APL_6_cell

June 28, 2021

[1]:
```
if True:
    import numpy as np
    import pandas as pd
    from scipy.optimize import curve_fit

    # Add lab library
    import sys
    sys.path.insert(0, '/home/trevormjs/Documents/Science/APL/Lab')

    #----------------------------------------------------------------------#
    #                        matplotlib plotting                           #
    #----------------------------------------------------------------------#
    import matplotlib.pyplot as plt
    import matplotlib as mpl
    from jupyterthemes import jtplot
    from Helper.plotting import my_graph
    # Edit the font, font size, and axes width
    # mpl.rcParams['font.family'] = 'Avenir'
    plt.rcParams['font.size'] = 24
    plt.rcParams['axes.linewidth'] = 2
    jtplot.style(theme='monokai', context='notebook', ticks=False, grid=False)

    #----------------------------------------------------------------------#
    #                           bokeh plotting                             #
    #----------------------------------------------------------------------#
    from bokeh.plotting import figure, show, output_notebook
    from bokeh.themes import Theme
    from bokeh.io import curdoc, export_png
    from bokeh.models import (Range1d, Label, ColumnDataSource, LabelSet,
                              Legend)
    from Helper.plotting import style
    output_notebook()
    # curdoc().theme = Theme(filename="../Helper/theme.yml")

    #----------------------------------------------------------------------#
    #                          plotly plotting                             #
    #----------------------------------------------------------------------#
    import plotly.express as ex

    #-------------------------------------------------------------------#
    #                       error and unit handling                      #
    #-------------------------------------------------------------------#
    from uncertainties import ufloat
    import Helper.numbers as nu
    from Helper.record import Measurement, Unit

    %load_ext autoreload
    %autoreload 2
```

1 Measure Inductance

[2]:

```
def get_oscillation_start(data):
    on_end_ind = data.loc[data.mV > 5].index[-1]
    off_end_ind = data.loc[(data.mV < .5)
                           & (data.mV > 0)].index[-1]
    return data.loc[on_end_ind:off_end_ind]
```

1.1 Data

1.1.1 Measurements

[3]:

```
# Inductances and uncertainties
R_A, R_B = 17.22, 17.41 # Ohms
```

[4]:

```
C_standard = 47.23e-9
C_standard = ufloat(C_standard, C_standard*.03)
```

[68]:

```
nu.print_unc(C_standard)
```

```
0.000000047 +- 0.000000001
```

[68]:

```
(4.7e-08, 1e-09, 9)
```

1.1.2 Load

[5]:

```
[[A_circuit, A_circuit_config]] = nu.read_scope_csv('./Data/16_A_A1.csv')

[[B_circuit, B_circuit_config]] = nu.read_scope_csv('./Data/16_A_B1.csv')
```

```
{'record_length': [2500.0, 'Points'],
 'sample_interval': [2e-06, 's'],
 'trigger_point': [459.999982265, 'Samples']}

{'record_length': [2500.0, 'Points'],
 'sample_interval': [2e-06, 's'],
 'trigger_point': [520.000002728, 'Samples']}
```

[6]:

```
[[A_circuit_short, A_circuit_short_config]] = nu.read_scope_csv('./Data/16_A_A2.
↪csv')

[[B_circuit_short, B_circuit_short_config]] = nu.read_scope_csv('./Data/16_A_B2.
↪csv')
```

```
{'record_length': [2500.0, 'Points'],
 'sample_interval': [4.0000000467e-07, 's'],
 'trigger_point': [-1700.0001, 'Samples']}
```

```
{'record_length': [2500.0, 'Points'],
 'sample_interval': [4.0000000467e-07, 's'],
 'trigger_point': [-2270.0, 'Samples']}
```

1.2 Plot

1.2.1 Process

[7]:

```
a = get_oscillation_start(A_circuit)
a.insert(0, 'AB', 'A')
b = get_oscillation_start(B_circuit)
b.insert(0, 'AB', 'B')
ab = pd.concat([a, b])
ab.index = range(ab.shape[0])
```

[8]:

```
short_a = A_circuit_short.copy()
short_a.insert(0, 'AB', 'A')

short_b = B_circuit_short.copy()
short_b.insert(0, 'AB', 'B')

short = pd.concat([short_a, short_b])
short.index = range(short.shape[0])
```

