Oscillating Circuit Analysis: Voltage Modeling

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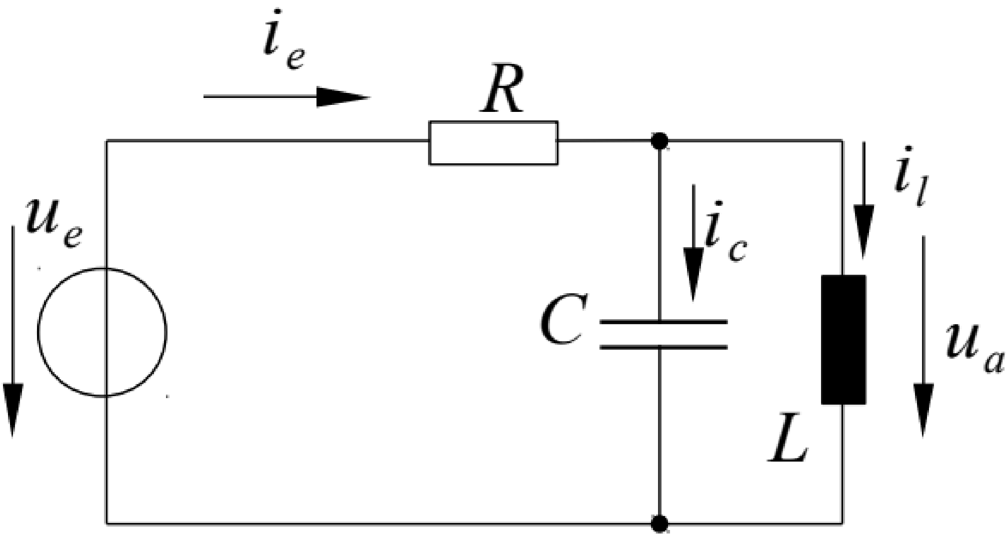


$$u_e(t) = \hat{u} \sin(2\pi f t)$$

```
In [ ]:
from math import pi
import numpy as np
import matplotlib.pyplot as plt
from scipy import signal as sig
from scipy import integrate as sci
from OMPython import ModelicaSystem
import pandas as pd
```

```
In [ ]:
VOLTAGE_MAX =   2       # V
FREQUENCY   =   1       # Hz
RESISTOR    =   20      # Ohm
COIL        =   9e-3    # H
CAPACITOR   =   1000e-6 # F

TOTALTIME   =   2       # s
TIMESTEP    =   1e-3    # s
time = np.arange(0, TOTALTIME, TIMESTEP)

plt.rcParams['axes.grid'] = True
```

