

# Structured Electronic Design

## Operational Amplifiers: modeling

# Modeling techniques

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## Macro models

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Suppliers provide Spice simulation models for operational amplifiers

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- DC analysis for static voltage and current handling
- Statistical analysis for DC operating point

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Spice nullor model

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## Spice nullor model

Placement:

Subcircuit call  $\longrightarrow$  X1 out+ out- in+ in- nullor

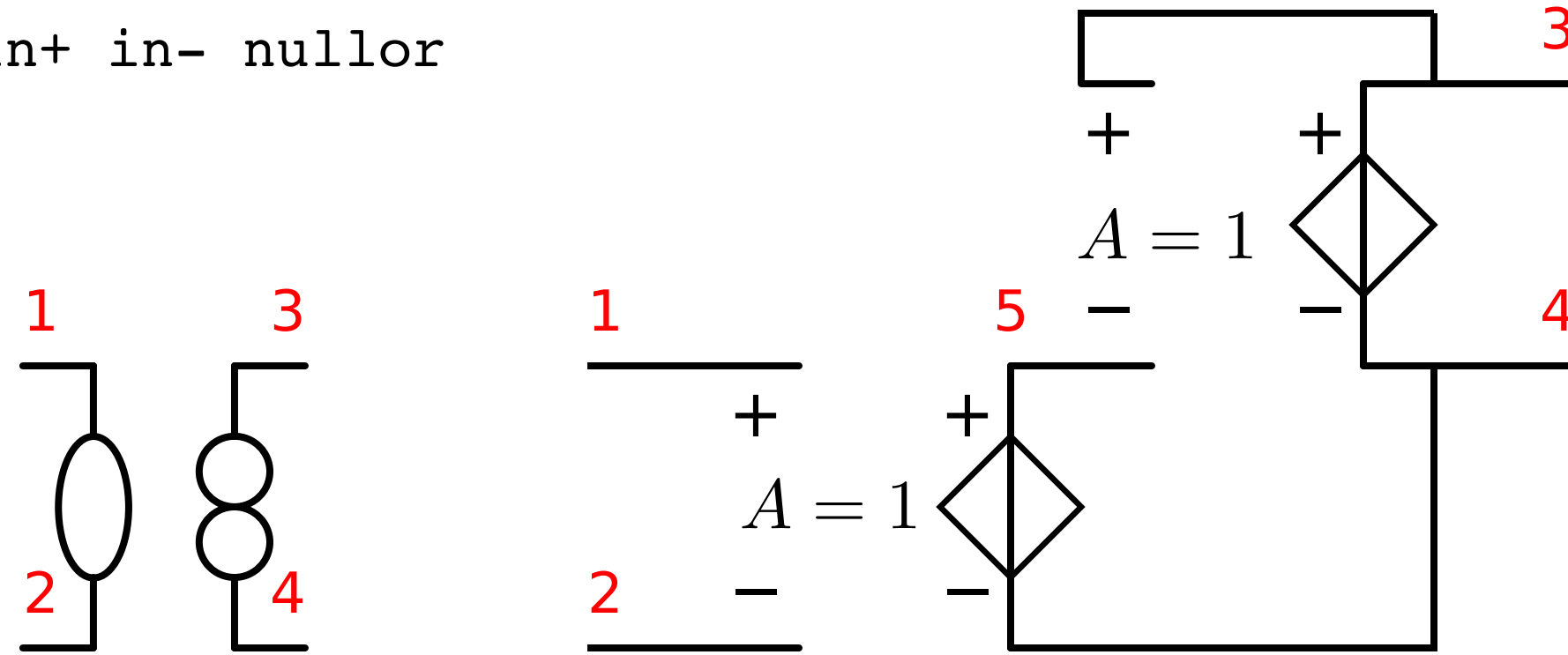
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Figure 18.21



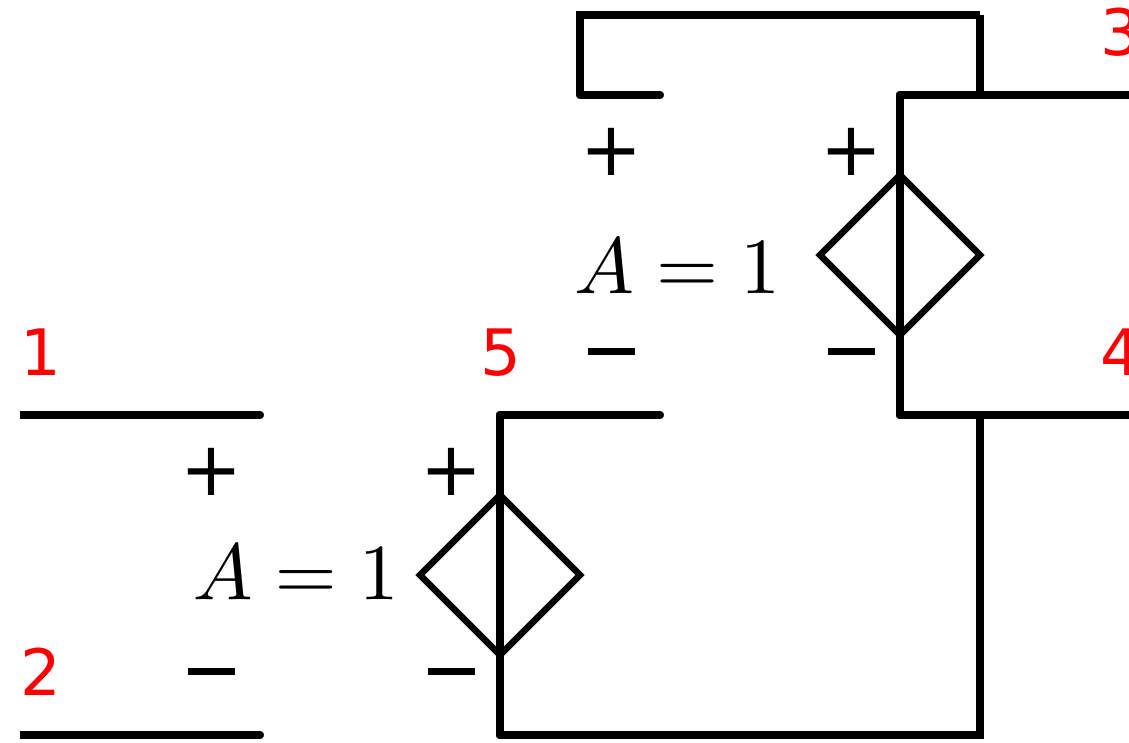
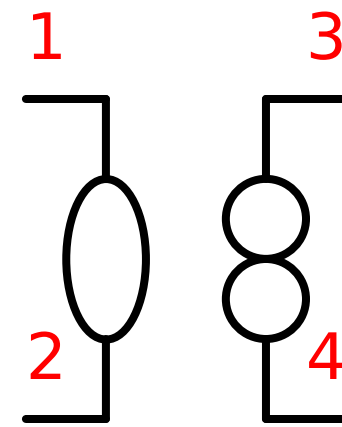
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Definition:

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E1 3 4 3 5 1
E2 5 4 1 2 1
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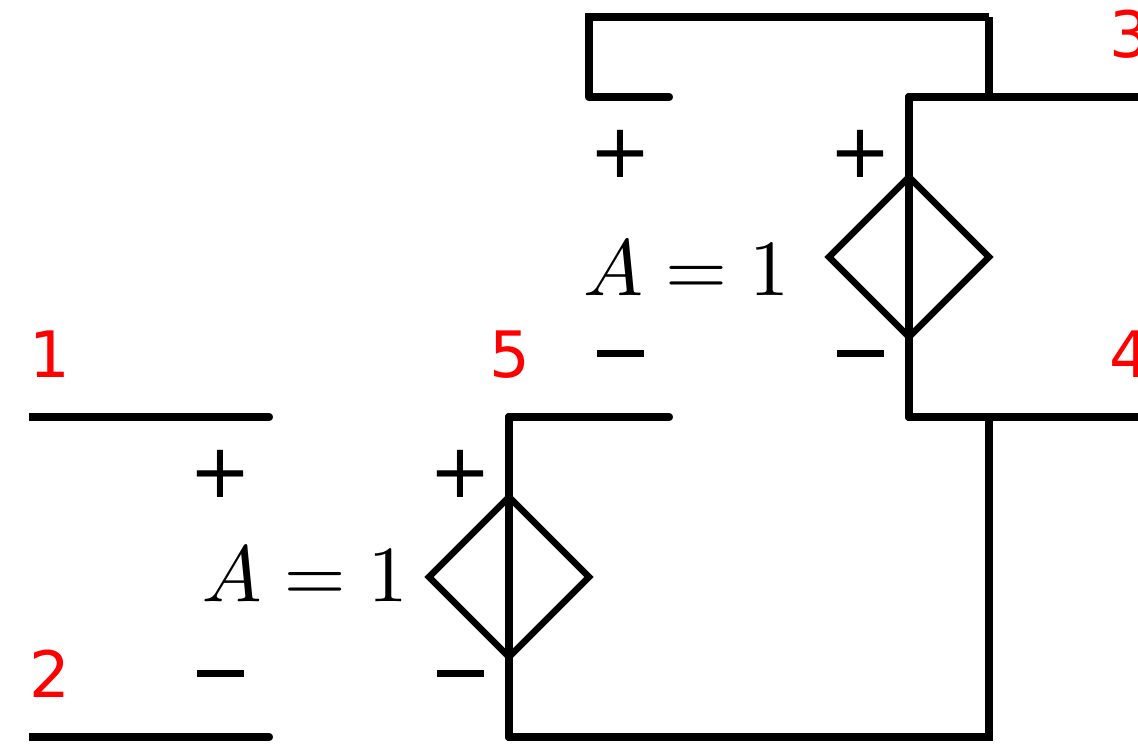
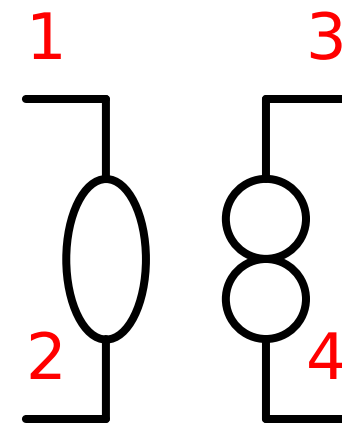
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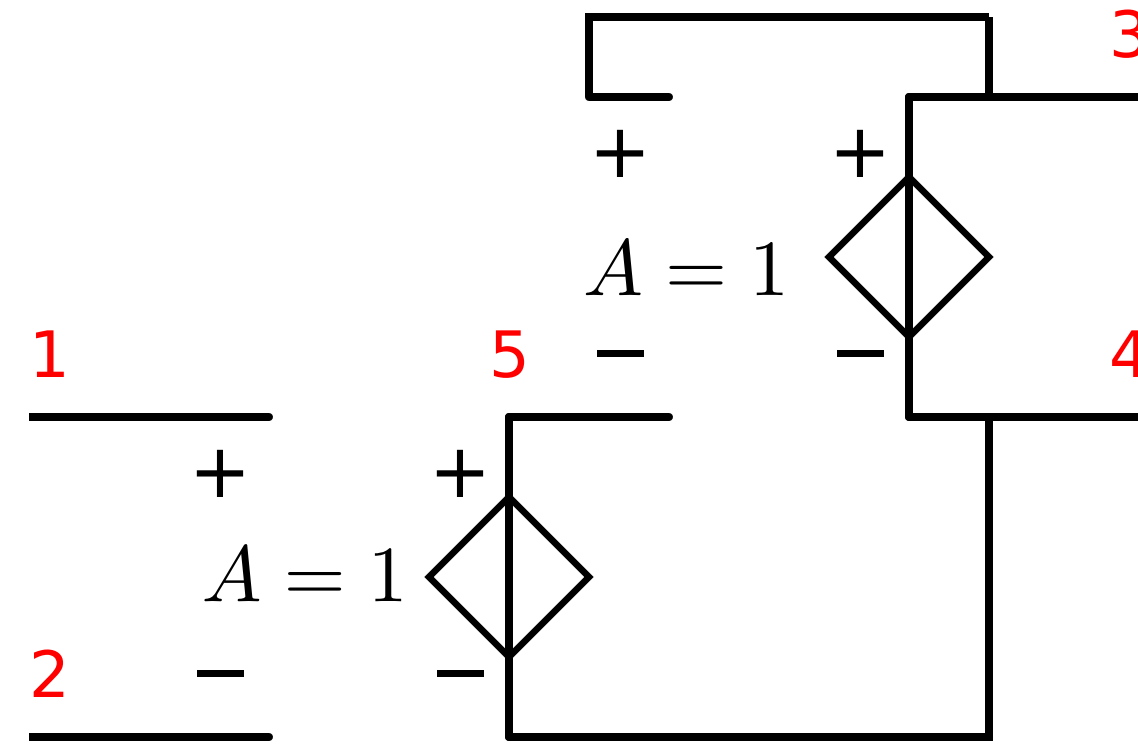
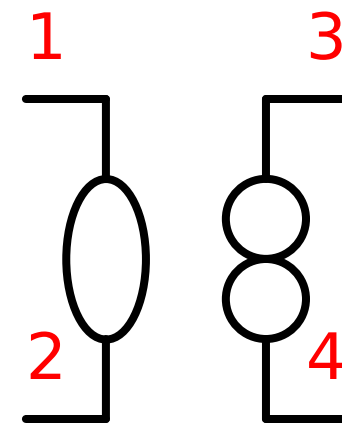
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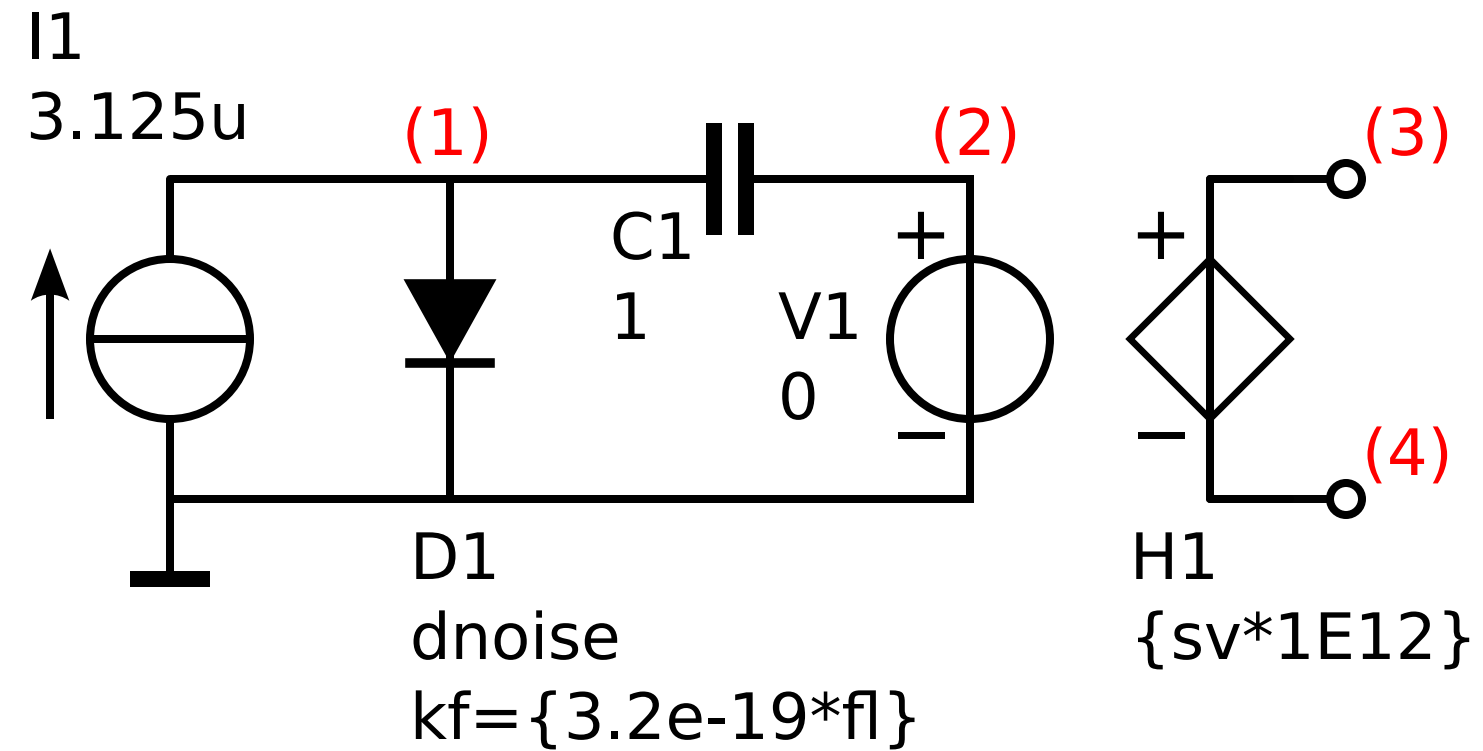
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Spice voltage noise source with  
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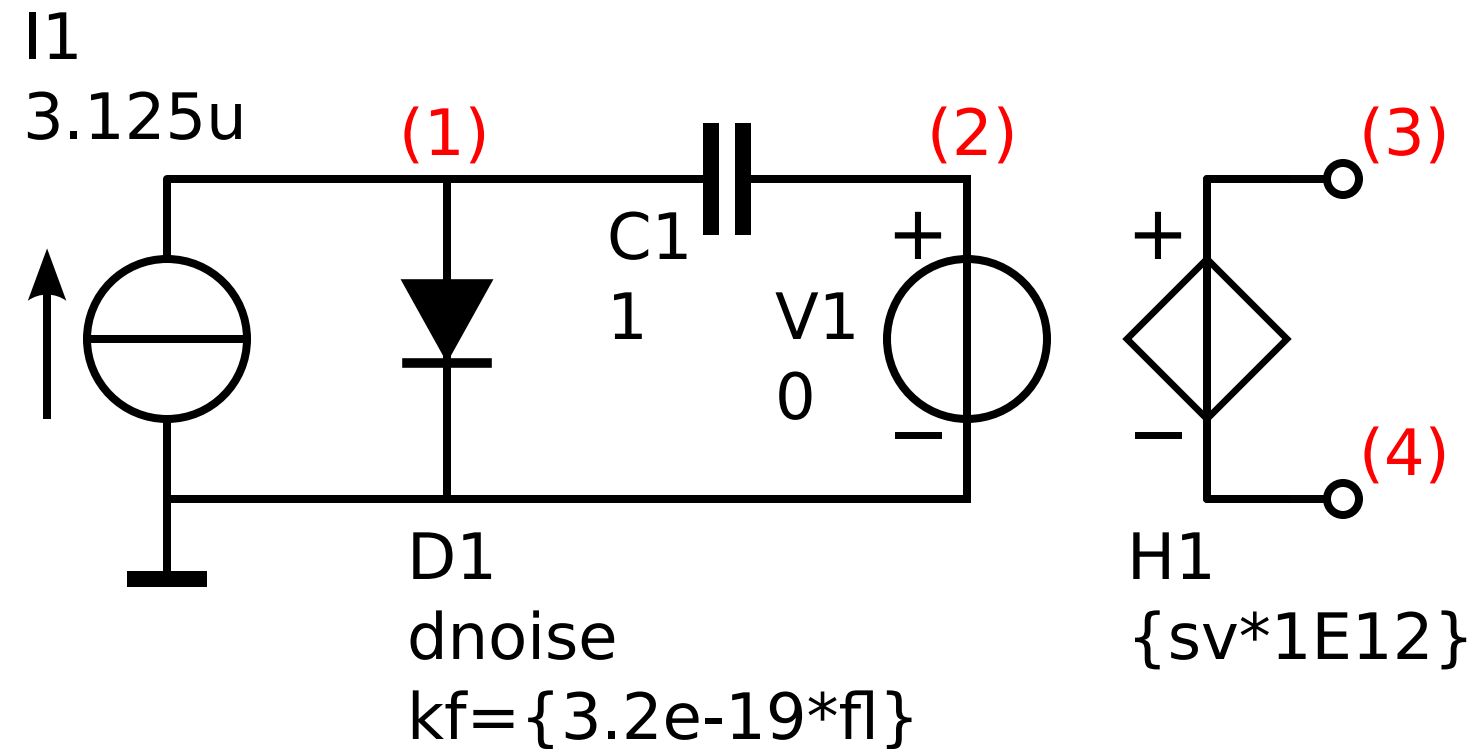
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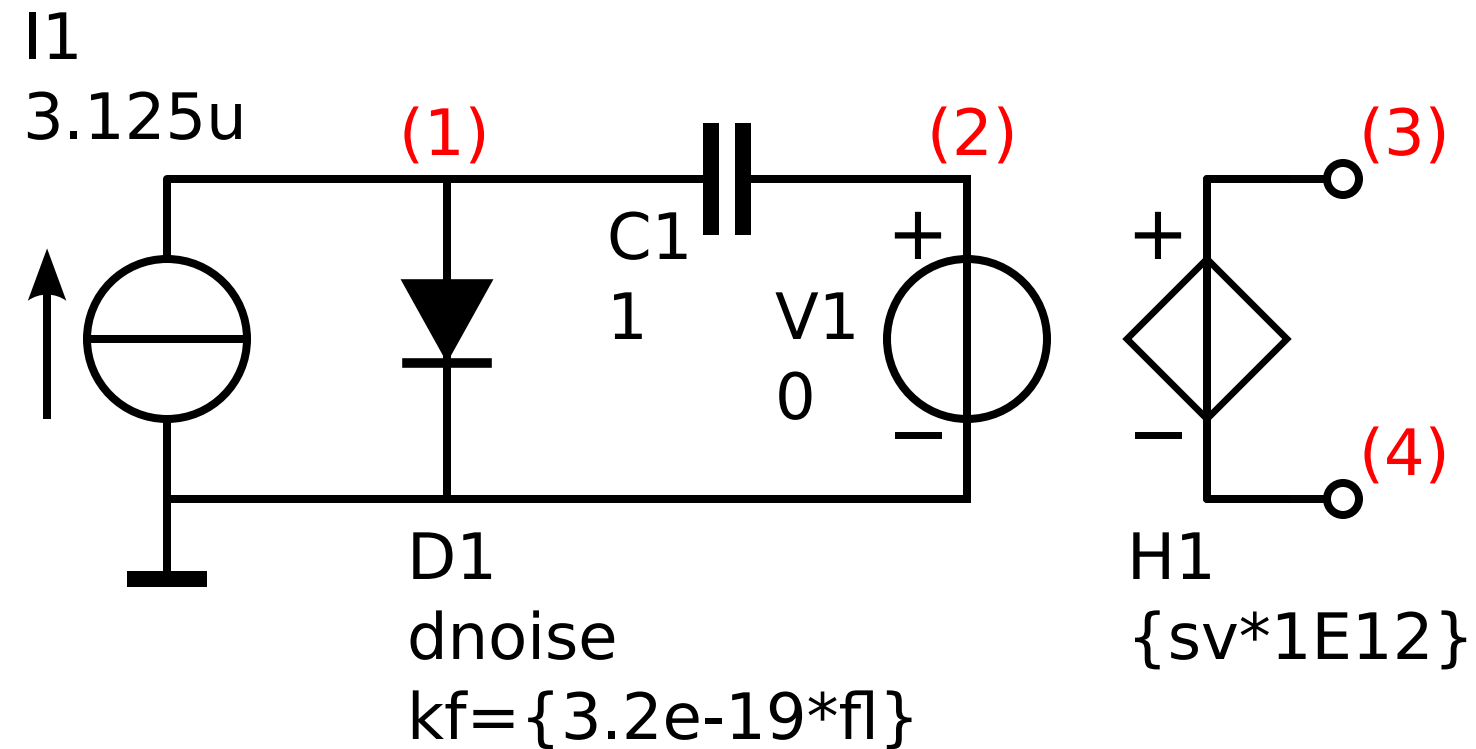
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Diode noise: 
$$S_i = 2qI_D \left( 1 + \frac{KF I_D^{AF-1}}{2qf} \right)$$