1.2.2 Show

[9]:

```
def plotly_style(fig):
    fig.update_layout(
        font={'size': 26},
        xaxis={
            'linecolor': 'black',
            'linewidth': 2,
            'mirror': True
        },
        yaxis={
            'linecolor': 'black',
            'linewidth': 2,
            'mirror': True
        },
        plot_bgcolor='rgba(0,0,0,0)',
        legend={'title': ''}
    )
```

[10]:
```
fig = ex.line(short, 'ts','mV', color = 'AB', labels = {
                     "ts": "t (s)"
                 })
plotly_style(fig)
fig.write_image('../Images/16_uncoupled_short_window.png')
fig
```

[11]:
```
fig = ex.line(ab, 'ts', 'mV', color='AB', labels={
    "ts": "t (s)"
})
plotly_style(fig)
fig.write_image('../Images/16_uncoupled_full_window.png')
fig
```

1.3 Fit

[12]:
```
def my_sine(x, a, b, c):
    return a*np.sin(b*x+c)

def my_exp(x, d):
    return np.exp(-d/2*x)

def sine_with_offset(x, a, b, c, offset):
    return my_sine(x, a, b, c) + offset

def damped_oscillation_with_offset(x, a, b, c, d, offset):
    return my_sine(x, a, b, c) * my_exp(x, d) + offset
```

1.3.1 Short

A

[60]:
```
A_circuit_short = A_circuit_short.loc[(A_circuit_short.ts > 0.0009752) &
                                      (A_circuit_short.ts < 0.0014119)]

[a, b, c, offset], pcov = pop, pcov = curve_fit(
    sine_with_offset,
    A_circuit_short.ts,
    A_circuit_short.mV,
    maxfev=1000
)

while c < -2*np.pi:
    c += 2*np.pi
    pop[2] += 2*np.pi
```

```
A_circuit_short['fit'] = [
    sine_with_offset(x, *pop) for x in A_circuit_short.ts]

fig = figure(height=400)
fig.scatter(A_circuit_short.ts*1e3,
            A_circuit_short.mV,
            color='red',
            legend_label='data')
fig.line(A_circuit_short.ts*1e3,
         A_circuit_short.fit,
         color='black',
         line_width=3,
         legend_label=f"{pop[0]:.2f}cos({pop[1]:.0f} * t + {pop[2]:.2f})")

style(fig)

fig.yaxis.axis_label = 'mV'
fig.xaxis.axis_label = 't (ms)'
fig.y_range = Range1d(-3.2, 6.2)
show(fig)
export_png(fig, filename='../Images/16_channel_A_one_period_fit.png')
```

```
[60]: '/home/trevormjs/Documents/Science/APL/Lab/Images/16_channel_A_one_period_fit.pn
      g'
```

[61]:
```
np.sqrt(np.diag(pcov))
```

```
[61]: array([4.74084131e-03, 2.52718292e+01, 3.01097351e-02, 5.90134507e-03])
```

[64]:
```
a_short_unc = np.sqrt(np.diag(pcov))[1] # [amp, omega, phi, offset]

omega_a_short = ufloat(b, a_short_unc)

print(omega_a_short)

L_a_short = 1/(omega_a_short**2*C_standard)

u = nu.print_unc(L_a_short)
```

```
14661+/-25
0.099 +- 0.003
```

[58]:
```
omega_a_short
```

```
[58]: -14608.317168155214+/-0.6038170056685077
```

B

[65]:

```
B_circuit_short = B_circuit_short.loc[(B_circuit_short.ts > 0.0009752) &
                                      (B_circuit_short.ts < 0.0014119)]

[a, b, c, offset], pcov = pop, pcov = curve_fit(
    sine_with_offset,
    B_circuit_short.ts,
    B_circuit_short.mV,
    maxfev=1000
)

while c < -2*np.pi:
    c += 2*np.pi
    pop[2] += 2*np.pi

B_circuit_short['fit'] = [
    sine_with_offset(x, *pop) for x in B_circuit_short.ts]

fig = figure(height=400)
fig.scatter(B_circuit_short.ts*1e3,
            B_circuit_short.mV,
            color='red',
            legend_label='data')
fig.line(B_circuit_short.ts*1e3,
         B_circuit_short.fit,
         color='black',
         line_width=3,
         legend_label=f"{pop[0]:.2f}cos({pop[1]:.0f} * t + {pop[2]:.2f})")

style(fig)

fig.yaxis.axis_label = 'mV'
fig.xaxis.axis_label = 't (ms)'
fig.y_range = Range1d(-3.2, 6.2)
show(fig)
export_png(fig, filename='../Images/16_channel_B_one_period_fit.png')
```

