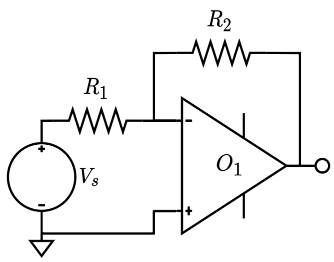
Operational amplifier circuits

1. Simple inverting op-amp

The ideal operational amplifier is supported as a 3-terminal element. Let's see how the program handles circuits with OpAmps included. The analysis is done as with any other circuit.

```
circuit = Circuit('circuits/r_op_amp.txt');
circuit.list
```

```
ans =
    'Vs 1 0 AC Vs
     R1 1 2 R1
     R2 2 3 R2
     O1 0 2 3
     '
```




```
ELAB.analyze(circuit)
```

```
Symbolic analysis successful (0.210827 sec).
```

```
circuit.symbolic_node_voltages
```

ans =

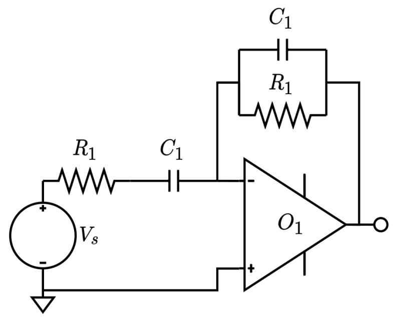
$$\begin{pmatrix} v_1 = \mathrm{Vs} \\ v_2 = 0 \\ v_3 = -\dfrac{R_2\,\mathrm{Vs}}{R_1} \end{pmatrix}$$

2. Inverting op-amp with additional reactive elements.

This is a slightly more complex example. We are still dealing with an inverting amplifier configuration.

```
circuit = Circuit('circuits/rc_op_amp.txt');
circuit.list
```

```
ans =
    'Vs 1 0 AC Vs
     R1 1 2 20000
     R2 3 4 20000
     C1 2 3 C1
     C2 3 4 C2
     O1 0 3 4
     '
```



Suppose we want to know what values for the capacitors, we need to choose, to achieve poles at $p_1 = -1000\,\mathrm{rad}/s$ and $p_2 = -5000\,\mathrm{rad}/s$.

```
ELAB.ec2sd(circuit,1,4)
```

```
Symbolic analysis successful (0.383169 sec).
Symbolic transfer function calculated successfully (3.916859e-01 sec).
ans =
```

$$\frac{v_4}{v_1} = -\frac{C_1\,R_2\,s}{(C_1\,R_1\,s+1)\,(C_2\,R_2\,s+1)}$$

From this transfer function, it is immediately apparent, that if $R_1 = R_2 = 20k\Omega$, then $C_1 = 1/1000R_1 = 0.05\mu F$ and $C_2 = 1/5000 = 0.01\mu F$.

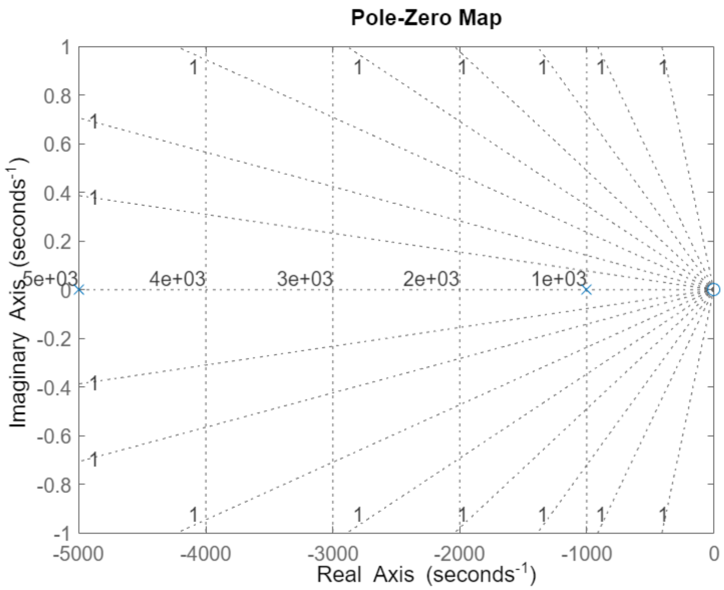
```
circuit.Capacitors(1).capacitance = 0.05e-6;
```

```
ans = 5.0000e-08
```

```
circuit.Capacitors(2).capacitance = 0.01e-6;

circuit = Circuit('circuits/rc_op_amp_num.txt');
TF = ELAB.ec2tf(circuit,1,4)
```