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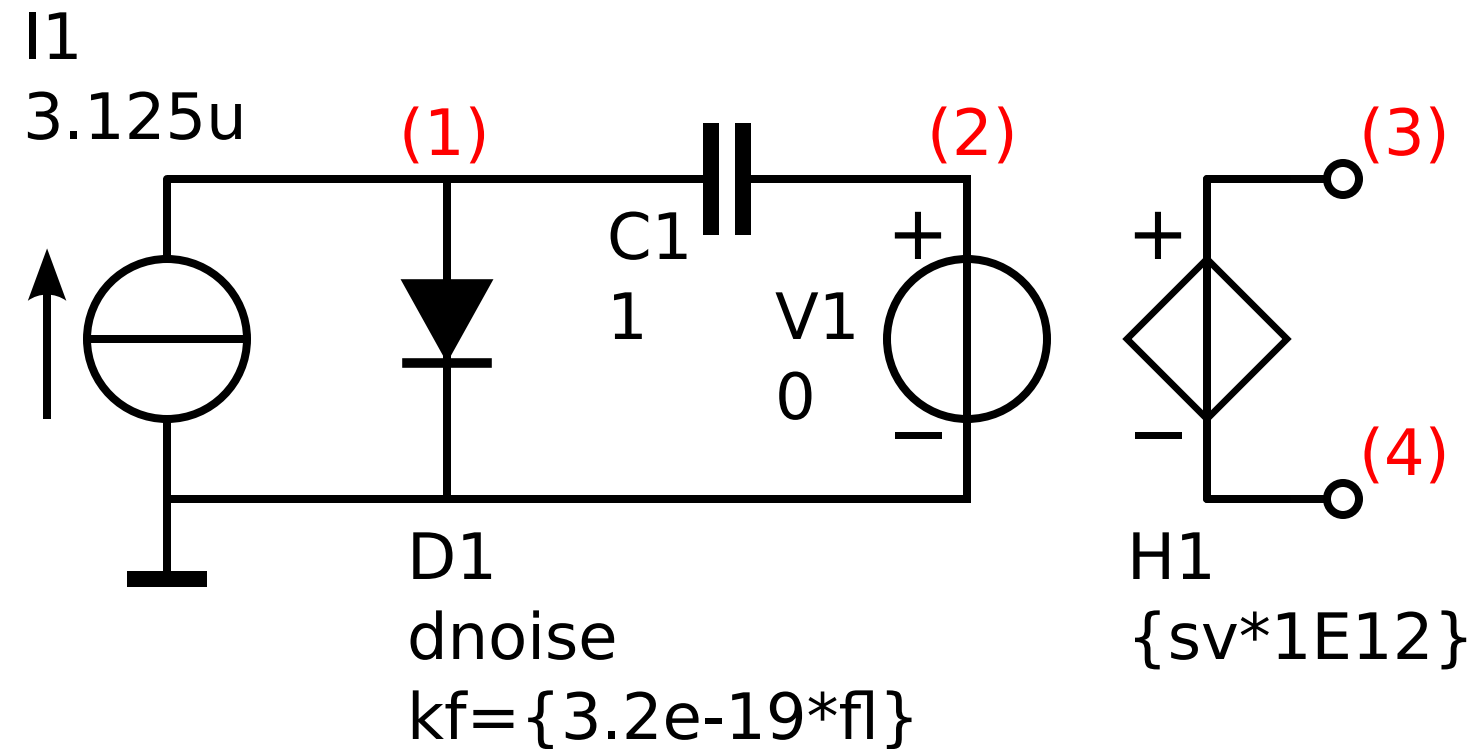


Spice current noise source with  
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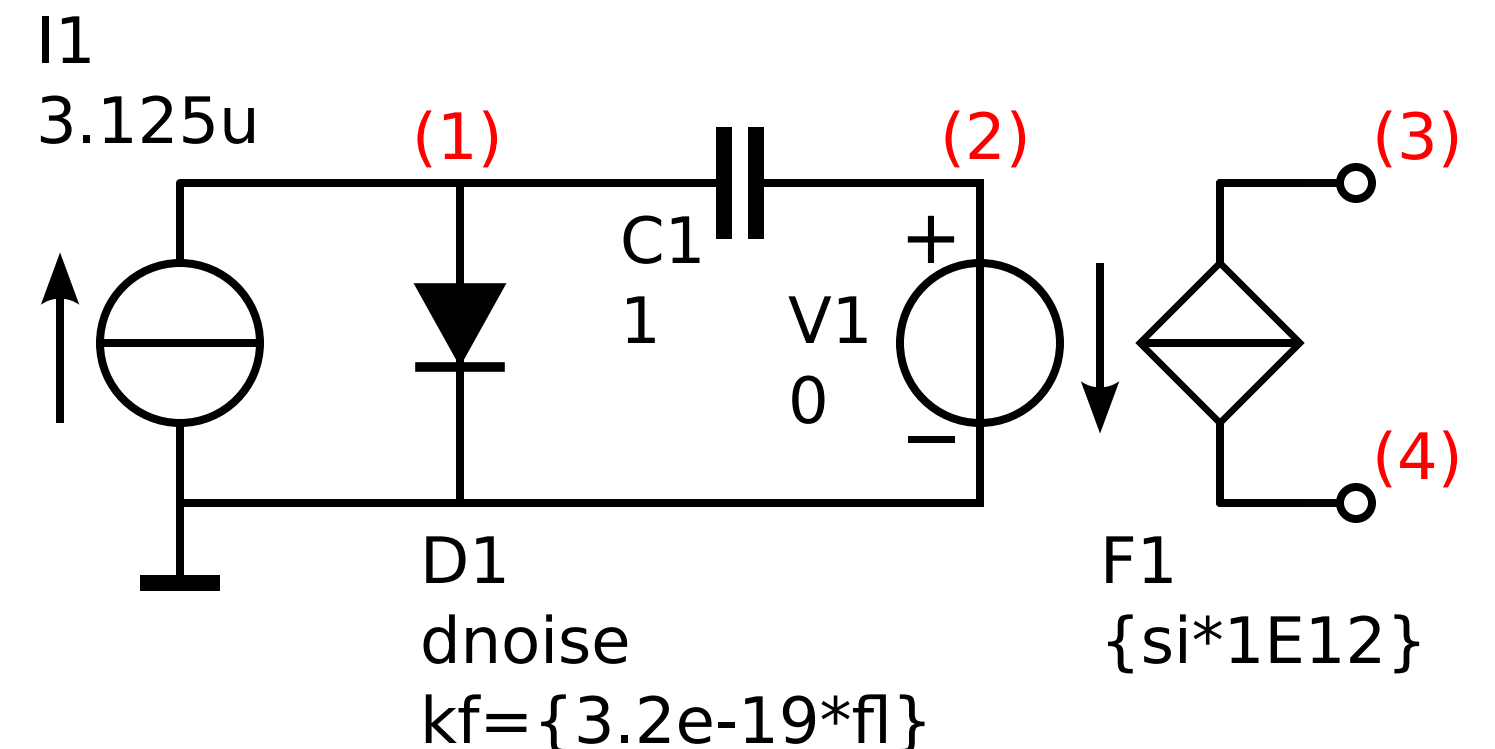
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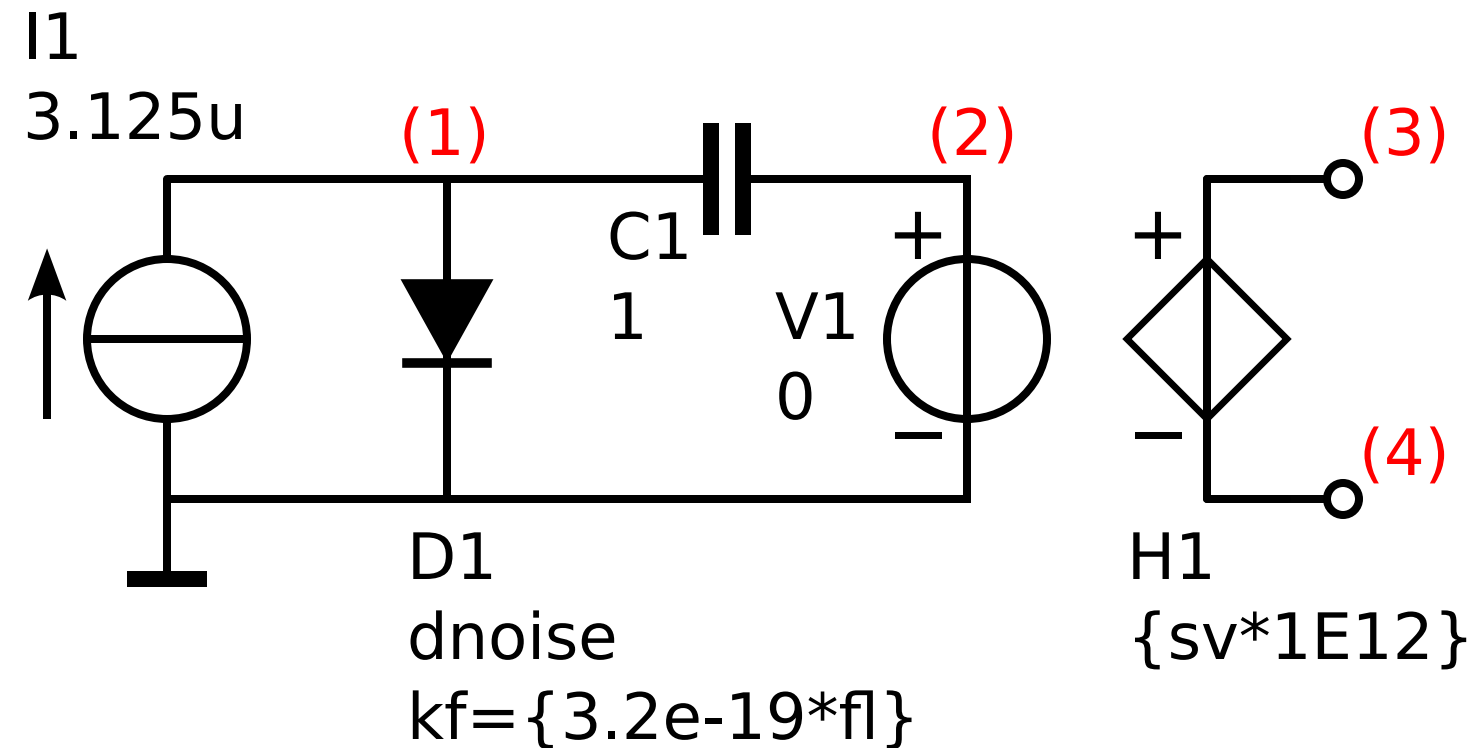
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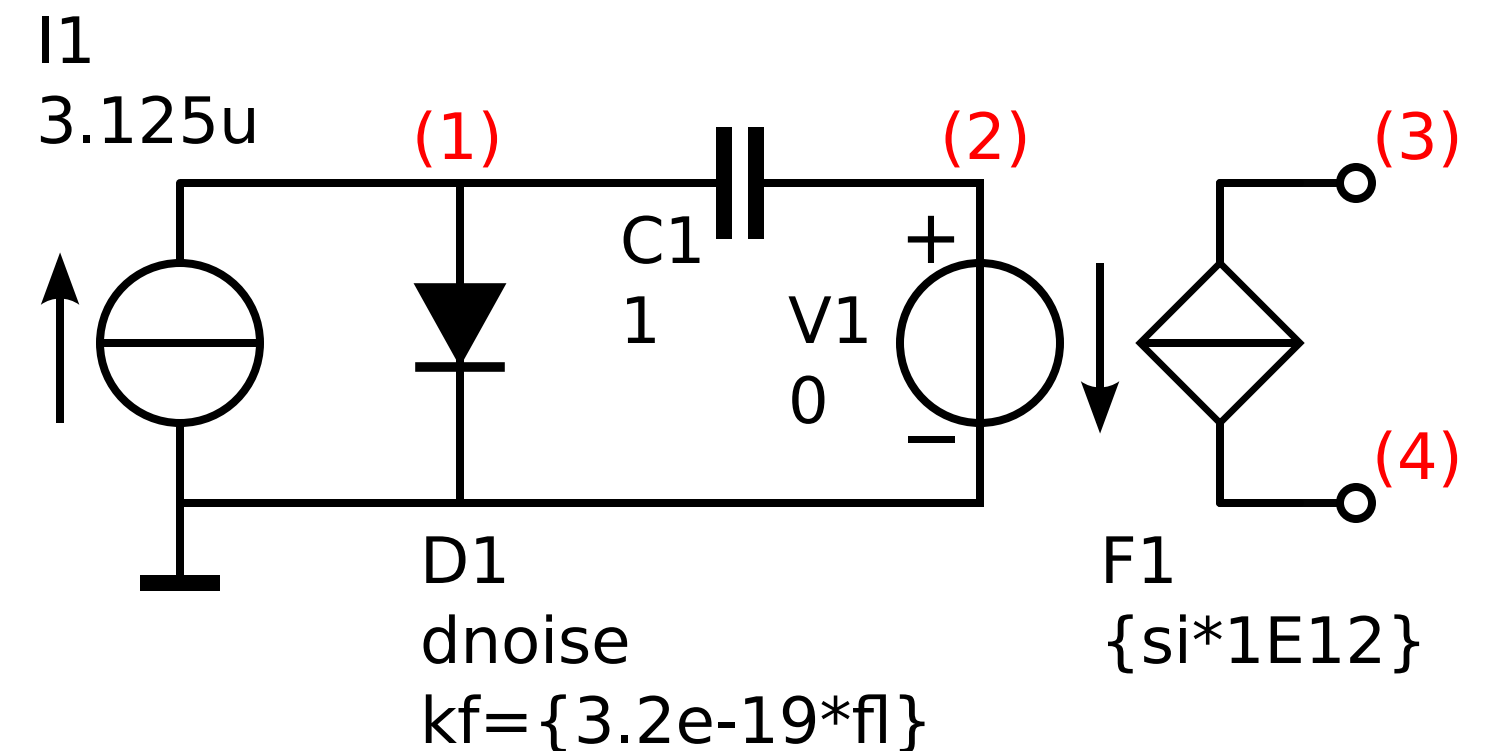
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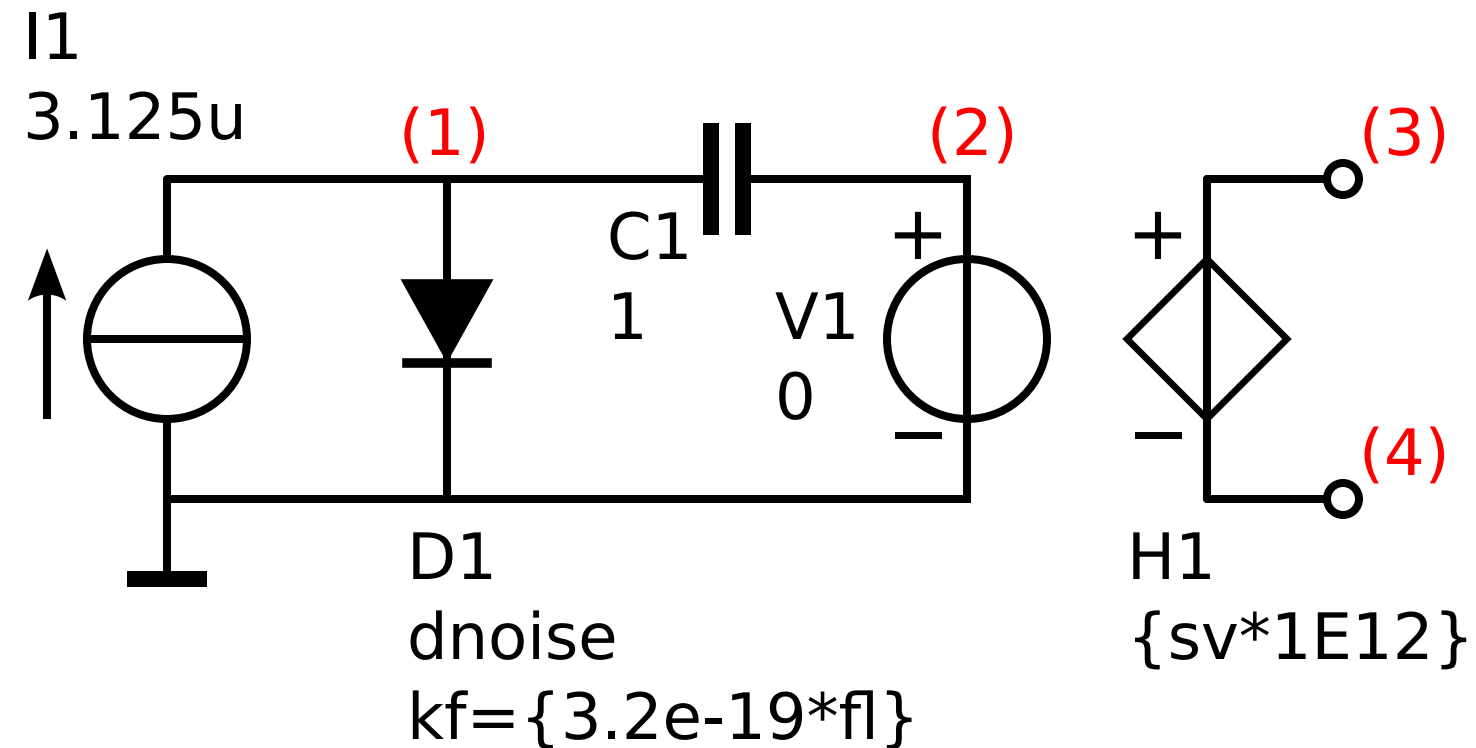