[65]:

```
'/home/trevormjs/Documents/Science/APL/Lab/Images/16_channel_B_one_period_fit.pn
g'
```

[66]:

```
b_short_unc = np.sqrt(np.diag(pcov))[1] # [amp, omega, phi, offset]

omega_b_short = ufloat(b, b_short_unc)

L_b_short = 1/(omega_b_short**2*C_standard)

u = nu.print_unc(L_b_short)
```

```
0.101 +- 0.003
```

[67]:
```
omega_b_short
```

[67]:
```
-14459.904212734504+/-28.01755162920532
```

1.3.2 Full

[90]:
```
fits = pd.DataFrame(index = ['A','$\omega$','$\phi$','$\gamma$','offset'])
```

A

[91]:
```
A_circuit = get_oscillation_start(A_circuit)

[a, b, c, d, offset], pcov = pop, pcov = curve_fit(
    damped_oscillation_with_offset,
    A_circuit.ts,
    A_circuit.mV,
    maxfev=10000,
    p0=[0, b, c, 0, offset]
)

if 'fit' not in A_circuit.columns:
    A_circuit.insert(2, 'fit', [
        damped_oscillation_with_offset(
            x, *pop
        ) for x in A_circuit.ts
    ])
else:
    A_circuit['fit'] = [
        damped_oscillation_with_offset(
            x, *pop
        ) for x in A_circuit.ts
    ]
fits.insert(0, 'A', pop)
A_omega = ufloat(b, pcov[1].mean())
A_gamma = ufloat(d, pcov[-2].mean())
```

[92]:
```
fig = figure(height=400)
fig.scatter(A_circuit.ts*1e3,
            A_circuit.mV,
            color='red',
            legend_label='Data')

fig.line(A_circuit.ts*1e3,
         A_circuit.fit,
         color='black',
         line_width=3,
         legend_label=f"{pop[0]:.2f}cos({pop[1]:.0f}*t + {pop[2]:.2f})␣
 ↪exp(-{pop[3]:.0f}/2*x)")
```

```
fig.xaxis.axis_label = 't (ms)'
fig.y_range = Range1d(-5, 8.8)
style(fig)
fig.yaxis.axis_label = 'mV'
fig.xaxis.axis_label = 't (ms)'
show(fig)
export_png(fig, filename='../Images/16_channel_A_full_fit.png')
```

```
[92]: '/home/trevormjs/Documents/Science/APL/Lab/Images/16_channel_A_full_fit.png'
```

B

```
[93]: B_circuit = get_oscillation_start(B_circuit)

      [a, b, c, d, offset], pcov = pop, pcov = curve_fit(
          damped_oscillation_with_offset,
          B_circuit.ts,
          B_circuit.mV,
          maxfev=10000,
          p0=[0, b, c, 0, offset]
      )

      if 'fit' not in B_circuit.columns:
          B_circuit.insert(2, 'fit', [
              damped_oscillation_with_offset(x, *pop) for x in B_circuit.ts])
      else:
          B_circuit['fit'] = [
              damped_oscillation_with_offset(x, *pop) for x in B_circuit.ts]
      fits.insert(0, 'B', pop)
      B_omega = ufloat(b, pcov[1].mean())
      B_gamma = ufloat(d, pcov[-2].mean())
```

```
[94]: fig = figure(title='B fit', height=400)
      fig.scatter(B_circuit.ts*1e3,
                  B_circuit.mV,
                  color='red',
                  legend_label='Data')

      fig.line(B_circuit.ts*1e3,
               B_circuit.fit,
               color='black',
               line_width=3,
               legend_label=f"{pop[0]:.2f}cos({-pop[1]:.0f}*t + {pop[2]:.2f})␣
       ↪exp(-{pop[3]:.0f}/2*x)")
      fig.xaxis.axis_label = 't (ms)'
      fig.y_range = Range1d(-5, 9)
      style(fig)
```

```
fig.yaxis.axis_label = 'mV'
fig.xaxis.axis_label = 't (ms)'
show(fig)
export_png(fig, filename='../Images/l6_channel_B_full_fit.png')
```

```
[94]: '/home/trevormjs/Documents/Science/APL/Lab/Images/l6_channel_B_full_fit.png'
```

