

plt.show()
```



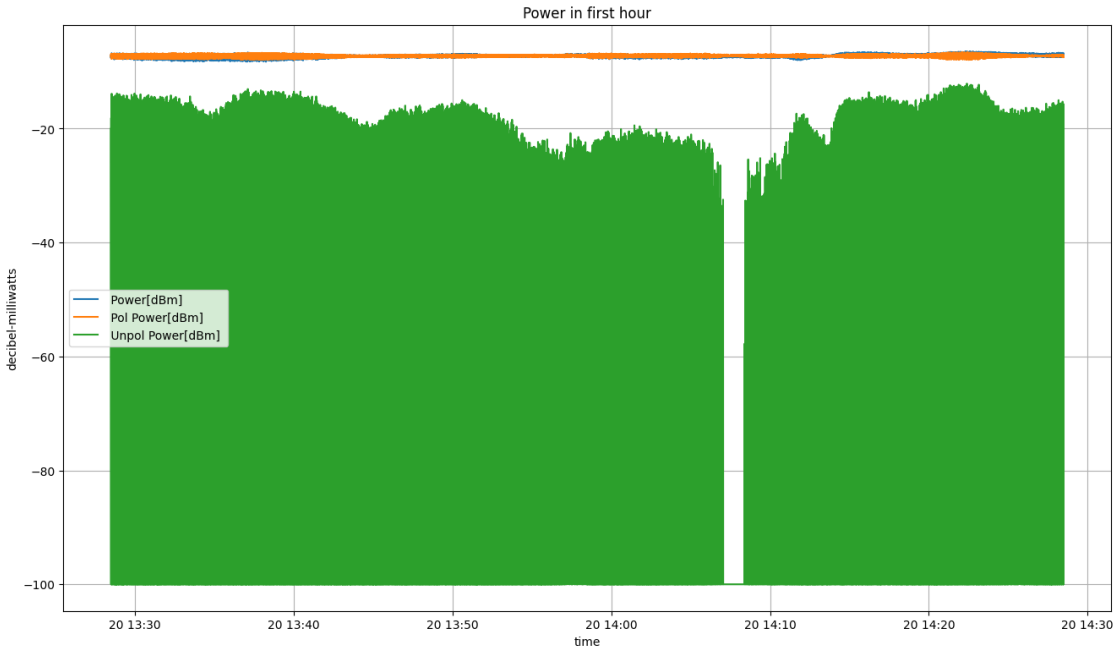
[52]:
```
first_second = power_dbm.loc[(power_dbm.index >= start_time) & (power_dbm.index
  ↪< end_time_second)]

plt.figure(figsize = (16,9))
plt.plot(first_second.index, first_second[columns[17]], label = columns[17])
plt.plot(first_second.index, first_second[columns[18]], label = columns[18])
plt.plot(first_second.index, first_second[columns[19]], label = columns[19])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first second')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```



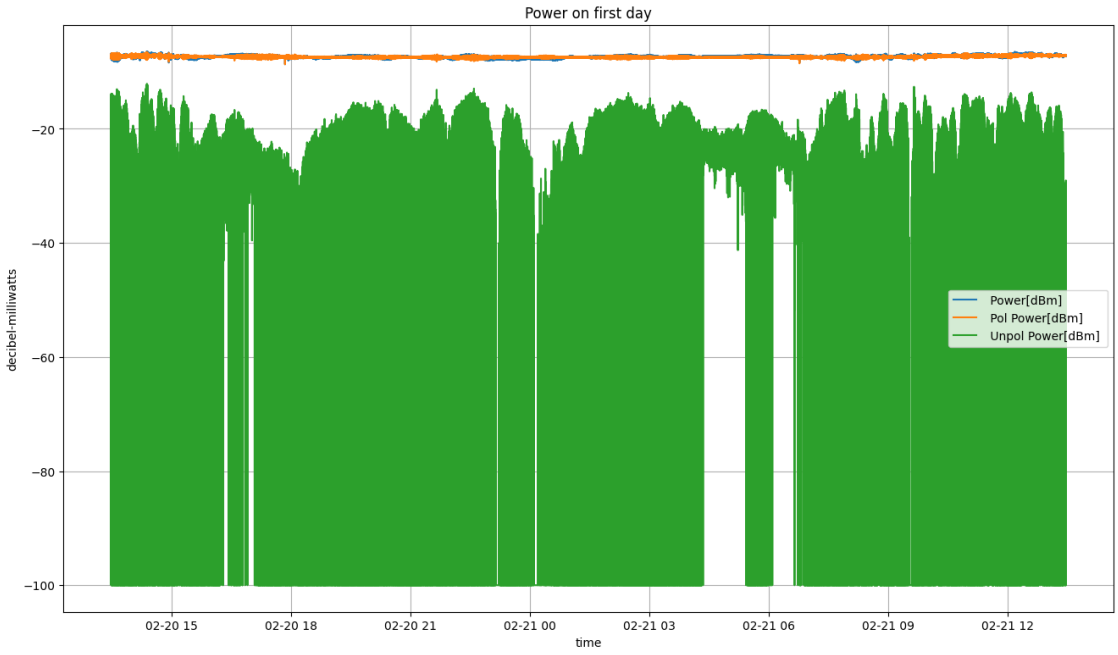
[53]:
```
first_minute = power_dbm.loc[(power_dbm.index >= start_time) & (power_dbm.index
 ↪< end_time_minute)]

plt.figure(figsize = (16,9))
plt.plot(first_minute.index, first_minute[columns[17]], label = columns[17])
plt.plot(first_minute.index, first_minute[columns[18]], label = columns[18])
plt.plot(first_minute.index, first_minute[columns[19]], label = columns[19])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first minute')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```



[54]:
```
first_hour = power_dbm.loc[(power_dbm.index >= start_time) & (power_dbm.index <␣
↪end_time_hour)]

plt.figure(figsize = (16,9))
plt.plot(first_hour.index, first_hour[columns[17]], label = columns[17])
plt.plot(first_hour.index, first_hour[columns[18]], label = columns[18])
plt.plot(first_hour.index, first_hour[columns[19]], label = columns[19])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power in first hour')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```