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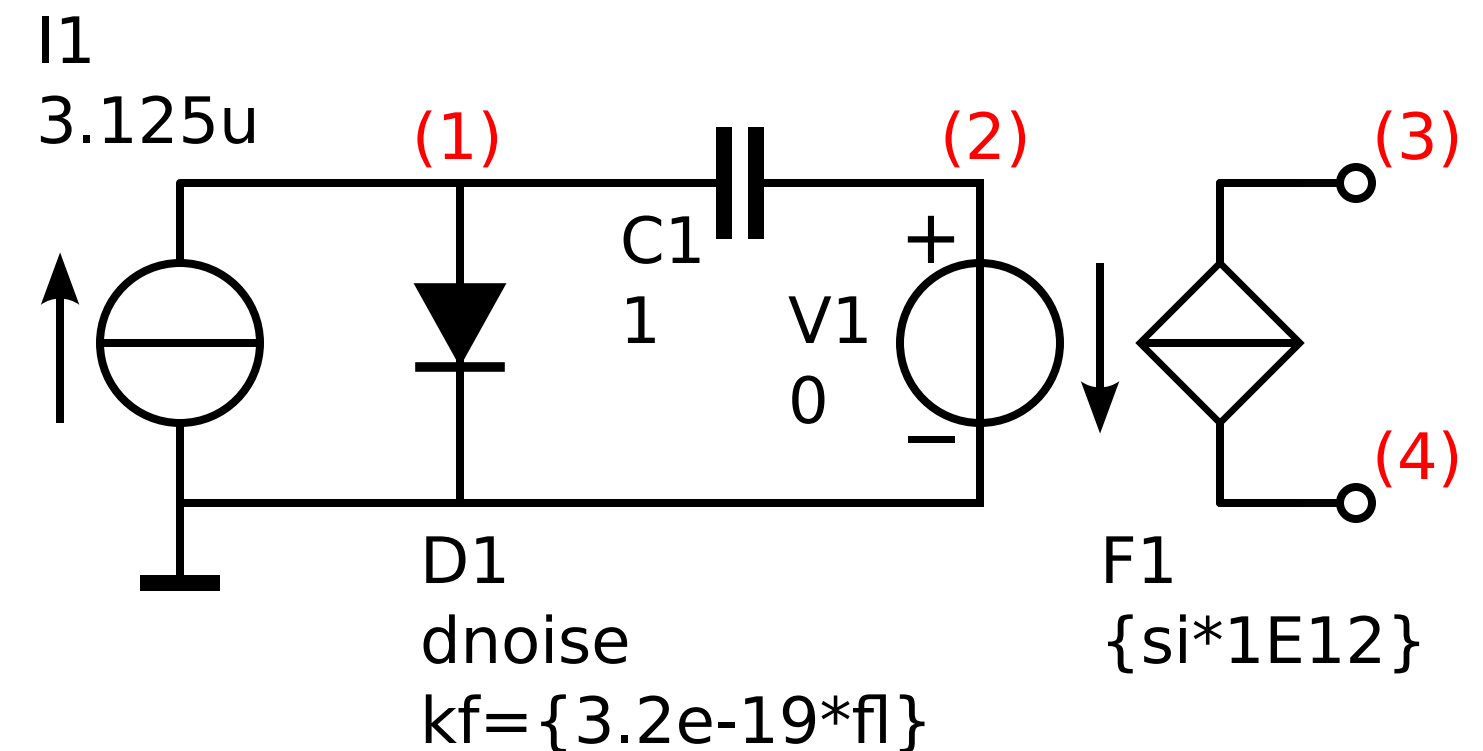
sv: floor noise spectrum in V/rt(Hz)  
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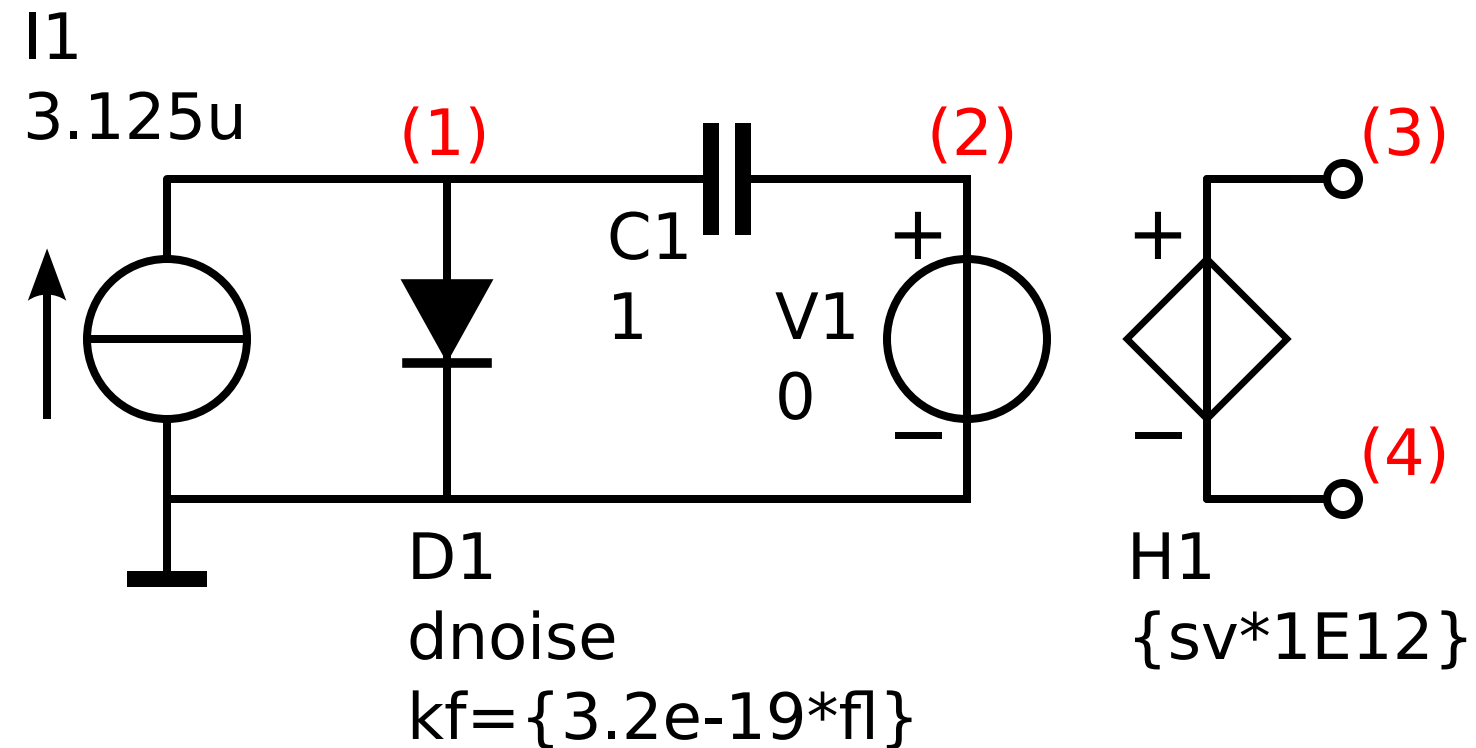
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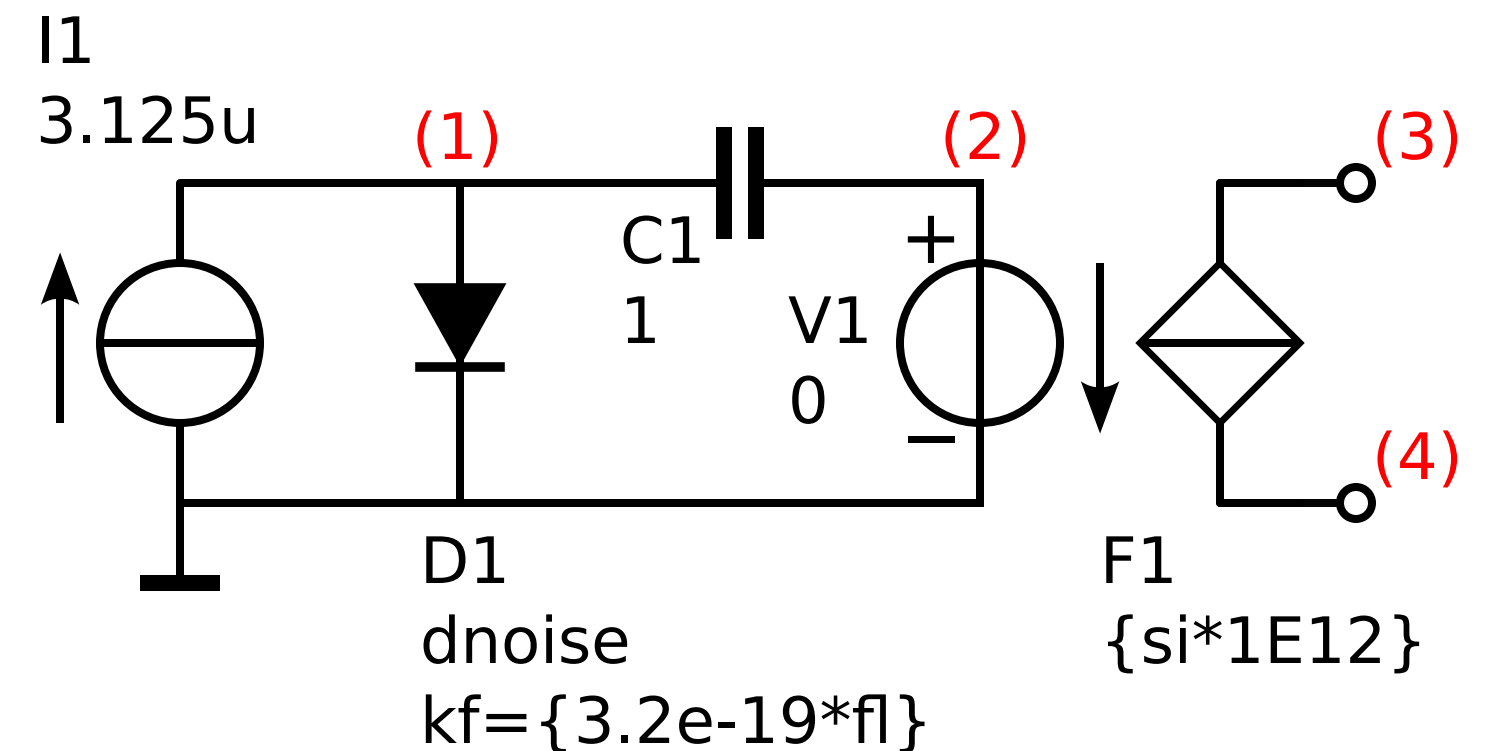
Study: section 8.3.2