1.4 Calculations

```
[75]: Ls = 1/(fits.iloc[1]**2*C_standard)
      fits.loc['$L$'] = Ls
```

```
[77]: fits
```

```
[77]:                         B                A
      A                4.501309         4.466655
      $\omega$      -14578.44002    -14587.045274
      $\phi$           15.853028        15.643011
      $\gamma$        651.265721       649.911187
      offset            0.199547         0.193248
      $L$       0.0996+/-0.0030  0.0995+/-0.0030
```

```
[24]: _ = nu.print_unc(L_a_short), nu.print_unc(L_b_short)
      print('L and uncertainty for one Period of wave')
```

```
0.099 +- 0.003
0.101 +- 0.003
L and uncertainty for one Period of wave
```

```
[78]: _ = nu.print_unc(A_omega), nu.print_unc(B_omega)
      _ = nu.print_unc(fits.iloc[-1, 0]), nu.print_unc(fits.iloc[-1, 1])
      print('L and uncertainty for full wave')
```

```
-14587.05 +- 0.03
-14578.44 +- 0.03
0.100 +- 0.003
0.100 +- 0.003
L and uncertainty for full wave
```

```
[26]: L1, L2 = fits.iloc[-1].tolist()
```

```
[27]: fits.loc['$L$'] = [Measurement(L.n, L.s, Unit(*' H')) for L in Ls]
      fits
```

```
[27]:                         B                A
      A                4.501309         4.466655
      $\omega$      -14578.44002    -14587.045274
      $\phi$           15.853028        15.643011
      $\gamma$        651.265721       649.911187
```

```
offset            0.199547           0.193248
$L$       0.1 +/- 0.003  H  0.1 +/- 0.003  H
```

[79]:
```
L1, L2
```

[79]:
```
(0.09962307569440526+/-0.0029886922708321573,
 0.09950557018408814+/-0.002985167105522644)
```

[28]:
```
fits.insert(0, 'Parameter', fits.index)
```

[29]:
```
print(fits.drop('offset', 0).to_latex(index=False, ))
fits.iloc[:, 1:]
```

```
\begin{tabular}{lll}
\toprule
Parameter &                B &                A \\
\midrule
        A &         4.501309 &         4.466655 \\
 \$\textbackslash omega\$ &      -14578.44002 &    -14587.045274 \\
   \$\textbackslash phi\$ &         15.853028 &         15.643011 \\
 \$\textbackslash gamma\$ &        651.265721 &        649.911187 \\
      \$L\$ & 0.1 +/- 0.003  H & 0.1 +/- 0.003  H \\
\bottomrule
\end{tabular}
```

[29]:
```
                          B                  A
A                  4.501309           4.466655
$\omega$       -14578.44002      -14587.045274
$\phi$            15.853028          15.643011
$\gamma$         651.265721         649.911187
offset             0.199547           0.193248
$L$       0.1 +/- 0.003  H  0.1 +/- 0.003  H
```

[81]:
```
fits.iloc[1]/fits.iloc[3]
```

[81]:
```
B    -22.38478
A   -22.444675
dtype: object
```

[82]:
```
22.38*.03
```

[82]:
```
0.6714
```

[102]:
```
_ = nu.print_unc(-A_omega)
nu.print_unc(-B_omega)
```

```
14587.05 +- 0.03
14578.44 +- 0.03
```

```
[102]: (14578.44, 0.03, 2)
```

```
[100]: _ = nu.print_unc(A_gamma)
       nu.print_unc(B_gamma)
```

```
649.9 +- 0.1
651.3 +- 0.1
```

```
[100]: (651.3, 0.1, 1)
```

```
[99]: _ = nu.print_unc(2/A_gamma)
      nu.print_unc(2/B_gamma)
```

```
0.0030773 +- 0.0000006
0.0030709 +- 0.0000006
```

```
[99]: (0.0030709, 6e-07, 7)
```