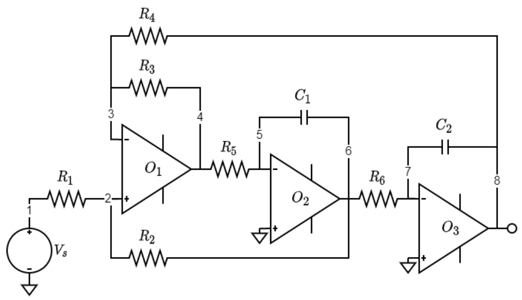
```
Symbolic analysis successful (0.350098 sec).

Numerical evaluation successful (0.0874597 sec).
Transfer function object created successfully (1.211225e-01 sec).

TF =

        -5000 s
  -------------------
  s^2 + 6000 s + 5e06

Continuous-time transfer function.
```

```
pzmap(TF); grid on;
```




```
circuit = Circuit('circuits/state_variable_filter.txt');
circuit.list
```

```
ans =
    'Vs 1 0 AC Vs
     R1 1 2 1000
     R2 2 6 19000
     R3 3 4 10000
     R4 3 8 10000
     R5 4 5 16000
     R6 6 7 16000
     C1 5 6 0.00000001
     C2 7 8 0.00000001
     O1 2 3 4
     O2 0 5 6
     O3 0 7 8
     '
```




```
bode(ELAB.ec2tf(circuit,1,4)); grid on; hold on;
```

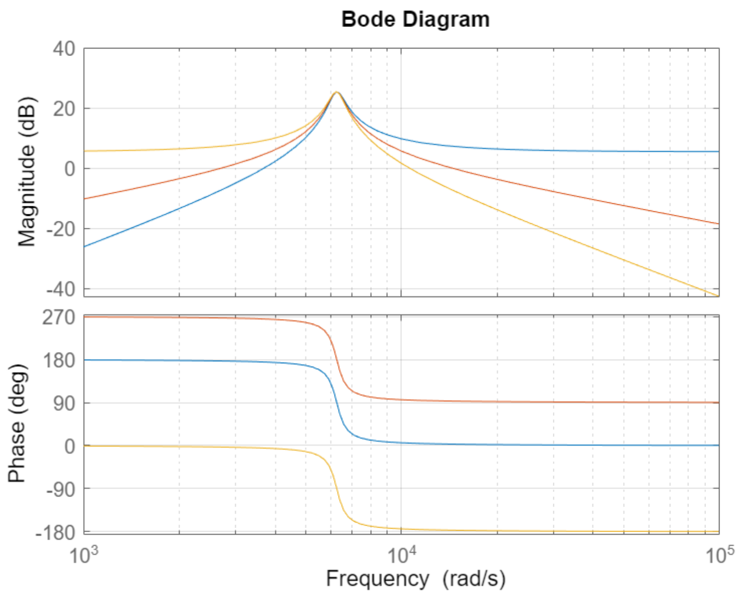
```
Symbolic analysis successful (1.07754 sec).

Numerical evaluation successful (0.241102 sec).
Transfer function object created successfully (2.675553e-01 sec).
```

```
bode(ELAB.ec2tf(circuit,1,6));
```

```
Transfer function object created successfully (2.028830e-02 sec).
```

```
bode(ELAB.ec2tf(circuit,1,8)); hold off;
```

```
Transfer function object created successfully (1.757560e-02 sec).
```




```
ELAB.ec2sd(circuit,1,8)
```

```
Symbolic transfer function calculated successfully (5.072700e-03 sec).
ans =
```

$$\frac{v_8}{v_1} = \frac{R_2\ (R_3 + R_4)}{R_1\,R_3 + R_2\,R_3 + C_2\,R_1\,R_3\,R_6\,s + C_2\,R_1\,R_4\,R_6\,s + C_1\,C_2\,R_1\,R_4\,R_5\,R_6\,s^2 + C_1\,C_2\,R_2\,R_4\,R_5\,R_6\,s^2}$$