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Small-signal dynamic model voltage-feedback OpAmp



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Use active and passive network elements or Laplace blocks

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Small-signal dynamic model voltage-feedback OpAmp

Use active and passive network elements or Laplace blocks

- differential-mode input impedance

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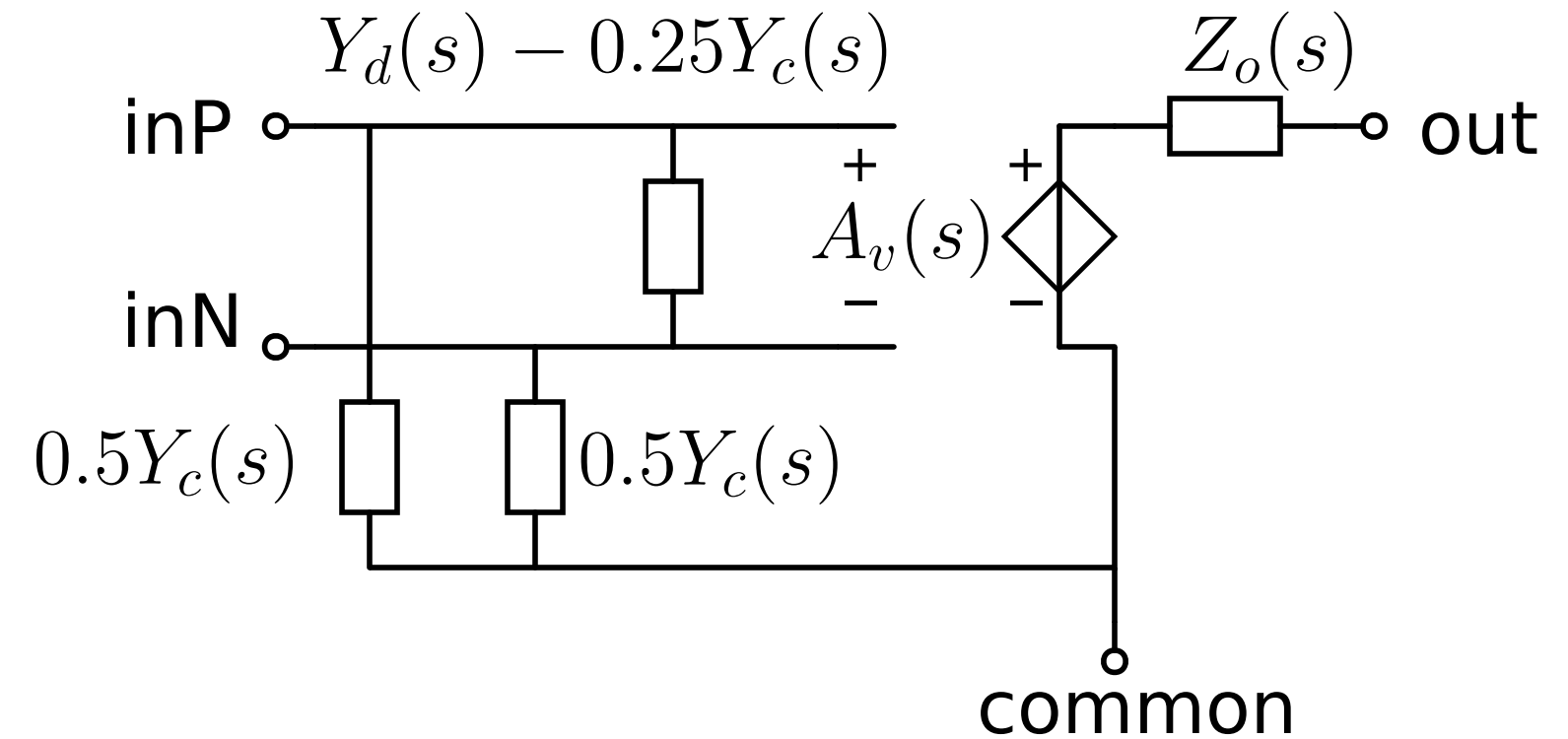
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- voltage transfer