2 Part B and C????

There is nothing here

3 Unilateral Excitation of Coupled Oscillators

3.1 Data

```
[103]: C_A = 47.23
       C_A = ufloat(C_A, C_A*.03)
       C_B = 47.27 #uF
       C_B = ufloat(C_B, C_B*.03)
```

```
[104]: [[coupled_A, coupled_config], [coupled_B, coupled_config]] = nu.
        ↪read_scope_csv('./Data/16_D_3.csv', 2)
       coupled_A = coupled_A.loc[(coupled_A.ts > -3.5e-4) & (coupled_A.ts < .015)]
       coupled_B = coupled_B.loc[(coupled_B.ts > -3.5e-4) & (coupled_B.ts < .015)]
       coupled_A.index = range(coupled_A.shape[0])
       coupled_B.index = range(coupled_B.shape[0])
```

```
{'record_length': [2500.0, 'Points'],
 'sample_interval': [9.999999747e-06, 's'],
 'trigger_point': [330.00002983, 'Samples']}

{'record_length': [2500.0, 'Points'],
 'sample_interval': [9.999999747e-06, 's'],
 'trigger_point': [330.00002983, 'Samples']}
```

```
[105]: fig = figure(width=1200)
       fig.line(coupled_A.ts, coupled_A.mV+80, color = 'red', legend_label = 'Channel␣
        ↪A')
```

```
fig.line(coupled_A.ts, coupled_B.mV-80, color = 'blue', legend_label = 'Channel␣
 ↪B')
fig.line(coupled_A.ts, (coupled_B.mV+coupled_A.mV), color = 'purple',␣
 ↪legend_label = 'Sum')
style(fig)
fig.xaxis.axis_label='t (s)'
fig.yaxis.axis_label='mV'
show(fig)
export_png(fig, filename='../Images/16_coupled_same_graph.png')
```

[105]:

```
'/home/trevormjs/Documents/Science/APL/Lab/Images/16_coupled_same_graph.png'
```

3.2 Fits

3.2.1 Fit Sum

[106]:

```
coupled_sum = coupled_A.mV + coupled_B.mV
coupled_sum -= coupled_sum.mean()
[a, b, c, gamma_sum, offset], pcov = pop, pcov = curve_fit(
    damped_oscillation_with_offset,
    coupled_A.ts,
    coupled_sum,
    maxfev=10000,
    p0=[0, b, c, 0, offset]
)
fit = np.array([damped_oscillation_with_offset(x, *pop) for x in coupled_A.ts])
fig = figure(height=400, width=800)
fig.scatter(coupled_A.ts, coupled_sum, color='red', legend_label='data')
fig.line(coupled_A.ts, fit, color='black', line_width=3, legend_label='fit')
style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
show(fig)
export_png(fig, filename='../Images/16_coupled_sum_fit.png')
```

[106]:

```
'/home/trevormjs/Documents/Science/APL/Lab/Images/16_coupled_sum_fit.png'
```

3.2.2 Sans Decay

[107]:

```
less_decay_A = nu.fft_filter((
    coupled_A.mV - coupled_A.mV.mean()), .08
) / np.exp(-gamma_sum/2*coupled_A.ts)

less_decay_A = less_decay_A[coupled_A.ts < 0.012]

less_decay_B = nu.fft_filter((
    coupled_B.mV - coupled_B.mV.mean()), .08
) / np.exp(-gamma_sum/2*coupled_A.ts)
```

```
less_decay_B = less_decay_B #[coupled_A.ts < 0.0322]

t = coupled_A.ts
```

[108]:
```
fig = figure(height=400, width=800)

fig.line(t[less_decay_A.index],
         less_decay_A+50, color='blue',
         legend_label='Channel A', line_width=3)

fig.line(t[less_decay_B.index],
         less_decay_B-50, color='red',
         legend_label='Channel B', line_width=3)

style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
fig.legend.orientation = 'horizontal'
fig.y_range=Range1d(-100, 150)
show(fig)
export_png(fig, filename='../Images/16_channels_sans_decay.png')
```

[108]:
```
'/home/trevormjs/Documents/Science/APL/Lab/Images/16_channels_sans_decay.png'
```

3.3 Beat Fits

3.3.1 A

[117]:
```
less_decay_A
```

[117]:
```
0       25.438967
1       31.469874
2       36.132294
3       38.895423
4       39.441135
          …
1230   -53.379362
1231   -50.799687
1232   -47.543357
1233   -44.018736
1234   -40.458941
Name: ts, Length: 1235, dtype: float64
```

[118]:
```
peaks
```

[118]:
```
array([  35,   79,  123,  168,  212,  257,  302,  346,  391,  436,  480,
        526,  568,  593,  637,  681,  725,  771,  814,  860,  905,  949,
        994, 1040, 1085, 1129, 1153, 1168, 1178, 1193, 1206, 1237, 1281,
       1328, 1371, 1417, 1460, 1466, 1508])
```