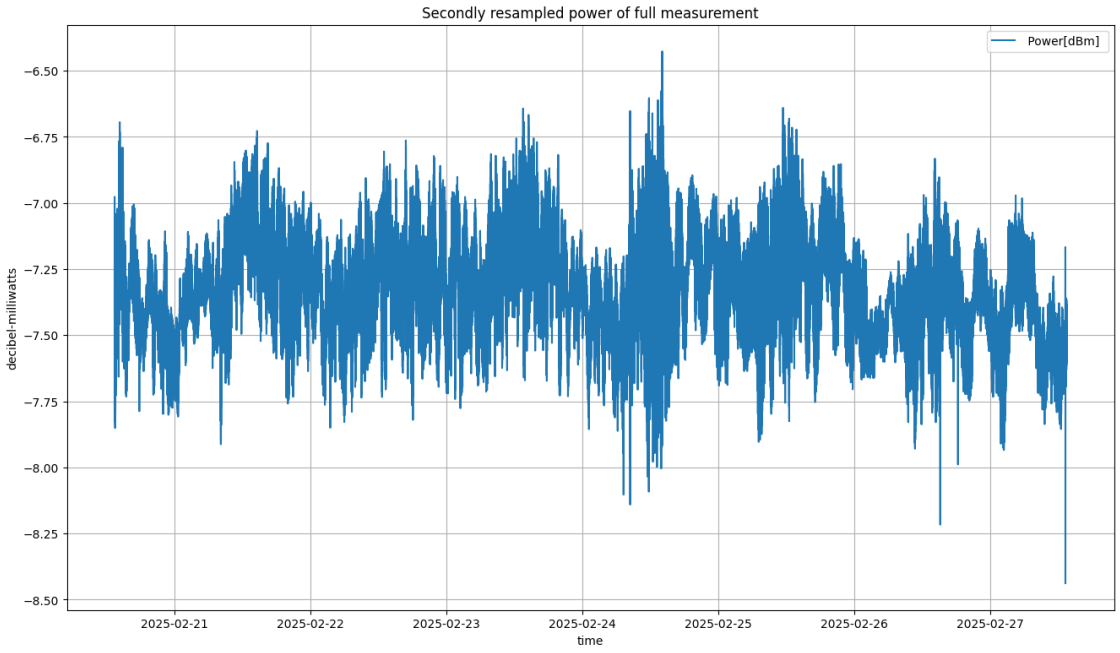


[55]:
```
first_day = power_dbm.loc[(power_dbm.index >= start_time) & (power_dbm.index <␣
↪end_time_day)]

plt.figure(figsize = (16,9))
plt.plot(first_day.index, first_day[columns[17]], label = columns[17])
plt.plot(first_day.index, first_day[columns[18]], label = columns[18])
plt.plot(first_day.index, first_day[columns[19]], label = columns[19])
plt.grid()
plt.legend(loc = 'best')
plt.title('Power on first day')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```

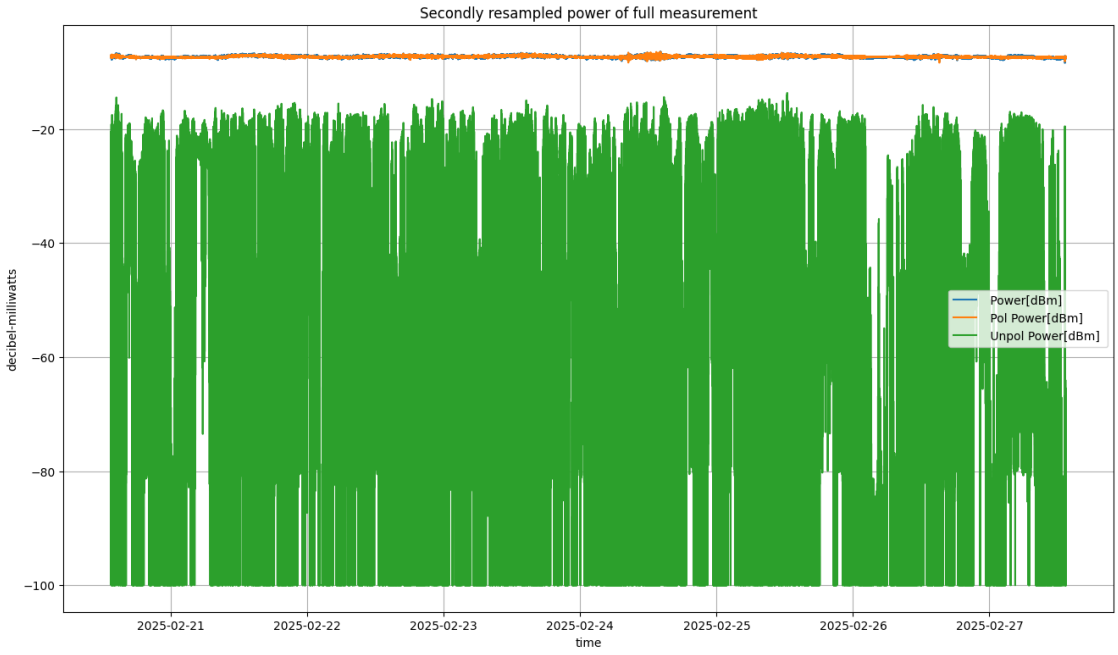


[56]:
```
power_dbm_seconds_resample = power_dbm.resample('s').mean()
```

[57]:
```
plt.figure(figsize = (16,9))
plt.plot(power_dbm_seconds_resample.index,␣
 ↪power_dbm_seconds_resample[columns[17]], label = columns[17])
plt.grid()
plt.legend(loc = 'best')
plt.title('Secondly resampled power of full measurement')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```



[58]:
```
plt.figure(figsize = (16,9))
plt.plot(power_dbm_seconds_resample.index,␣
 ↪power_dbm_seconds_resample[columns[17]], label = columns[17])
plt.plot(power_dbm_seconds_resample.index,␣
 ↪power_dbm_seconds_resample[columns[18]], label = columns[18])
plt.plot(power_dbm_seconds_resample.index,␣
 ↪power_dbm_seconds_resample[columns[19]], label = columns[19])
plt.grid()
plt.legend(loc = 'best')
plt.title('Secondly resampled power of full measurement')
plt.xlabel('time')
plt.ylabel('decibel-milliwatts')
plt.show()
```



3.5 Winkel (Azimuth, Ellipticity)

[59]:
```
angle = pd.read_csv(filename,skiprows=skip, usecols=[columns[0], columns[9],␣
↪columns[10]], sep=sep)
```

[60]:
```
angle[columns[0]] = pd.to_datetime(angle[columns[0]])
angle.set_index(columns[0], inplace=True)
```

[61]:
```
angle.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 2 columns):
 #   Column            Dtype
---  ------            -----
 0    Azimuth[°]       float64
 1    Ellipticity[°]   float64
dtypes: float64(2)
memory usage: 54.2 MB
```