Solving ODE with SCIPY

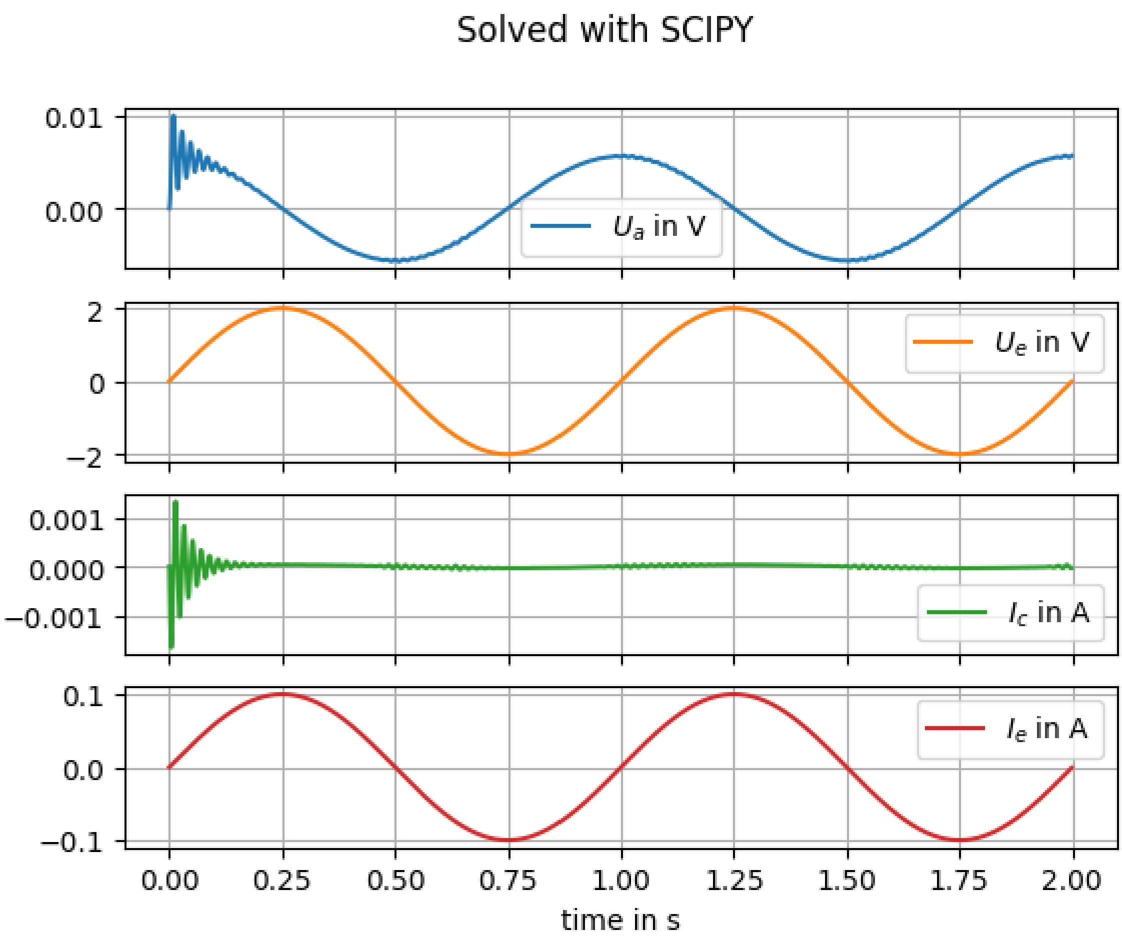
Das Entfernen von `method='LSODA'` hat keinen Effekt. Die Scipy-Funktion wählt eigenständig eine geeignete Methode aus.

Die Energie wird zwischen Kondensator und Spule periodisch ausgetauscht. Ihr komplexer Widerstand kompensiert sich. Bei ausreichender Kompensation dominiert der ohmsche Verbraucher.

In [ ]:
```
SYSTEM_ARRAY=np.array([[-1/(RESISTOR*CAPACITOR),    -1/CAPACITOR],
                                        [1/COIL,    0]])
INPUT_ARRAY=np.array([[1/(RESISTOR*CAPACITOR)],
                                           [0]])
OUTPUT_ARRAY=np.array([[           1,    0],
                        [           0,    1],
                        [-1/RESISTOR,    0]])
TRANSIT_ARRAY=np.array([         [0],
                                  [0],
                        [1/RESISTOR]])

INITIAL_STATE = np.array([0,0])     # [outputvoltage, outputcurrent]

def input_voltage(time):
    return VOLTAGE_MAX * np.sin(2 * pi * FREQUENCY * time)

def state_derivative(time, state):
    state=np.reshape(state, (2,1))
    state_derivative = SYSTEM_ARRAY.dot(state) + INPUT_ARRAY * input_voltage(tim
    return np.reshape(state_derivative, (1,2))

def output(state, time):
    return OUTPUT_ARRAY.dot(state) + TRANSIT_ARRAY * input_voltage(time)

ode_solution = sci.solve_ivp(state_derivative, [0, TOTALTIME], INITIAL_STATE, t_

results = output(ode_solution, time)
```

In [ ]:
```
task1 = pd.DataFrame({
    "time in s":    time,
    "$U_a$ in V":   results[0],
    "$U_e$ in V":   input_voltage(time),
    "$I_c$ in A":   results[1] - results[2],
    "$I_e$ in A":   results[2],
})
task1 = task1.set_index("time in s")

task1.plot(subplots=True, title="Solved with SCIPY")
```

Out[ ]:
```
array([<Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>,
       <Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>],
      dtype=object)
```



Solving ODE with Open-Modelica and Constants

Unresolved Error in I_a. It behaves the same as I_e, but an amplitude close to $0A$ for $t > 0.25s$ is expected. The model solution is probably not retuned correctly.