[131]:

```
fig = figure(width=800, height=300)

fig.line(t[less_decay_A.index],
         less_decay_A,
         color='blue',
         legend_label='A',
         line_width=3)


peaks = nu.find_peaks(less_decay_A)[0].tolist() + nu.
 ↪find_peaks(-less_decay_A)[0].tolist()
peaks = [p for p in peaks if abs(less_decay_A[p]) > 1]

fig.scatter(t[peaks],
            np.abs(less_decay_A[peaks]),
            color='red',
            legend_label='Absolute Value of Peaks',
            size=10)

[A, omega, phase, offset], pconv = curve_fit(
    sine_with_offset,
    t[peaks],
    np.abs(less_decay_A[peaks]),
    p0=[100, 1000, 0, 100]
)

fig.line(t[less_decay_A.index],
         t[less_decay_A.index].apply(
             sine_with_offset,
             a=A,
             b=omega,
             c=phase,
             offset=offset),
         legend_label='Beat Curve Fit',
         color='black')

fig.legend.location='top_right'
fig.legend.orientation = "horizontal"
fig.y_range = Range1d(-60, 100)
style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
show(fig)
export_png(fig, filename='../Images/16_channel_A_peaks_fit.png')
```

```
[131]: '/home/trevormjs/Documents/Science/APL/Lab/Images/l6_channel_A_peaks_fit.png'
```

```
[120]: coefs, freqs = nu.fft(less_decay_A,
                             coupled_A.ts,
                             20)


       peak_inds, _ = nu.find_peaks(coefs)
       peak_inds = peak_inds[coefs[peak_inds] > 2000]
       peak_coefs = coefs[peak_inds]
       peak_freqs = freqs[peak_inds]
       print(peak_freqs)

       fig = figure(width=700, height=300)

       fig.line(freqs[::100],
                coefs[::100],
                legend_label='FFT',
                color='blue',
                line_width=4)
       fig.scatter(peak_freqs,
                   peak_coefs,
                   legend_label='FFT Peaks',
                   color='red',
                   size=10)

       fig.x_range = Range1d(1500, 3000)

       style(fig)
       fig.xaxis.axis_label = 'f (Hz)'
       fig.yaxis.axis_label = 'mV'
       show(fig)
       export_png(fig, filename='../Images/l6_channel_A_fft.png')


       omega_A_fit = omega/2/np.pi
       omega_A_fft = peak_freqs[3]-peak_freqs[2]
       omega_test_A = np.array([omega_A_fit,
                                omega_A_fft])
       try:
           u = nu.print_unc(omega_test_A.mean(),
                            omega_test_A.std())
       except:
           print(omega_test_A.mean(),
                            omega_test_A.std())

       ts = coupled_A.ts[less_decay_A.index]
```

```
beat = .5+np.cos(
    ts*(omega_A_fft)*2*np.pi + .42
)/2

fig = figure(width=700, height=300)

fig.line(ts, beat, color='black', legend_label='Beat Frequency Estimate')
fig.line(ts,
         np.abs(less_decay_A / less_decay_A.max()),
         color='red', legend_label='Absolute Value of Curve')

fig.y_range = Range1d(-.05, 1.4)
style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
fig.legend.orientation='horizontal'
show(fig)
export_png(fig, filename='../Images/l6_channel_A_fft_beat.png')
```

```
[-2324.01153525 -2154.06658241  2154.06658241  2324.01153525]
```

```
170.9 +- 0.9
```

[120]:

```
'/home/trevormjs/Documents/Science/APL/Lab/Images/l6_channel_A_fft_beat.png'
```

[134]:

```
omega_test_A.mean(), omega_test_A.std()
```

[134]:

```
(170.85983611061215, 0.914883268451149)
```

3.3.2 B

[130]:

```
fig = figure(width=800, height=300)

fig.line(t[less_decay_B.index],
         less_decay_B,
         color='blue',
         legend_label='B',
         line_width=3)

peaks = nu.find_peaks(less_decay_B)[0].tolist() + nu.
 ↪find_peaks(-less_decay_B)[0].tolist()
peaks = [p for p in peaks if abs(less_decay_B[p]) > 1]

fig.scatter(t[peaks],
            np.abs(less_decay_B[peaks]),
            color='red',
            legend_label='Absolute Value of Peaks',
            size=10)

[A, omega, phase, offset], pconv = curve_fit(
    sine_with_offset,
    t[peaks],
    np.abs(less_decay_B[peaks]),
    p0=[100, 1000, 0, 100]
)

fig.line(t[less_decay_B.index],
         t[less_decay_B.index].apply(
             sine_with_offset,
             a=A,
             b=omega,
             c=phase,
             offset=offset),
         legend_label='Beat Curve Fit',
         color='black')

fig.legend.location='top_right'
fig.legend.orientation = "horizontal"
fig.y_range = Range1d(-60, 100)
style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
show(fig)
export_png(fig, filename='../Images/16_channel_B_peaks_fit.png')
```