[62]:
```
angle.isnull().sum()
```

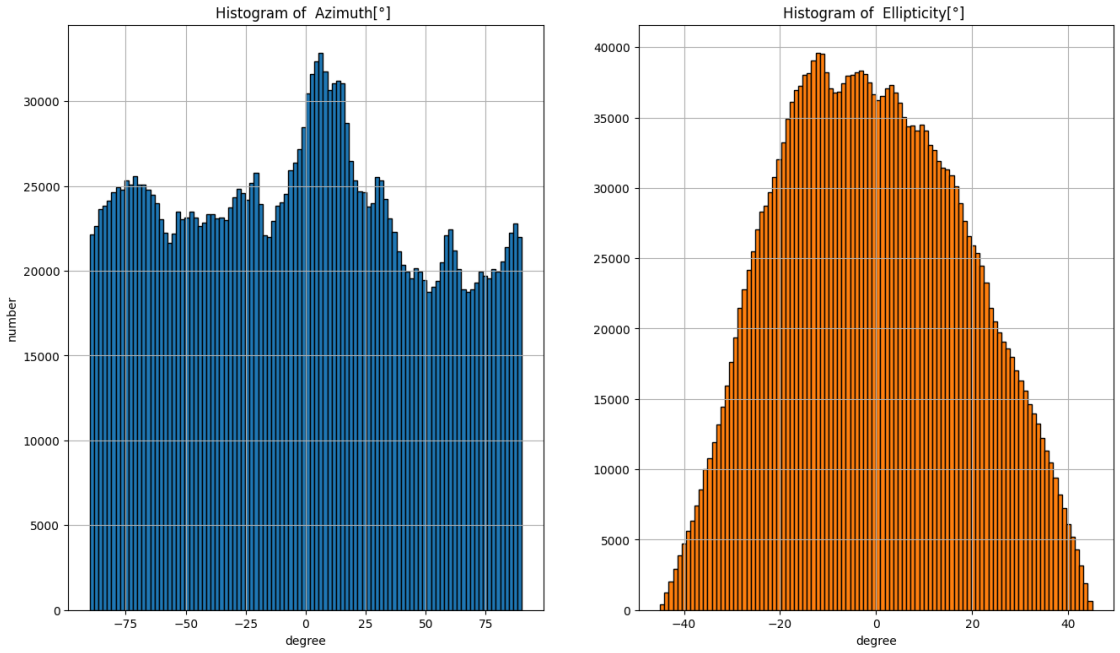
[62]:
```
Azimuth[°]         0
Ellipticity[°]     0
dtype: int64
```

[63]:
```
angle.describe()
```

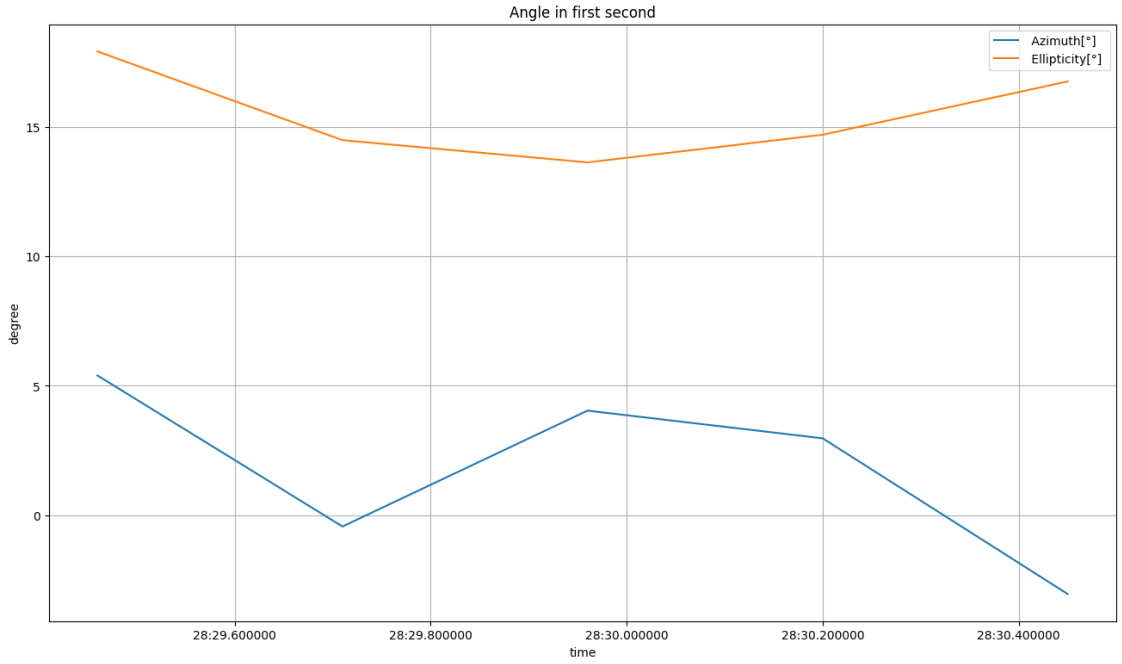
[63]:

	Azimuth[°]	Ellipticity[°]
count	2.369654e+06	2.369654e+06
mean	-2.375038e+00	-8.207911e-01
std	5.038627e+01	1.906634e+01
min	-9.000000e+01	-4.498000e+01
25%	-4.525000e+01	-1.561000e+01
50%	-9.900000e-01	-1.620000e+00
75%	3.744000e+01	1.354000e+01
max	9.000000e+01	4.497000e+01

[64]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 2, 1)
plt.hist(angle[columns[9]], bins=100, color='tab:blue', edgecolor='black')
plt.grid()
plt.xlabel('degree')
plt.ylabel('number')
plt.title(f'Histogram of {columns[9]}')

plt.subplot(1, 2, 2)
plt.hist(angle[columns[10]], bins=100, color='tab:orange', edgecolor='black')
plt.grid()
plt.xlabel('degree')
plt.title(f'Histogram of {columns[10]}')