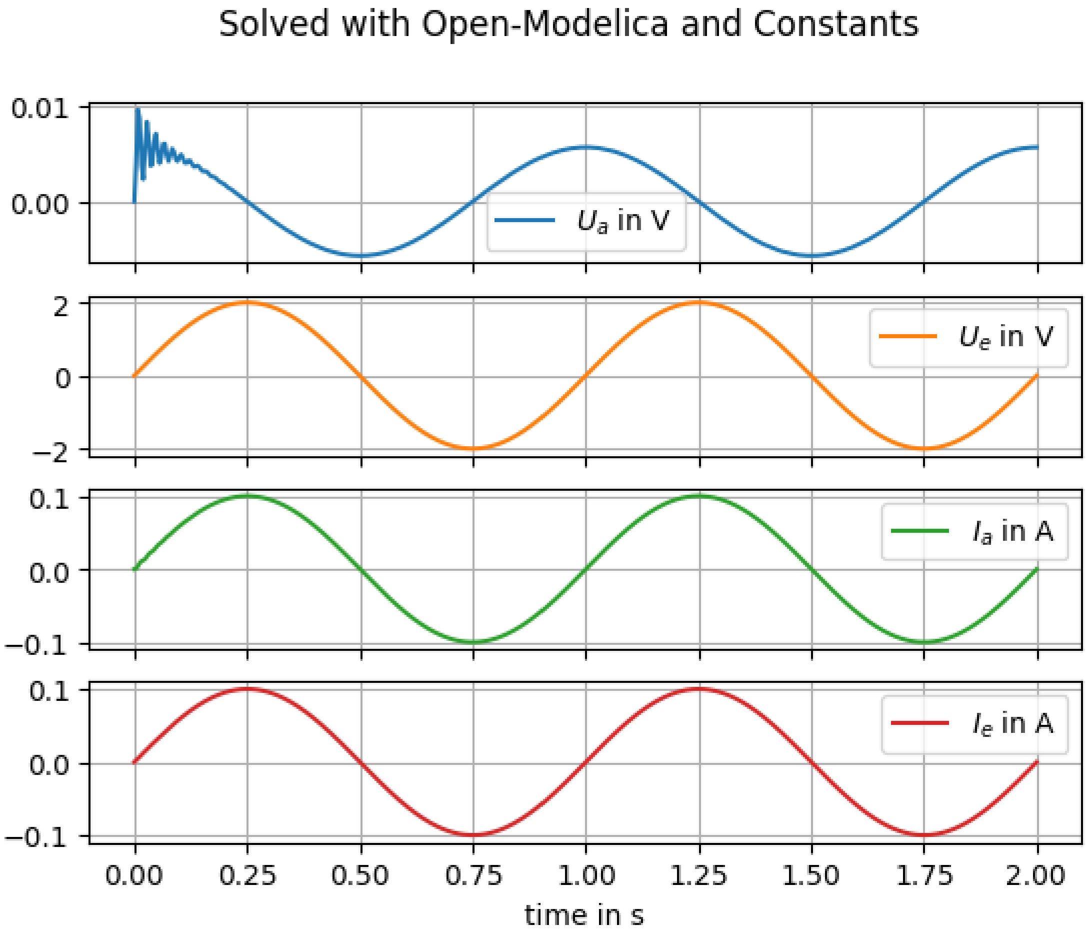
In [ ]:
```
modelname = "resonant_circuit"
model = ModelicaSystem(modelname+".mo", modelname)
model.setSimulationOptions('stopTime=2.0')

model.simulate()
```

```
Notification: Automatically loaded package Complex 4.0.0 due to uses annotation f
rom Modelica.
Notification: Automatically loaded package ModelicaServices 4.0.0 due to uses ann
otation from Modelica.
Notification: Automatically loaded package Modelica 4.0.0 due to usage.
Warning: The initial conditions are not fully specified. For more information set
-d=initialization. In OMEdit Tools->Options->Simulation->Show additional informat
ion from the initialization process, in OMNotebook call setCommandLineOptions("-d
=initialization").
```