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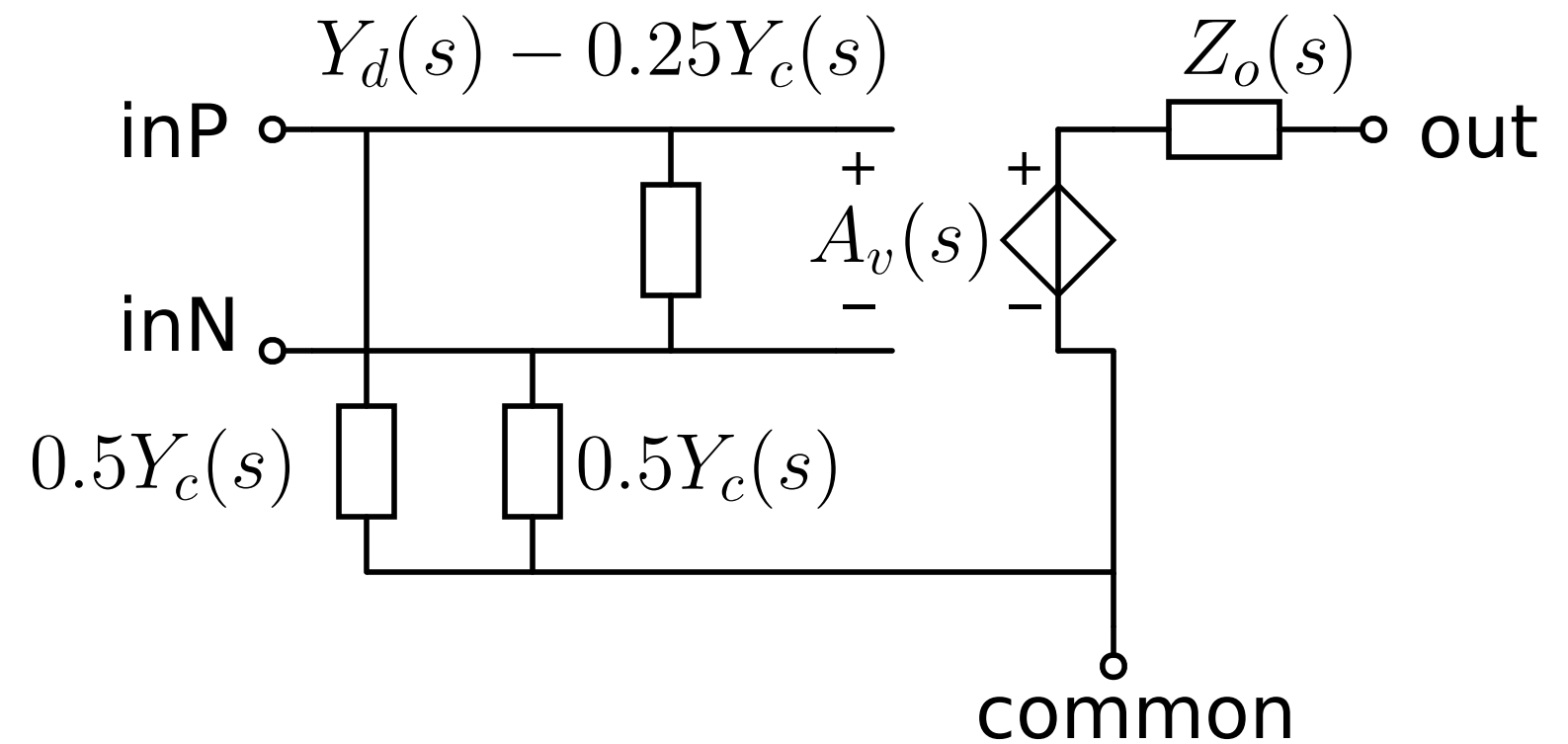
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$$Y_d(s) = G_d + sC_d$$



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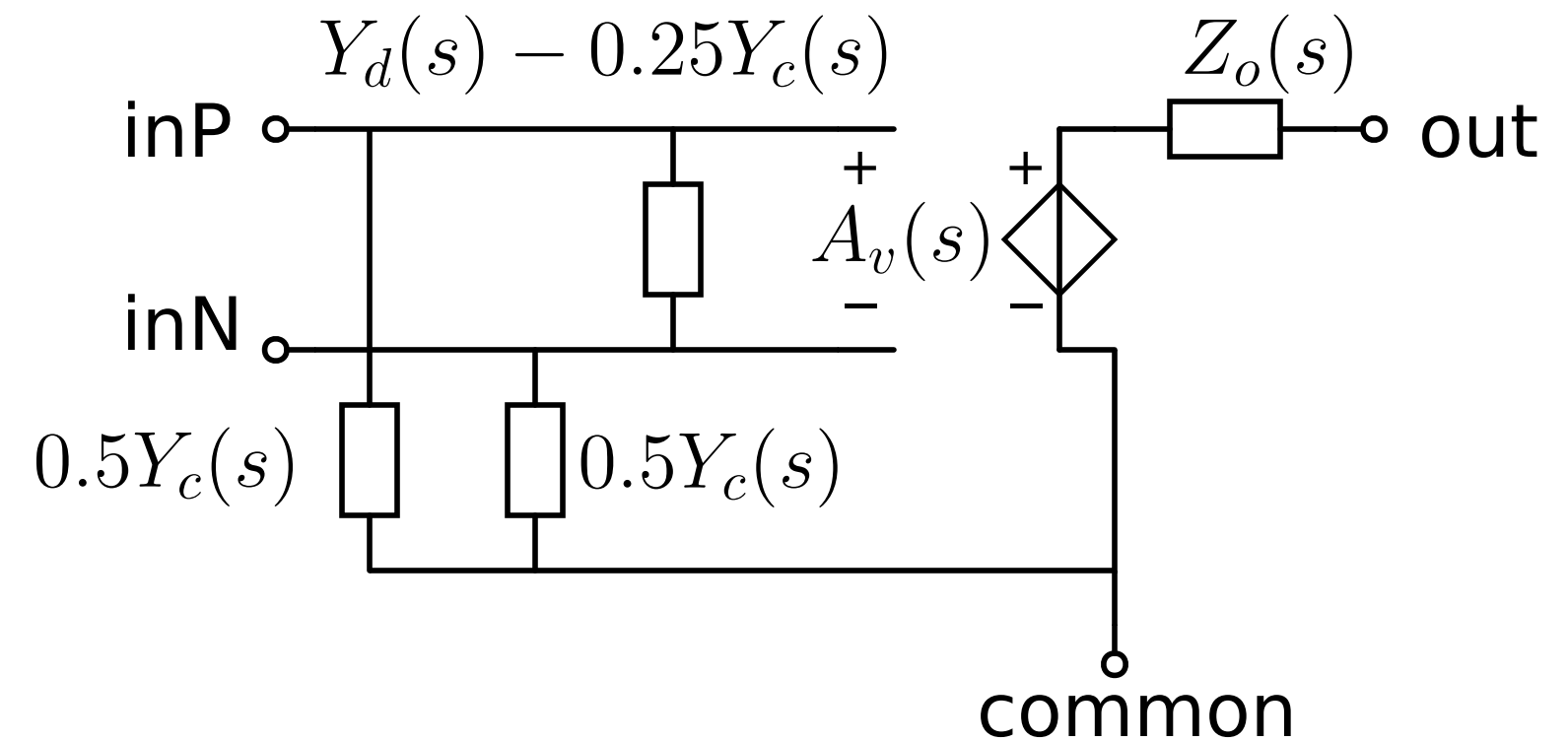
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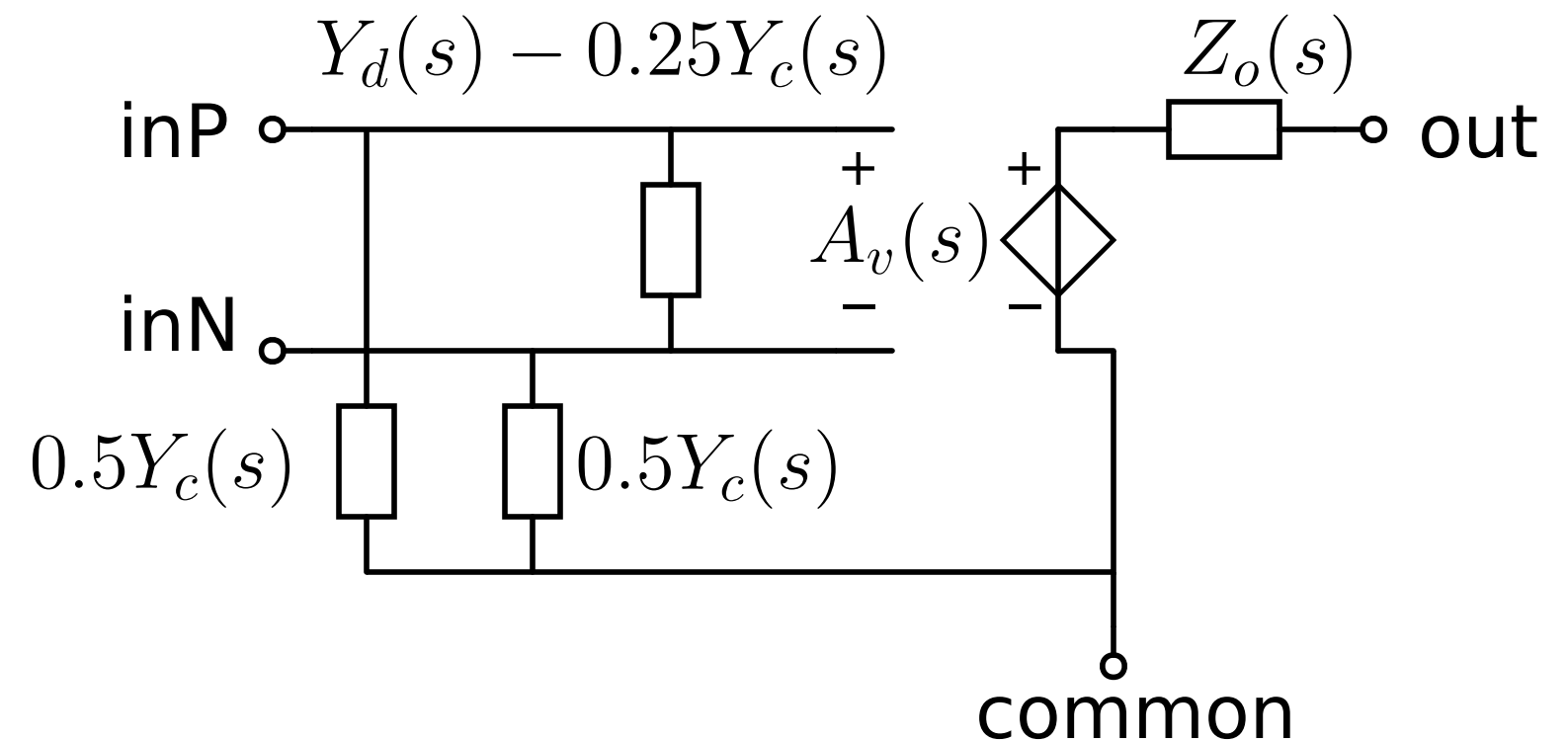
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$$Y_d(s) = G_d + sC_d$$

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$$A_v(s) = A_0 \frac{1+b_1s+b_2s^2+\dots+b_ms^m}{1+a_1s+a_2s^2+\dots+a_ns^n}$$