plt.show()
```

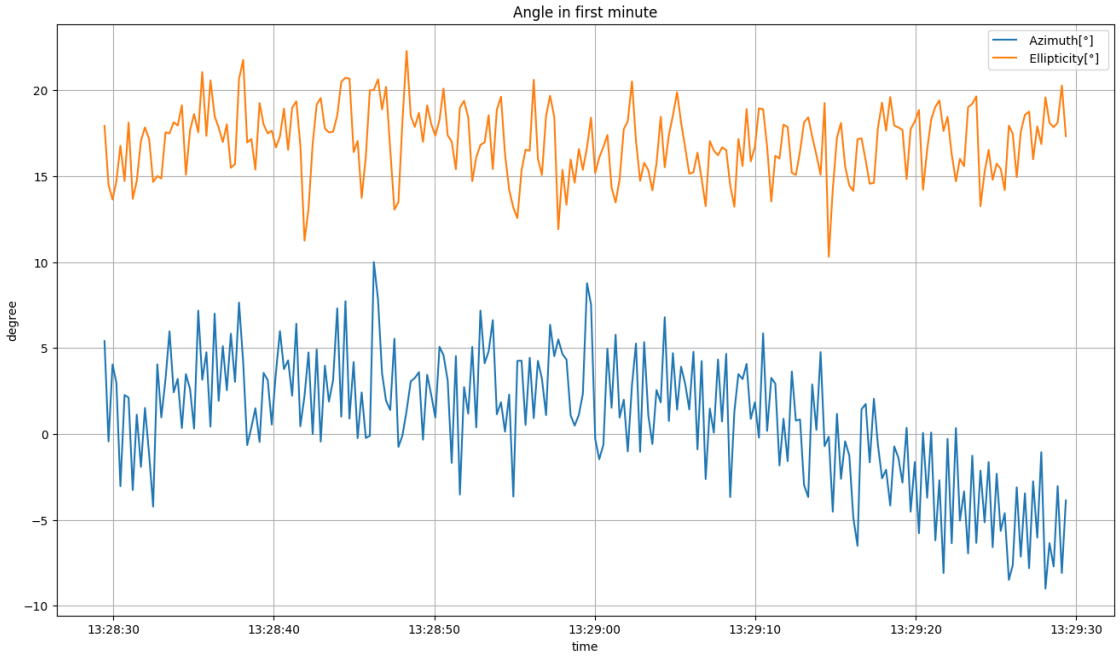


[65]:
```
first_second = angle.loc[(angle.index >= start_time) & (angle.index <␣
 ↪end_time_second)]

plt.figure(figsize = (16,9))
plt.plot(first_second.index, first_second[columns[9]], label = columns[9])
plt.plot(first_second.index, first_second[columns[10]], label = columns[10])
plt.grid()
plt.legend(loc = 'best')
plt.title('Angle in first second')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

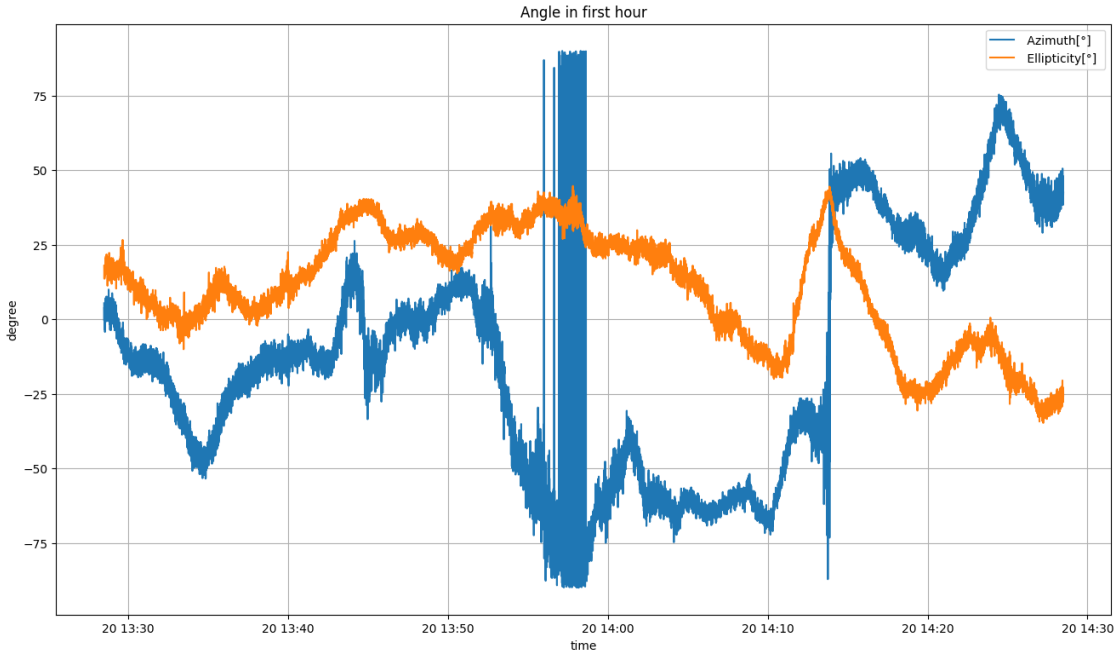


[66]:
```
first_minute = angle.loc[(angle.index >= start_time) & (angle.index <␣
 ↪end_time_minute)]

plt.figure(figsize = (16,9))
plt.plot(first_minute.index, first_minute[columns[9]], label = columns[9])
plt.plot(first_minute.index, first_minute[columns[10]], label = columns[10])
plt.grid()
plt.legend(loc = 'best')
plt.title('Angle in first minute')
plt.xlabel('time')
```