In [ ]:
```
task2 = pd.DataFrame({
    "time in s":    model.getSolutions('time').ravel(),
    "$U_a$ in V":   model.getSolutions("u_a").ravel(),
    "$U_e$ in V":   model.getSolutions("u_e").ravel(),
    "$I_a$ in A":   model.getSolutions("i_L").ravel(),
    "$I_e$ in A":   model.getSolutions("i_e").ravel(),
})
```

```
task2 = task2.set_index("time in s")

task2.plot(subplots=True, title="Solved with Open-Modelica and Constants")
```

Out[ ]:
```
array([<Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>,
       <Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>],
      dtype=object)
```



Solving ODE with Open-Modelica and Variable Parameters

In [ ]:
```
modelname = "blockdiagram"
model = ModelicaSystem(modelname+".mo", modelname)
model.setSimulationOptions('stopTime=2.0')
model.setParameters(f'resistor1.R={RESISTOR}')
model.setParameters(f'inductor1.L={COIL}')
model.setParameters(f'capacitor1.C={CAPACITOR}')

model.simulate()
```

```
Exception ignored in: <function ModelicaSystem.__del__ at 0x000001F3C4DE4FE0>
Traceback (most recent call last):
  File "c:\Users\janho\scoop\apps\python\current\Lib\site-packages\OMPython\__ini
t__.py", line 862, in __del__