[130]:
```
'/home/trevormjs/Documents/Science/APL/Lab/Images/16_channel_B_peaks_fit.png'
```

[123]:
```
coefs, freqs = nu.fft(less_decay_B,
                      coupled_B.ts,
                      20)



peak_inds, _ = nu.find_peaks(coefs)
peak_inds = peak_inds[coefs[peak_inds] > 2000]
peak_coefs = coefs[peak_inds]
peak_freqs = freqs[peak_inds]
print(peak_freqs)

fig = figure(width=700, height=300)

fig.line(freqs[::100],
         coefs[::100],
         legend_label='FFT',
         color='blue',
         line_width=4)
fig.scatter(peak_freqs,
            peak_coefs,
            legend_label='FFT Peaks',
            color='red',
            size=10)

fig.x_range = Range1d(1500, 3000)

style(fig)
fig.xaxis.axis_label = 'f (Hz)'
fig.yaxis.axis_label = 'mV'
show(fig)
export_png(fig, filename='../Images/16_channel_B_fft.png')


omega_B_fit = omega/2/np.pi
omega_B_fft = peak_freqs[3]-peak_freqs[2]
omega_test_B = np.array([omega_B_fit,
                         omega_B_fft])
u = nu.print_unc(omega_test_B.mean(),
                 omega_test_B.std())

ts = coupled_B.ts[less_decay_B.index]

beat = .5+np.sin(
    ts*(omega_B_fft)*2*np.pi-1.2
)/2

fig = figure(width=700, height=300)

fig.line(ts, beat, color='black', legend_label='Beat Frequency Estimate')
fig.line(ts,
         np.abs(less_decay_B / less_decay_B.max()),
         color='red', legend_label='Absolute Value of Curve')

fig.y_range = Range1d(-.05, 1.4)
style(fig)
fig.xaxis.axis_label = 't (s)'
fig.yaxis.axis_label = 'mV'
fig.legend.orientation='horizontal'
show(fig)
export_png(fig, filename='../Images/16_channel_B_fft_beat.png')
```

```
[-2324.20227032 -2153.01753949  2153.01753949  2324.20227032]
```

```
170 +- 1
```

```
[123]: '/home/trevormjs/Documents/Science/APL/Lab/Images/16_channel_B_fft_beat.png'
```

```
[132]: omega_test_B, omega_test_A
```

```
[132]: (array([168.34289478, 171.18473084]), array([171.77471938, 169.94495284]))
```

```
[133]: omega_test = np.concatenate([omega_test_A[1:], omega_test_B])*2*np.pi
       try:
           omega = ufloat(omega_test.mean(), omega_test.std())
           u = nu.print_unc(ufloat)
       except:
           display(omega_test.mean(), omega_test.std())
       omega
```

```
1067.0368731381238

7.309310375906648
```

```
[133]: 1067.0368731381238+/-7.309310375906648
```

$$F_{beat} = \frac{1}{2\pi\sqrt{L_{avg}C_{avg}}} - \frac{1}{2\pi\sqrt{L_{avg}(C_{avg}+2C_1}}$$

$$\frac{1}{2}\left[\frac{1}{L_2\left(\frac{1}{\sqrt{L_1 C}} - \omega_{beat}\right)^2} - C\right] = C_{coupling}$$

```
[385]: C_standard
```

```
[385]: 4.723e-08+/-1.4169e-09
```

```
[387]: C_coupling_actual = 4.14
       C_coupling_actual = ufloat(C_coupling_actual, C_coupling_actual*.03)
```

```
[ ]: C_coupling = 3.85e-9 # Farads
```

```
[386]: C_avg = 1/2*(C_A + C_B)*1e-9
       C_avg
```

```
[386]: 4.725e-08+/-1.0023239521232644e-09
```

```
[415]: omega
```

```
[415]: 1067.0368717253102+/-7.309312174905129
```

```
[429]: 1/((L1*C_avg)**.5)
```

```
[429]: 13508.317437105916+/-267.8661084215638
```