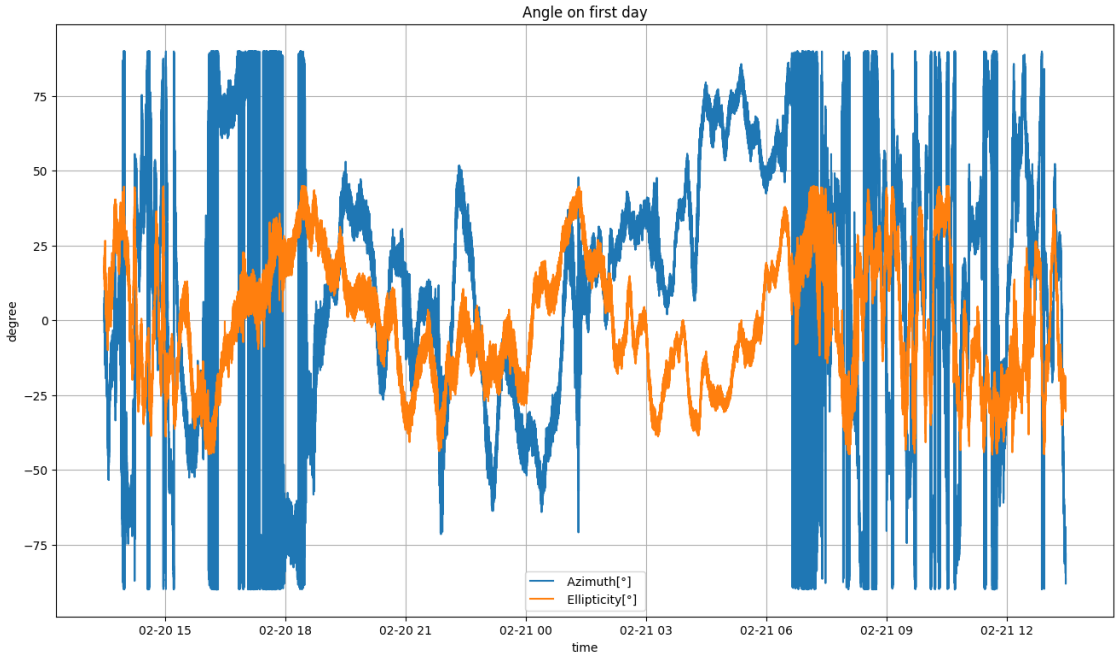
```
plt.ylabel('degree')
plt.show()
```



[67]:
```
first_hour = angle.loc[(angle.index >= start_time) & (angle.index <␣
 ↪end_time_hour)]

plt.figure(figsize = (16,9))
plt.plot(first_hour.index, first_hour[columns[9]], label = columns[9])
plt.plot(first_hour.index, first_hour[columns[10]], label = columns[10])
plt.grid()
plt.legend(loc = 'best')
plt.title('Angle in first hour')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

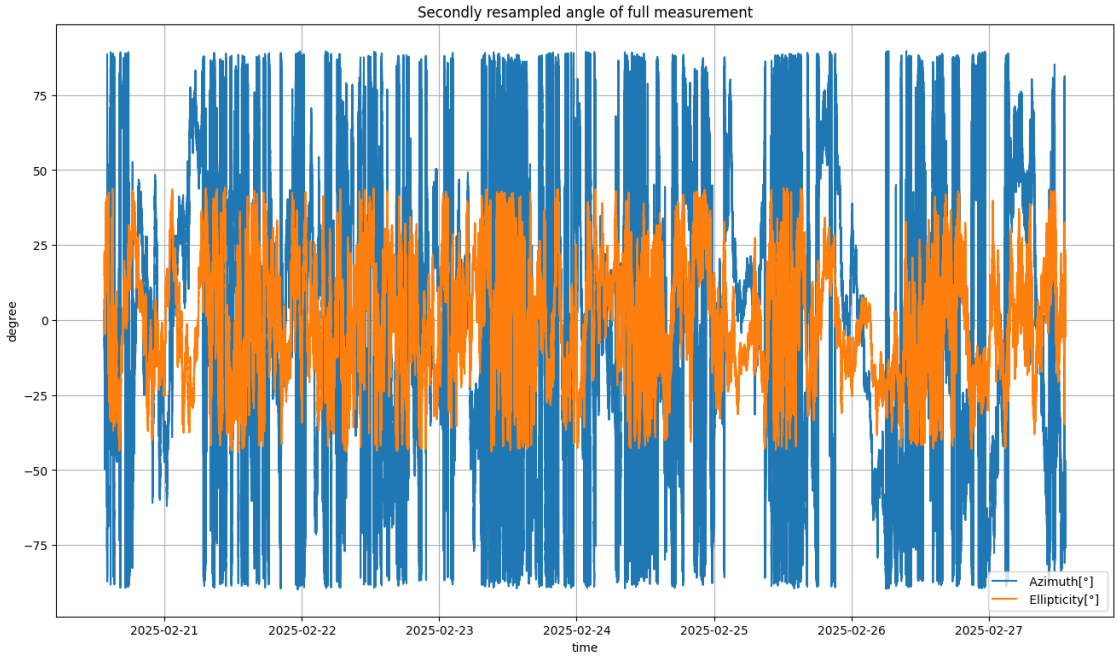


[68]:
```
first_day = angle.loc[(angle.index >= start_time) & (angle.index <␣
 ↪end_time_day)]

plt.figure(figsize = (16,9))
plt.plot(first_day.index, first_day[columns[9]], label = columns[9])
plt.plot(first_day.index, first_day[columns[10]], label = columns[10])
plt.grid()
plt.legend(loc = 'best')
plt.title('Angle on first day')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```



[69]:
```
angle_seconds_resample = angle.resample('s').mean()
```

[70]:
```
plt.figure(figsize = (16,9))
plt.plot(angle_seconds_resample.index, angle_seconds_resample[columns[9]],␣
 ↪label = columns[9])
plt.plot(angle_seconds_resample.index, angle_seconds_resample[columns[10]],␣
 ↪label = columns[10])
plt.grid()
plt.legend(loc = 'best')
plt.title('Secondly resampled angle of full measurement')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```



3.6 Stokes-Parameter (S0, S1, S2, S3 / Normalized S1, S2, S3)

[71]:
```
stokes = pd.read_csv(filename,skiprows=skip, usecols=[columns[0], columns[5],␣
↪columns[6], columns[7], columns[8]], sep=sep)
```

```
C:\Users\laura\AppData\Local\Temp\ipykernel_17264\3101761779.py:1: DtypeWarning:
Columns (5) have mixed types. Specify dtype option on import or set
low_memory=False.
  stokes = pd.read_csv(filename,skiprows=skip, usecols=[columns[0], columns[5],
columns[6], columns[7], columns[8]], sep=sep)
```

[72]:
```
stokes[columns[0]] = pd.to_datetime(stokes[columns[0]])
stokes.set_index(columns[0], inplace=True)
```

[73]:
```
stokes.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 4 columns):
 #   Column     Dtype
---  ------     -----
 0    S 0 [mW]  object
 1    S 1 [mW]  float64
 2    S 2 [mW]  float64
 3    S 3 [mW]  float64
```

```
dtypes: float64(3), object(1)
memory usage: 90.4+ MB
```

[74]:
```
stokes.isnull().sum()
```

[74]:
```
S 0 [mW]    0
S 1 [mW]    0
S 2 [mW]    0
S 3 [mW]    0
dtype: int64
```

[75]:
```
stokes.describe()
```

[75]:

	S 1 [mW]	S 2 [mW]	S 3 [mW]
count	2.369654e+06	2.369654e+06	2.369654e+06
mean	1.119711e-02	-3.962398e-03	-5.020136e-03
std	1.096478e-01	1.056081e-01	1.047504e-01
min	-2.349000e-01	-2.198000e-01	-2.017000e-01
25%	-8.511000e-02	-9.668000e-02	-9.554000e-02
50%	1.477000e-02	-2.372500e-03	-1.044000e-02
75%	1.104000e-01	8.352000e-02	8.420000e-02
max	2.405000e-01	2.174000e-01	2.031000e-01

[76]:
```
normalized_stokes = pd.read_csv(filename,skiprows=skip, usecols=[columns[0],␣
↪columns[2], columns[3], columns[4]], sep=sep)
```

[77]:
```
normalized_stokes[columns[0]] = pd.to_datetime(normalized_stokes[columns[0]])
normalized_stokes.set_index(columns[0], inplace=True)
```

[78]:
```
normalized_stokes.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 3 columns):
 #   Column            Dtype
---  ------            -----
 0    Normalized s 1   float64
 1    Normalized s 2   float64
 2    Normalized s 3   float64
dtypes: float64(3)
memory usage: 72.3 MB
```

[79]:
```
normalized_stokes.isnull().sum()
```

[79]:
```
Normalized s 1    0
Normalized s 2    0
Normalized s 3    0
```