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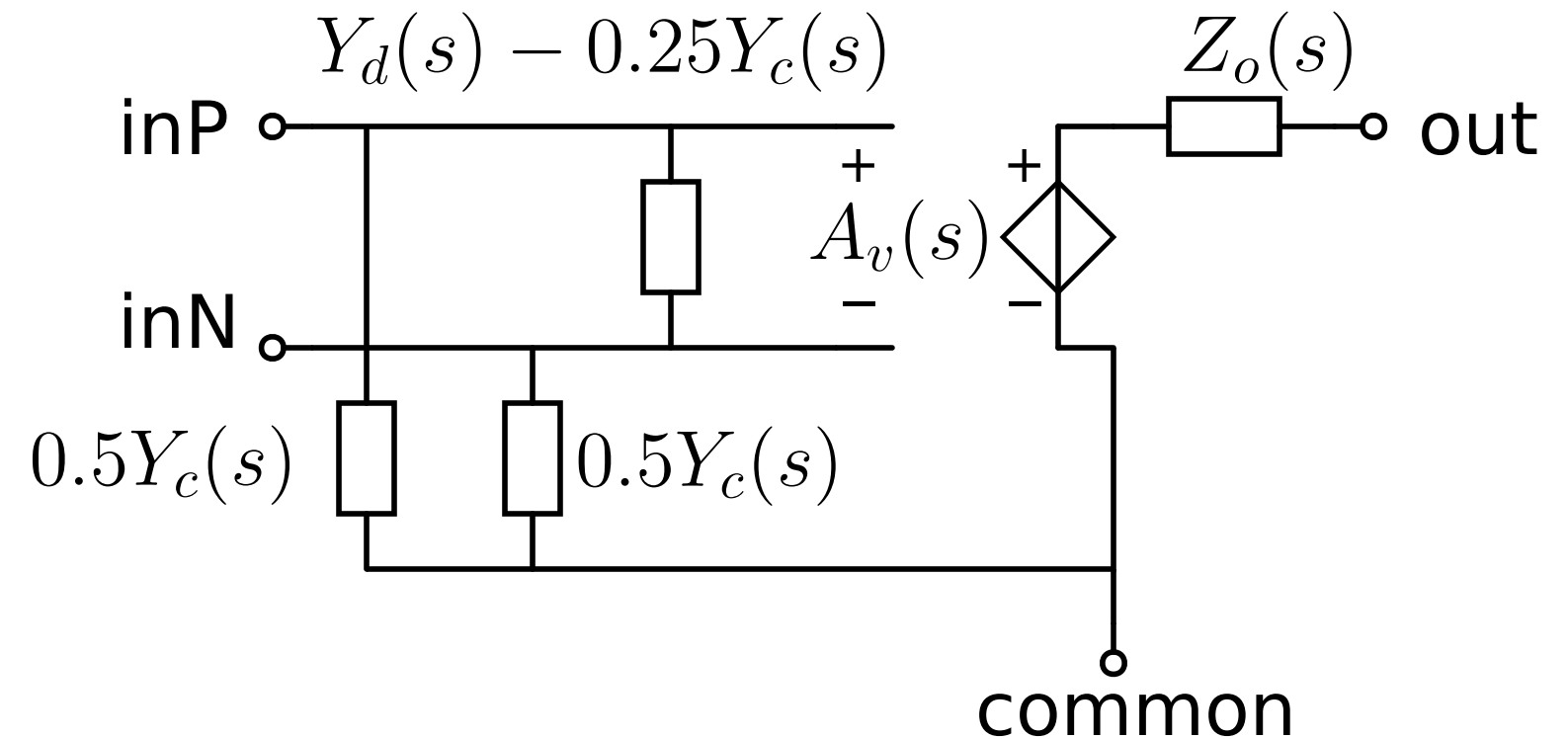
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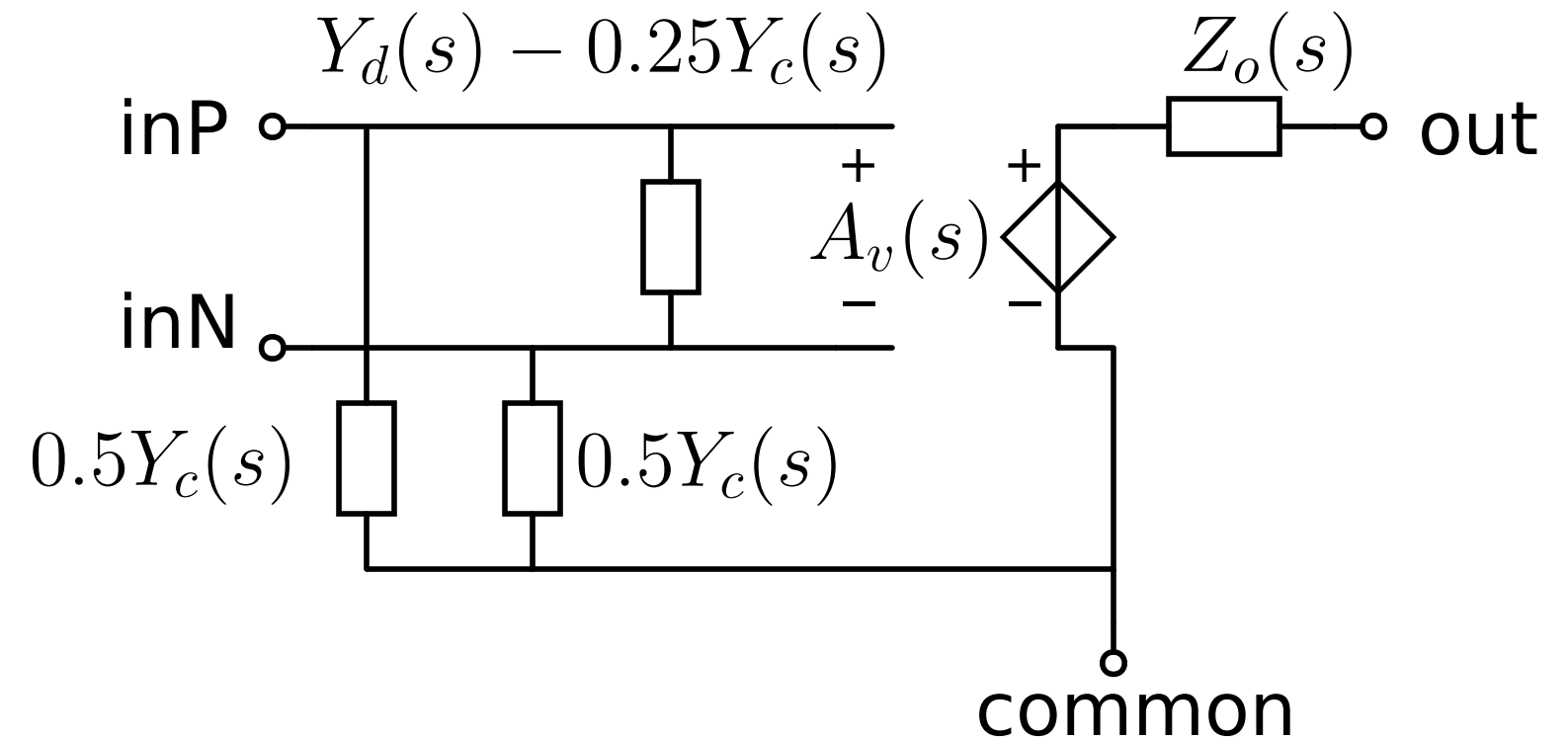


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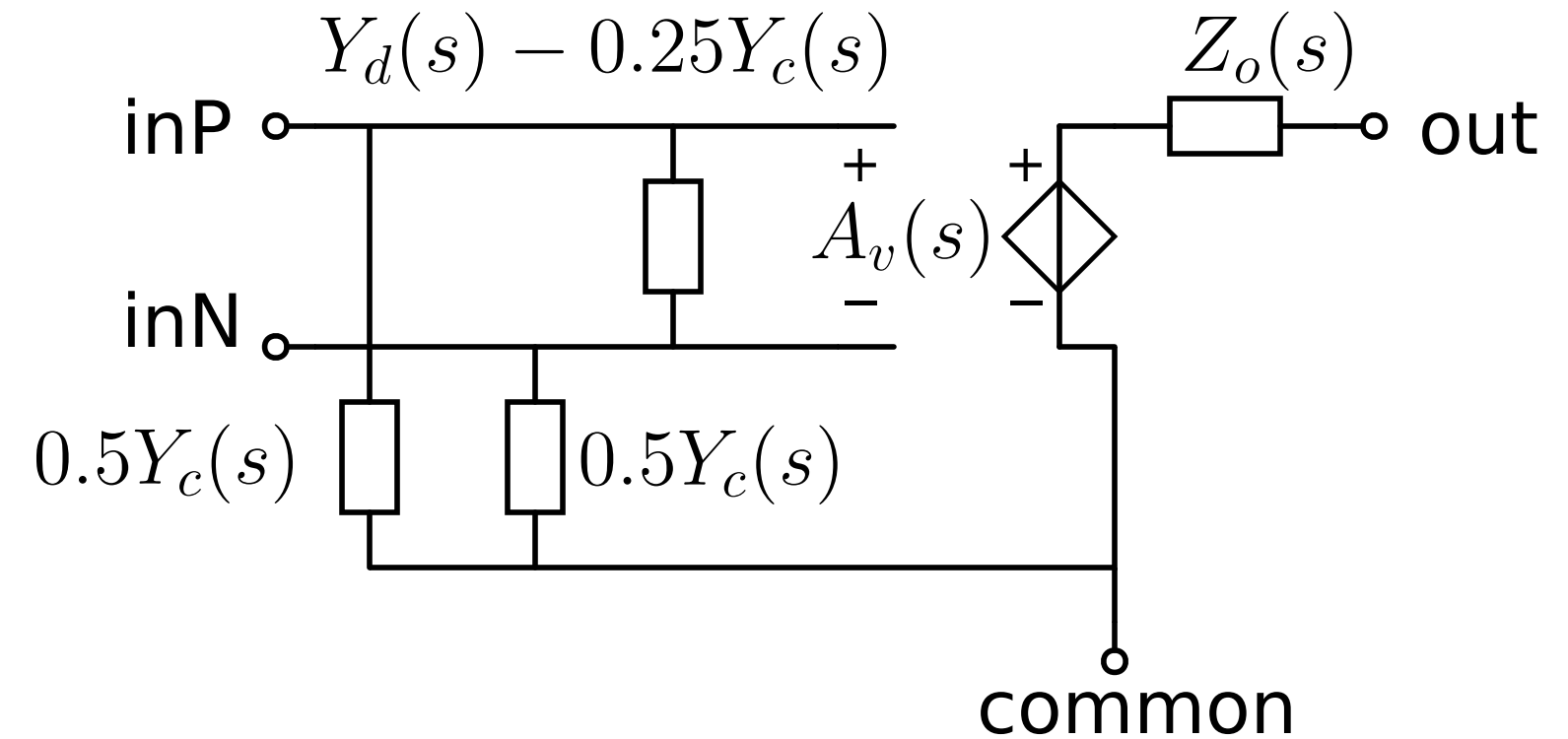
$Z_o(s)$  complex impedance not always specified in data sheet

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## Small-signal dynamic model current-feedback OpAmp