[424]:

```
C_coup = .5*((1/(
    L2*(1/((L1*C_avg)**.5)-omega)**2)
    )-C_avg)
_ = nu.print_unc(C_coup*1e9)
print(C_coupling_actual)
```

```
3.9 +- 0.1
4.14+/-0.12
```

[427]:

```
4.14-.12, 3.9 + .15
```

[427]:

```
(4.02, 4.05)
```

[ ]:

```

```

4 Beats

[46]:

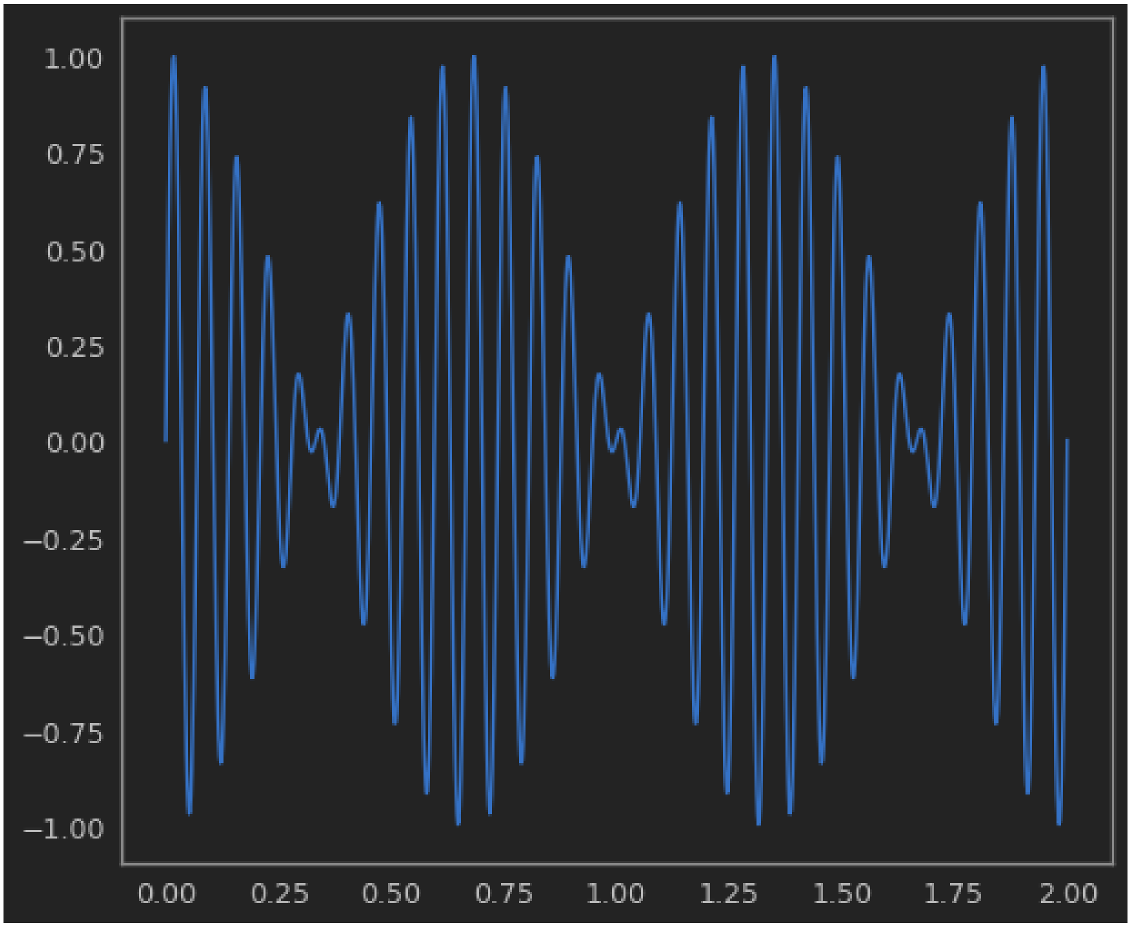
```
t = np.linspace(0, 2, 1000)
omega_plus = 15
omega_minus = 13.5
q = 1
beat = np.sin(2*np.pi*(omega_plus+omega_minus)/2*t) * \
    np.cos(2*np.pi*(omega_plus-omega_minus)/2*t)
```

[47]:

```
plt.plot(t, beat)
```

[47]:

```
[<matplotlib.lines.Line2D at 0x7fe5e456bee0>]
```


1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

```
[ ]:
```