```
dtype: int64
```

[80]:
```
normalized_stokes.describe()
```

[80]:
```
       Normalized s 1   Normalized s 2   Normalized s 3
count     2.369654e+06     2.369654e+06     2.369654e+06
mean      6.296412e-02    -1.947966e-02    -2.810160e-02
std       5.914234e-01     5.698981e-01     5.659980e-01
min      -1.000000e+00    -1.000000e+00    -1.000000e+00
25%      -4.600000e-01    -5.200000e-01    -5.200000e-01
50%       8.000000e-02    -1.000000e-02    -6.000000e-02
75%       6.000000e-01     4.500000e-01     4.600000e-01
max       1.000000e+00     1.000000e+00     1.000000e+00
```

3.7 Power-Split-Ratio & Phase Difference

[81]:
```
modality = pd.read_csv(filename,skiprows=skip, usecols=[columns[0],␣
 ↪columns[20], columns[21]], sep=sep)
```

[82]:
```
modality[columns[0]] = pd.to_datetime(modality[columns[0]])
modality.set_index(columns[0], inplace=True)
```

[83]:
```
modality.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 2369654 entries, 2025-02-20 13:28:29.460000 to 2025-02-27
13:28:39.060000
Data columns (total 2 columns):
 #   Column                 Dtype
---  ------                 -----
 0    Power-Split-Ratio     float64
 1    Phase Difference[°]   float64
dtypes: float64(2)
memory usage: 54.2 MB
```

[84]:
```
modality.isnull().sum()
```

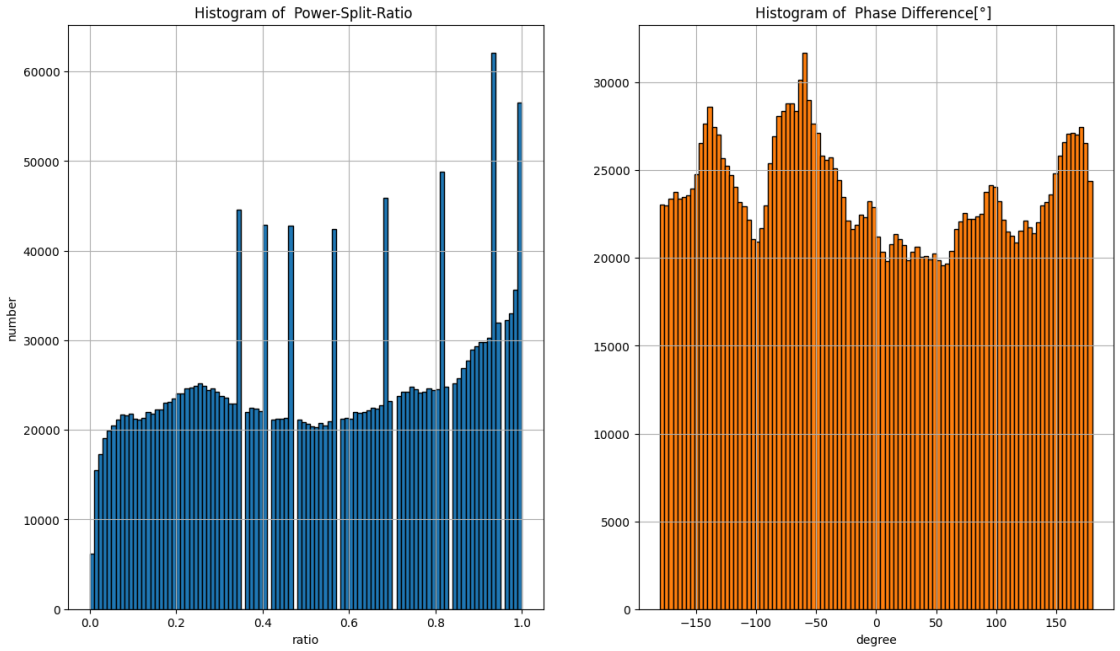
[84]:
```
Power-Split-Ratio       0
Phase Difference[°]     0
dtype: int64
```

[85]:
```
modality.describe()
```

[85]:
```
       Power-Split-Ratio   Phase Difference[°]
count        2.369654e+06          2.369654e+06
mean         5.314885e-01         -3.031721e+00
std          2.957300e-01          1.053810e+02
min          0.000000e+00         -1.800000e+02
```

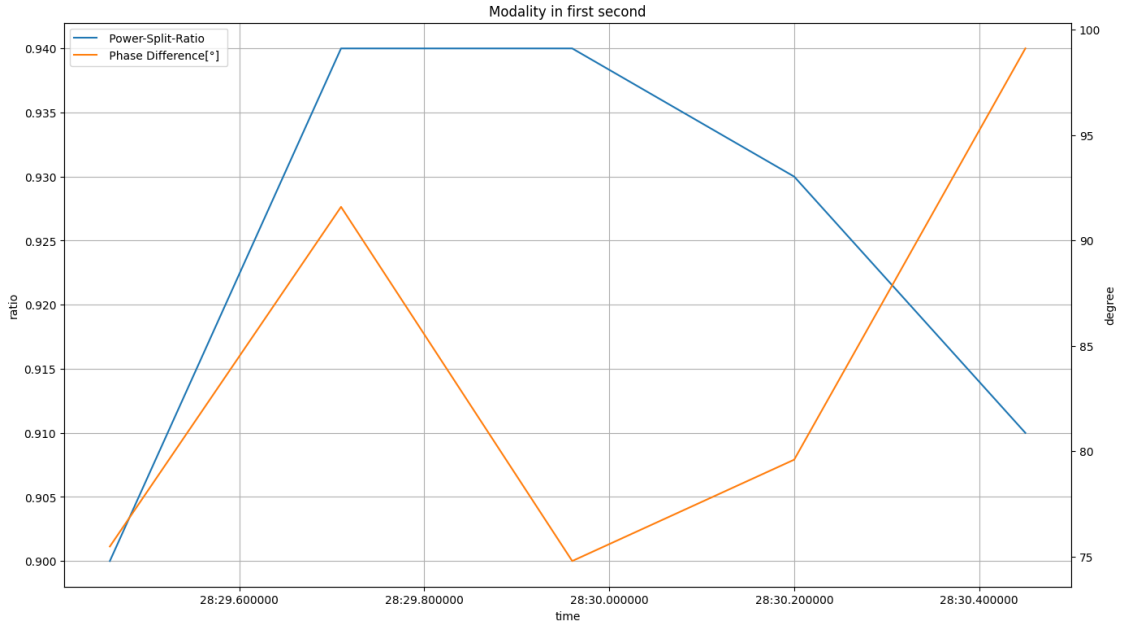
```
25%          2.700000e-01          -9.181000e+01
50%          5.400000e-01          -1.049000e+01
75%          8.000000e-01           9.062000e+01
max          1.000000e+00           1.800000e+02
```

[86]:
```
plt.figure(figsize = (16,9))
plt.subplot(1, 2, 1)
plt.hist(modality[columns[20]], bins=100, color='tab:blue', edgecolor='black')
plt.grid()
plt.xlabel('ratio')
plt.ylabel('number')
plt.title(f'Histogram of {columns[20]}')