    OMCSessionBase.__del__(self)
  File "c:\Users\janho\scoop\apps\python\current\Lib\site-packages\OMPython\__ini
t__.py", line 172, in __del__
    self._omc_log_file.close()
    ^^^^^^^^^^^^^^^^^^
AttributeError: 'ModelicaSystem' object has no attribute '_omc_log_file'
```

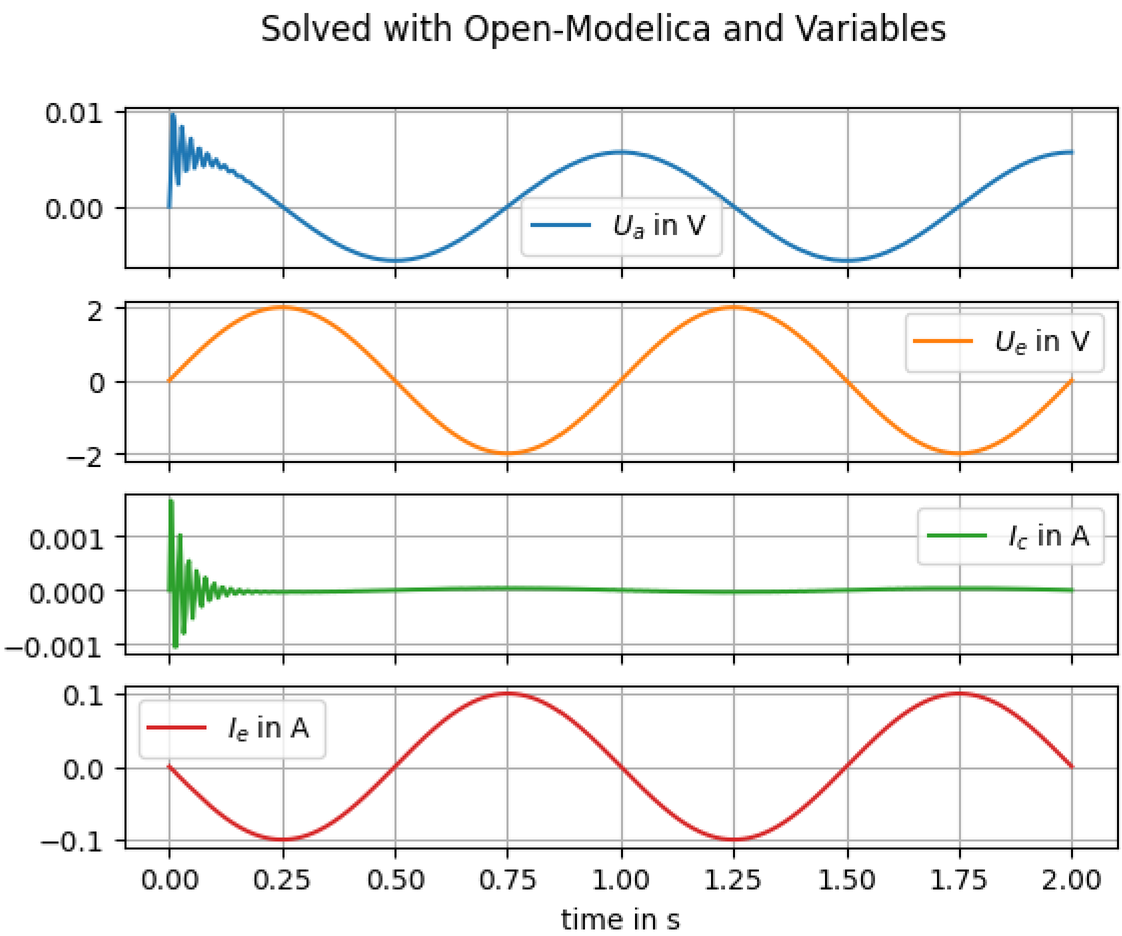
```
Notification: Automatically loaded package Complex 4.0.0 due to uses annotation f
rom Modelica.
Notification: Automatically loaded package ModelicaServices 4.0.0 due to uses ann
otation from Modelica.
Notification: Automatically loaded package Modelica 4.0.0 due to usage.
[C:/Users/janho/AppData/Roaming/.openmodelica/libraries/Modelica 4.0.0+maint.om/E
lectrical/Analog/Sources/SineVoltage.mo:5:3-5:61:writable] Warning: Parameter sin
eVoltage1.f has no value, and is fixed during initialization (fixed=true), using
available start value (start=1.0) as default value.
Warning: The initial conditions are not fully specified. For more information set
-d=initialization. In OMEdit Tools->Options->Simulation->Show additional informat
ion from the initialization process, in OMNotebook call setCommandLineOptions("-d
=initialization").
```