plt.subplot(1, 2, 2)
plt.hist(modality[columns[21]], bins=100, color='tab:orange', edgecolor='black')
plt.grid()
plt.xlabel('degree')
plt.title(f'Histogram of {columns[21]}')

plt.show()
```



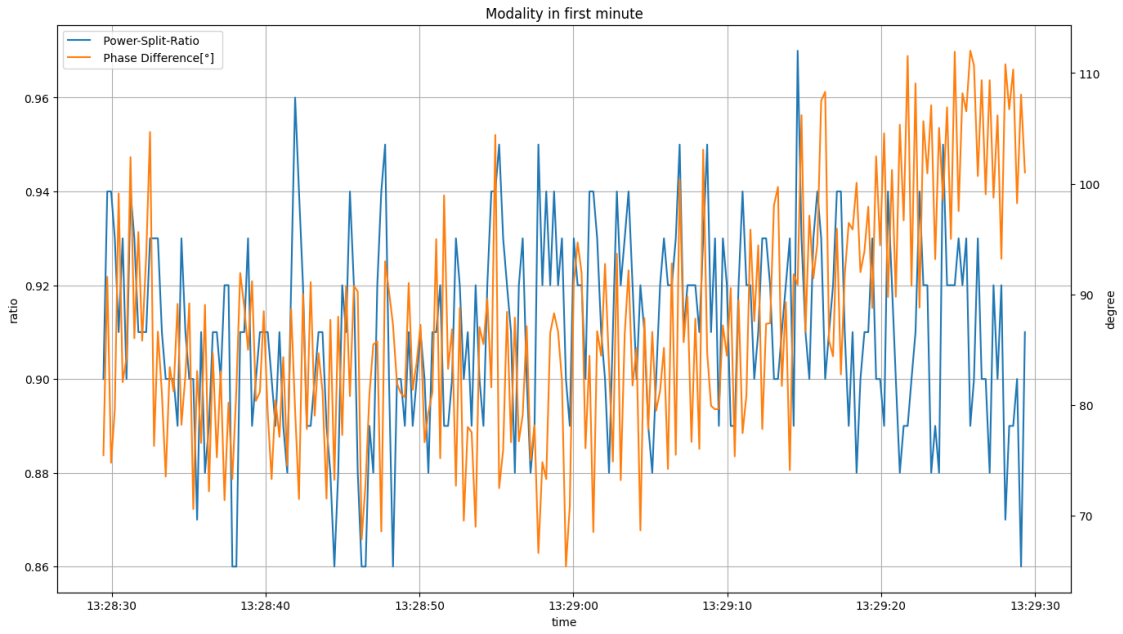
[87]:
```
first_second = modality.loc[(modality.index >= start_time) & (modality.index <␣
↪end_time_second)]

fig, ax1 = plt.subplots(figsize=(16, 9))
```

```
ax1.plot(first_second.index, first_second[columns[20]], color='tab:blue',␣
 ↪label=columns[20])
ax1.set_xlabel('time')
ax1.set_ylabel('ratio')
ax1.grid()

ax2 = ax1.twinx()
ax2.plot(first_second.index, first_second[columns[21]], color='tab:orange',␣
 ↪label=columns[21])
ax2.set_ylabel('degree')

plt.title('Modality in first second')

lines_1, labels_1 = ax1.get_legend_handles_labels()
lines_2, labels_2 = ax2.get_legend_handles_labels()
plt.legend(lines_1 + lines_2, labels_1 + labels_2, loc='best')

plt.show()
```



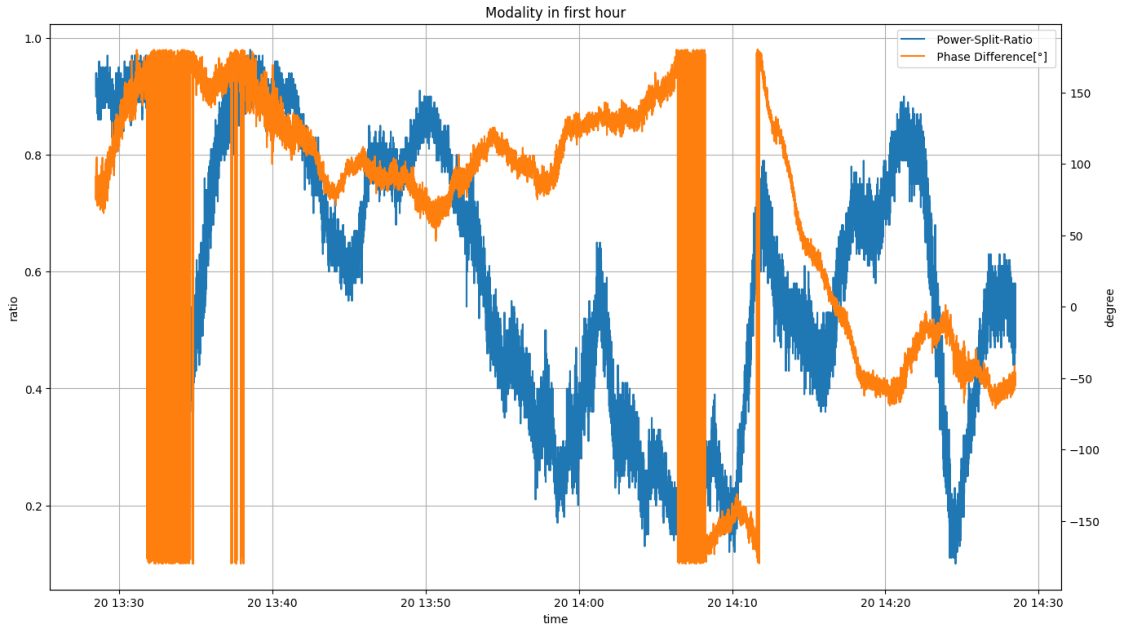
[88]:
```
first_minute = modality.loc[(modality.index >= start_time) & (modality.index <␣
 ↪end_time_minute)]