In [ ]:

```python
task3 = pd.DataFrame({
    "time in s":    model.getSolutions('time').ravel(),
    "$U_a$ in V":   model.getSolutions("inductor1.v").ravel(),
    "$U_e$ in V":   model.getSolutions("sineVoltage1.v").ravel(),
    "$I_c$ in A":   model.getSolutions("capacitor1.i").ravel(),
    "$I_e$ in A":   model.getSolutions("sineVoltage1.i").ravel()
})
task3 = task3.set_index("time in s")

task3.plot(subplots=True, title="Solved with Open-Modelica and Variables")
```

Out[ ]:

```
array([<Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>,
       <Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>],
      dtype=object)
```



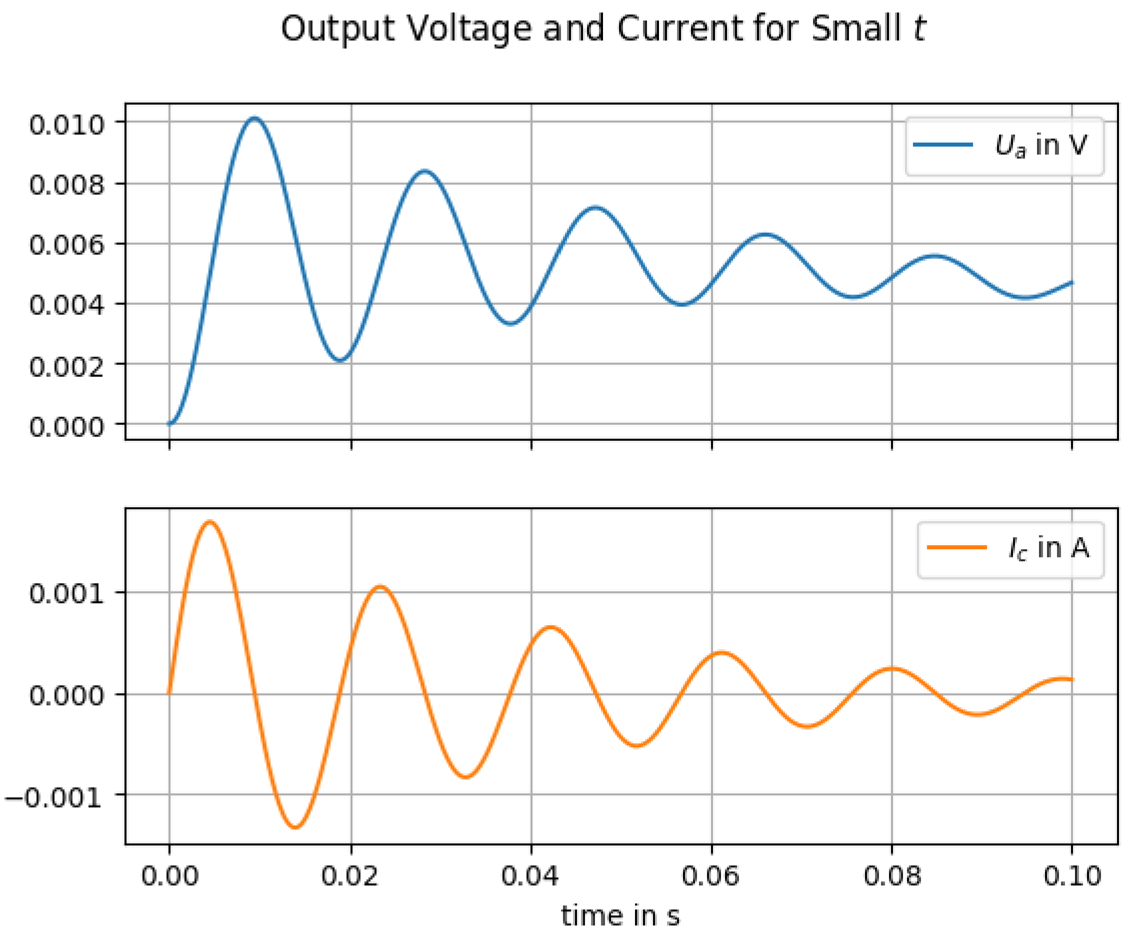
Frequencies of the Circuit

Die Eigenfrequenz ist durch $f_0 = \frac{1}{2\pi\tau}$ gekennzeichnet.

In [ ]:
```
model.setSimulationOptions('stopTime=0.1')
model.simulate()
```

In [ ]:
```
task4 = pd.DataFrame({
    "time in s":    model.getSolutions('time').ravel(),
    "$U_a$ in V":   model.getSolutions("inductor1.v").ravel(),
    "$U_e$ in V":   model.getSolutions("sineVoltage1.v").ravel(),
    "$I_c$ in A":   model.getSolutions("capacitor1.i").ravel(),
    "$I_e$ in A":   model.getSolutions("sineVoltage1.i").ravel()
})
task4 = task4.set_index("time in s")

task4.plot(subplots=True, title="Output Voltage and Current for Small $t$", y=["
```

Out[ ]:
```
array([<Axes: xlabel='time in s'>, <Axes: xlabel='time in s'>],
      dtype=object)
```



Bode Diagram and Pole Points

Mit anwenden des Spannungsteilers ergibt sich $U_a(t) = U_e(t) \cdot \frac{X_L||X_C}{R+X_L||X_C}$.

Die Übertragungsfunktion lautet demnach

$$G(s) = \frac{U_a(s)}{U_e(s)} = \frac{\frac{sL}{1+s^2LC}}{R + \frac{sl}{1+s^2LC}} = \frac{s\frac{L}{R}}{s^2LC + s\frac{L}{R} + 1}$$

und die Eigenwerte der Systemmatrix ergeben sich zu

$$\begin{pmatrix} -\frac{1}{RC} - \lambda & -\frac{1}{C} \\ \frac{1}{L} & -\lambda \end{pmatrix} = \frac{\lambda}{RC} + \lambda^2 + \frac{1}{LC}.$$

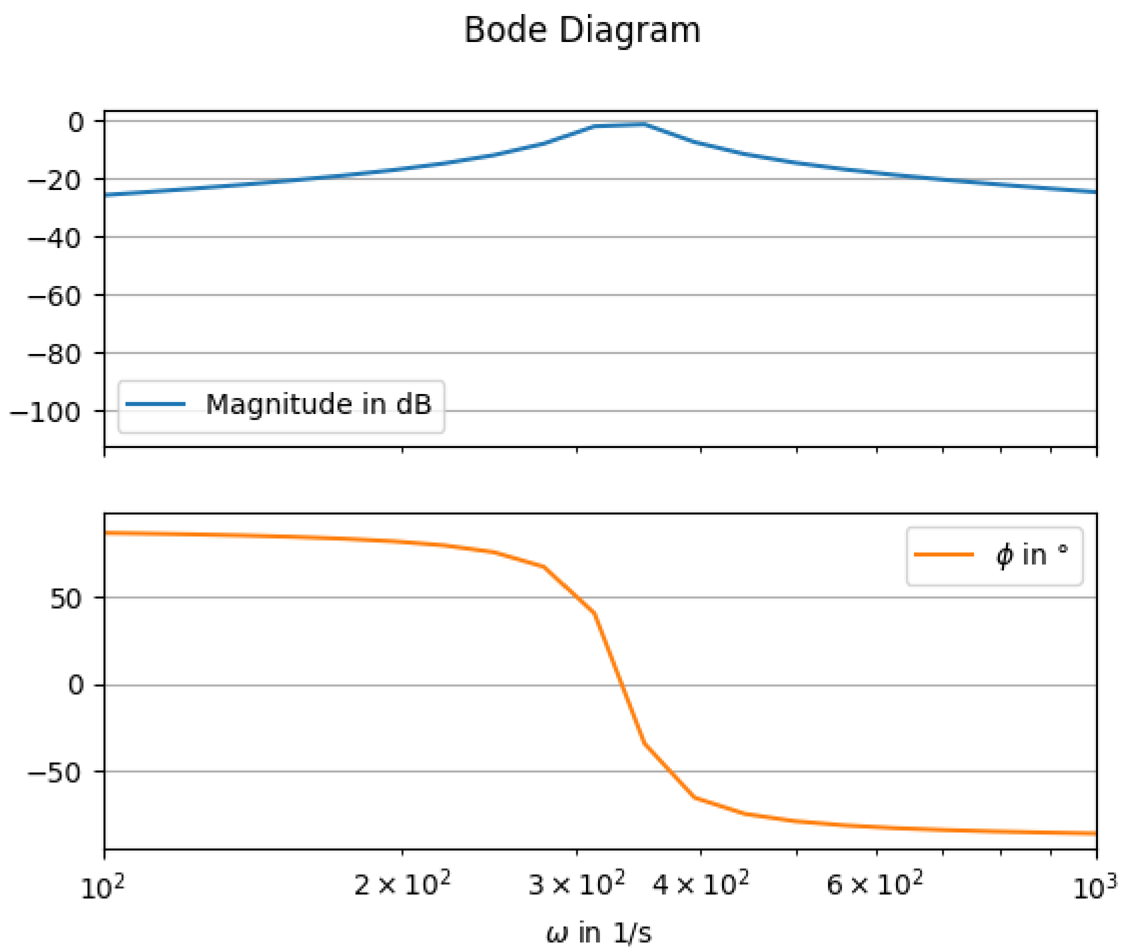
Die Eigenfrequenz wird mit $f_0 = \frac{1}{2\pi\tau} = \frac{1}{2\pi\frac{RL}{R+L}}$ berechnet.