fig, ax1 = plt.subplots(figsize=(16, 9))
```

```
ax1.plot(first_minute.index, first_minute[columns[20]], color='tab:blue',␣
 ↪label=columns[20])
ax1.set_xlabel('time')
ax1.set_ylabel('ratio')
ax1.grid()

ax2 = ax1.twinx()
ax2.plot(first_minute.index, first_minute[columns[21]], color='tab:orange',␣
 ↪label=columns[21])
ax2.set_ylabel('degree')

plt.title('Modality in first minute')

lines_1, labels_1 = ax1.get_legend_handles_labels()
lines_2, labels_2 = ax2.get_legend_handles_labels()
plt.legend(lines_1 + lines_2, labels_1 + labels_2, loc='best')

plt.show()
```



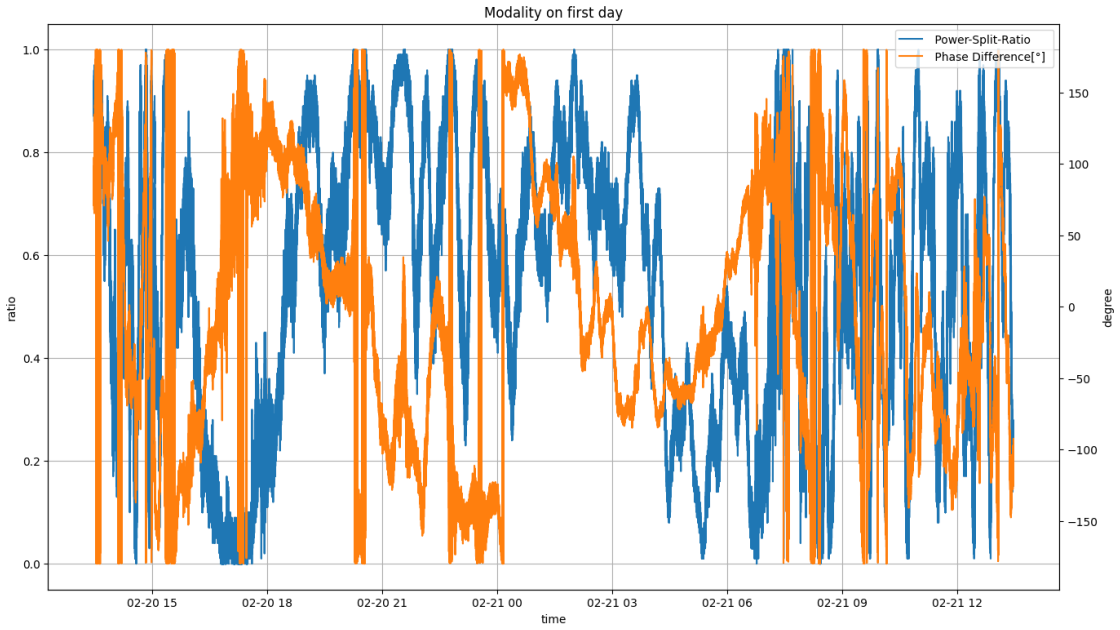
[89]:
```
first_hour = modality.loc[(modality.index >= start_time) & (modality.index <␣
 ↪end_time_hour)]

fig, ax1 = plt.subplots(figsize=(16, 9))

ax1.plot(first_hour.index, first_hour[columns[20]], color='tab:blue',␣
 ↪label=columns[20])
```

```
ax1.set_xlabel('time')
ax1.set_ylabel('ratio')
ax1.grid()

ax2 = ax1.twinx()
ax2.plot(first_hour.index, first_hour[columns[21]], color='tab:orange',␣
 ↪label=columns[21])
ax2.set_ylabel('degree')

plt.title('Modality in first hour')

lines_1, labels_1 = ax1.get_legend_handles_labels()
lines_2, labels_2 = ax2.get_legend_handles_labels()
plt.legend(lines_1 + lines_2, labels_1 + labels_2, loc='best')

plt.show()
```



[90]:
```
first_day = modality.loc[(modality.index >= start_time) & (modality.index <␣
 ↪end_time_day)]

fig, ax1 = plt.subplots(figsize=(16, 9))

ax1.plot(first_day.index, first_day[columns[20]], color='tab:blue',␣
 ↪label=columns[20])
ax1.set_xlabel('time')
ax1.set_ylabel('ratio')
```

```
ax1.grid()

ax2 = ax1.twinx()
ax2.plot(first_day.index, first_day[columns[21]], color='tab:orange',␣
 ↪label=columns[21])
ax2.set_ylabel('degree')

plt.title('Modality on first day')

lines_1, labels_1 = ax1.get_legend_handles_labels()
lines_2, labels_2 = ax2.get_legend_handles_labels()
plt.legend(lines_1 + lines_2, labels_1 + labels_2, loc='best')

plt.show()
```



[91]:
```
modality_seconds_resample = modality.resample('s').mean()
```

[92]:
```
fig, ax1 = plt.subplots(figsize=(16, 9))

ax1.plot(modality_seconds_resample.index,␣
 ↪modality_seconds_resample[columns[20]], color='tab:blue', label=columns[20])
ax1.set_xlabel('time')
ax1.set_ylabel('ratio')
ax1.grid()

ax2 = ax1.twinx()
```

```
ax2.plot(modality_seconds_resample.index,␣
 ↪modality_seconds_resample[columns[21]], color='tab:orange',␣
 ↪label=columns[21])
ax2.set_ylabel('degree')

plt.title('Secondly resampled modality of full measurement')

lines_1, labels_1 = ax1.get_legend_handles_labels()
lines_2, labels_2 = ax2.get_legend_handles_labels()
plt.legend(lines_1 + lines_2, labels_1 + labels_2, loc='best')

plt.show()
```