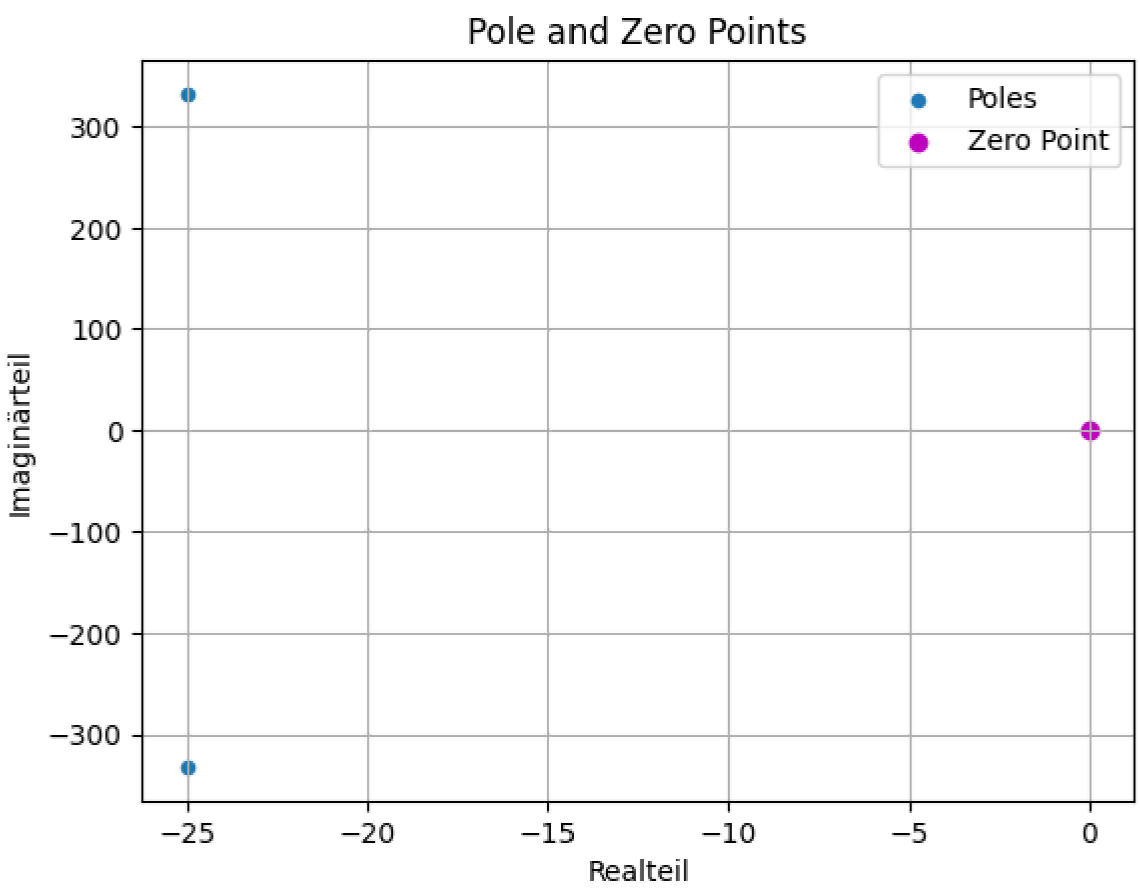
In [ ]:
```
resonant_frequency = 1 / (2 * pi * RESISTOR * COIL / ( RESISTOR + COIL ) )

NUMERATOR = [COIL / RESISTOR, 0]
DENOMINATOR = [COIL * CAPACITOR, COIL / RESISTOR, 1]

system = sig.TransferFunction(NUMERATOR, DENOMINATOR)
angular_f, magnitude, phase = sig.bode(system)
zeros = system.zeros
poles = system.poles
print(f"Poles:\t\t\t{poles}\nZero Points:\t\t{zeros}\nResonant frequency:\t{resc
```

```
Poles:                  [-25.+332.39451125j -25.-332.39451125j]
Zero Points:            [0.]
Resonant frequency:     17.691840312920746 Hz
```

In [ ]:
```
task5 = pd.DataFrame({
    r"$\omega$ in 1/s":  angular_f,
    "Magnitude in dB":  magnitude,
    r"$\phi$ in °":      phase,
})
task5 = task5.set_index(r"$\omega$ in 1/s")

task5.plot(subplots=True, title="Bode Diagram", logx=True, xlim=(100,1000))

task51 = pd.DataFrame({
    "Realteil":     poles.real,
    "Imaginärteil": poles.imag,
})
ax = task51.plot.scatter(x="Realteil",y="Imaginärteil", title="Pole and Zero Poi
ax = plt.scatter(x=0, y=zeros, label="Zero Point", color="m")
plt.legend()
```

Out[ ]:
```
<matplotlib.legend.Legend at 0x1f3c905a360>
```


Bode Diagram
0
−20
−40
−60
−80
−100
Magnitude in dB
50
0
−50
ϕ in °
10^2
2×10^2
3×10^2
4×10^2
6×10^2
10^3
ω in 1/s


Pole and Zero Points
Poles
Zero Point
300
200
100
0
−100
−200
−300
Imaginärteil
−25
−20
−15
−10
−5
0
Realteil