Use active and passive network elements or Laplace blocks

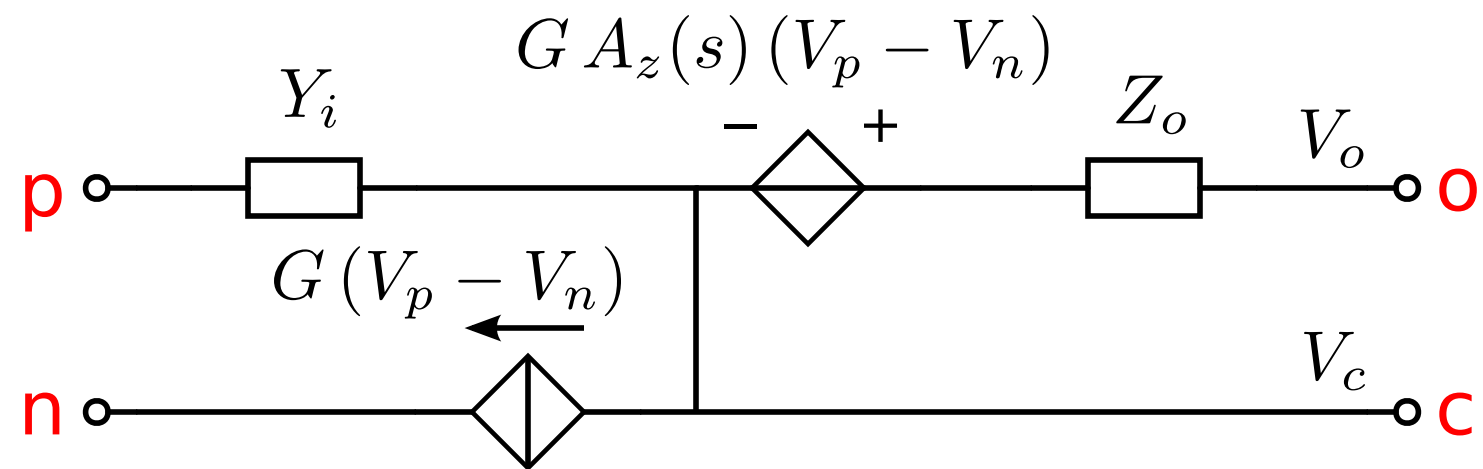
- input impedance noninverting input
- transconductance input stage
- output impedance
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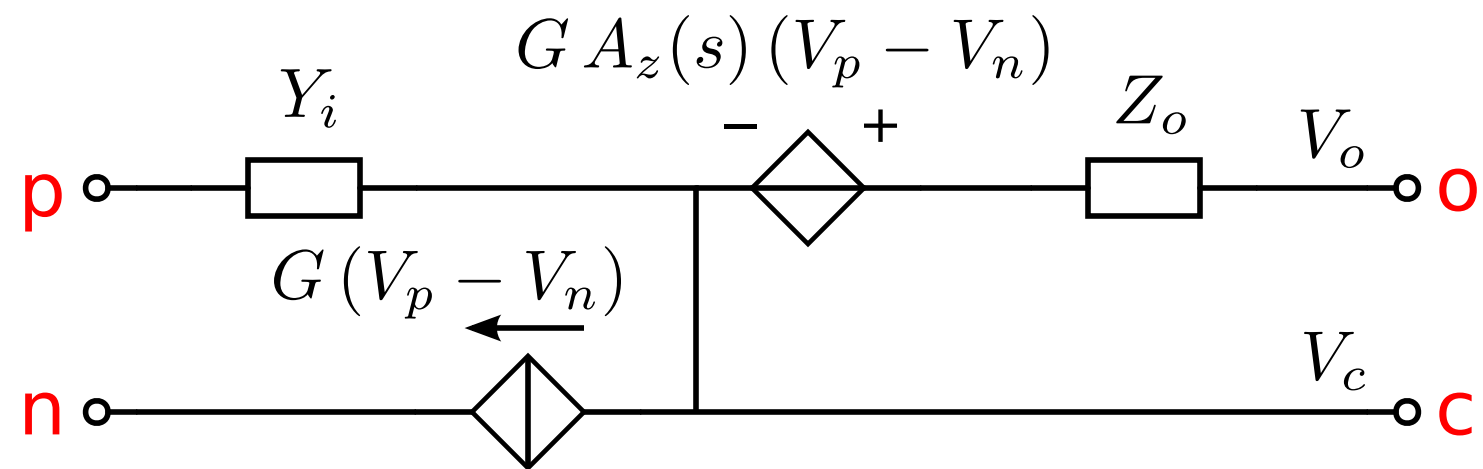
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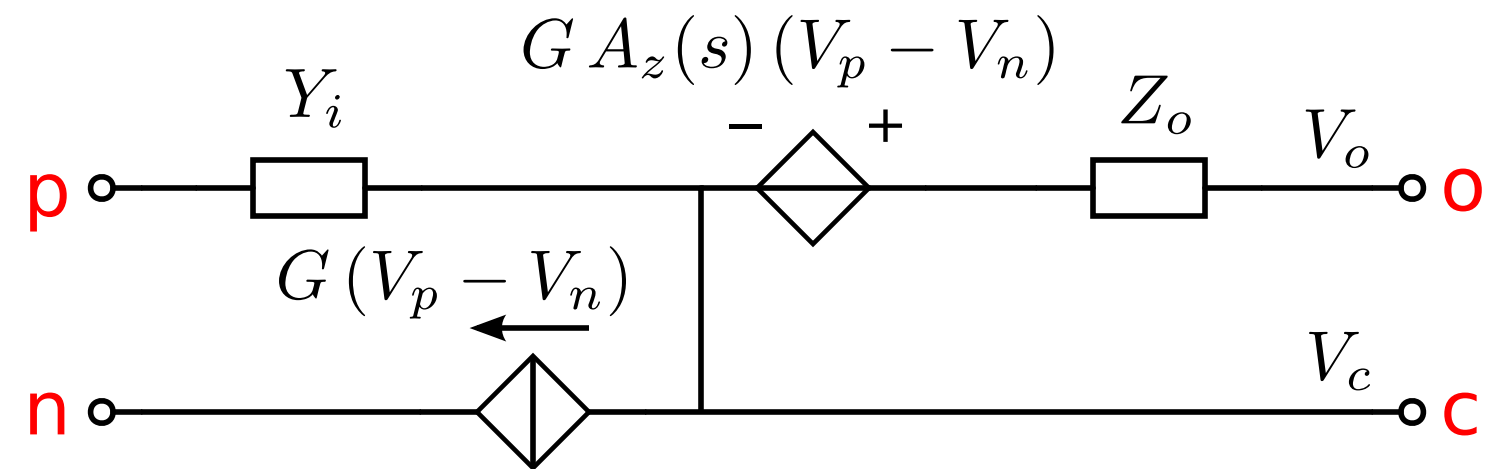


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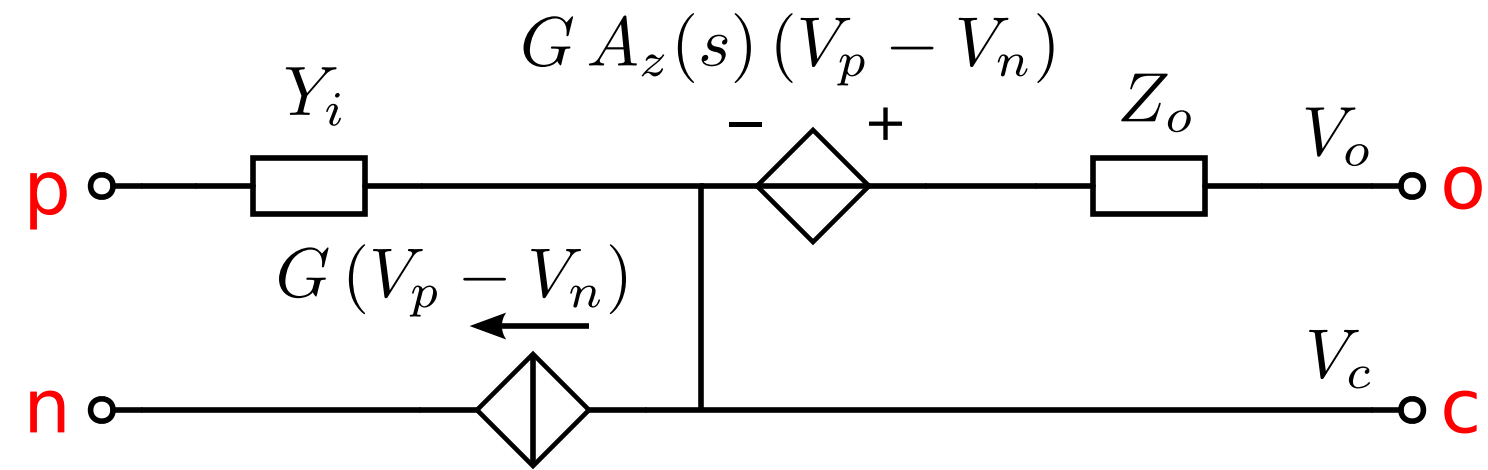
$Z_o(s)$  complex impedance not always specified in data sheet

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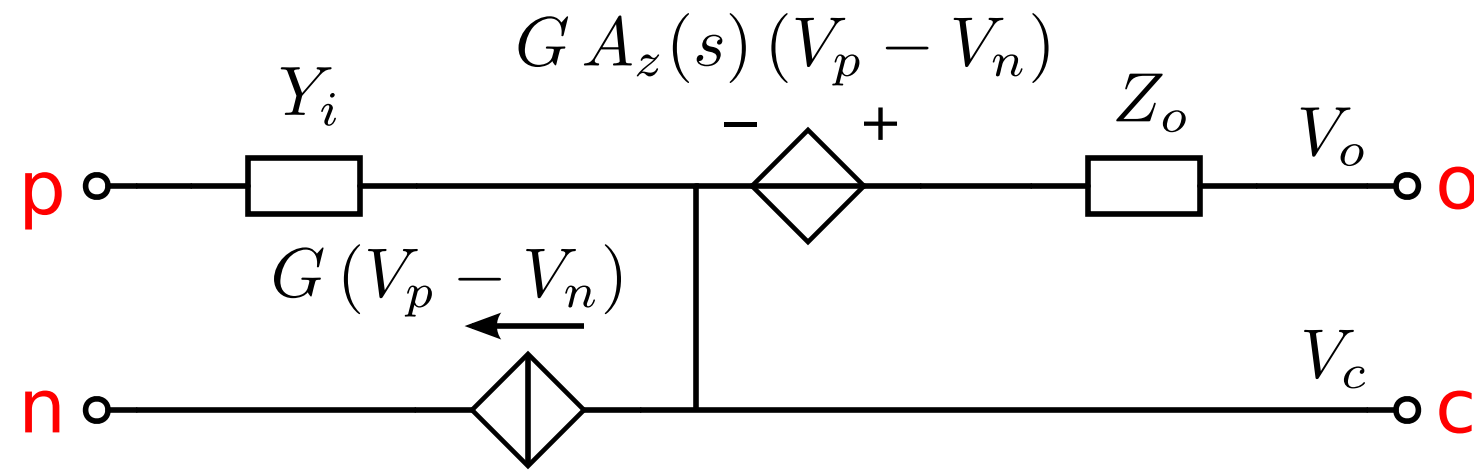
$$A_z(s) = Z_0 \frac{1+b_1s+b_2s^2+\dots+b_ms^m}{1+a_1s+a_2s^2+\dots+a_ns^n}$$

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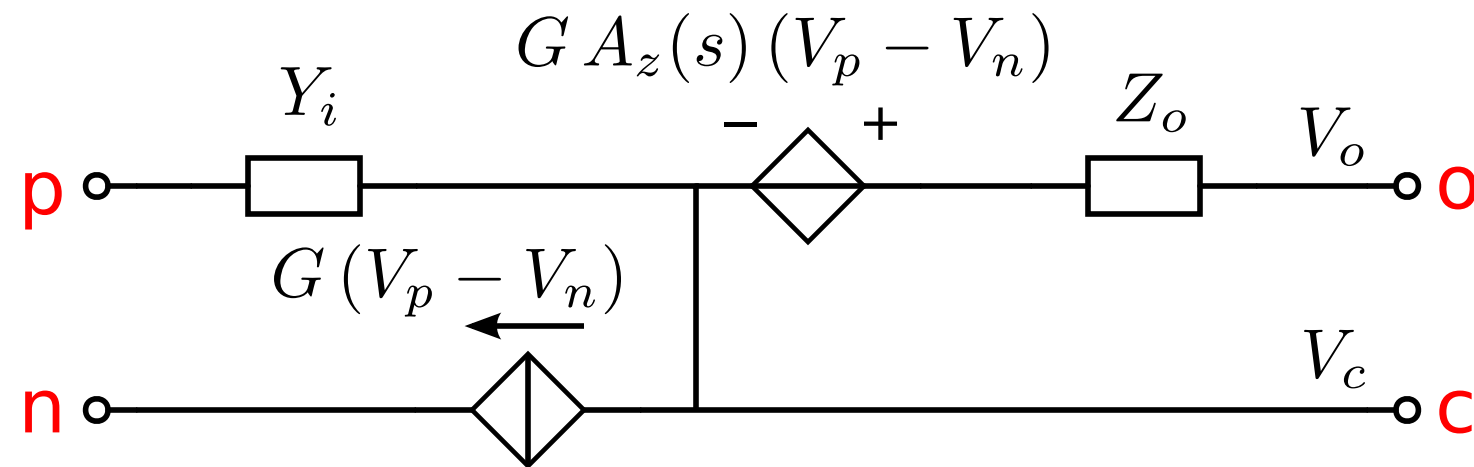
$$A_z(s) = Z_0 \frac{1+b_1s+b_2s^2+\dots+b_ms^m}{1+a_1s+a_2s^2+\dots+a_ns^n} \quad \text{First order: } A_z(s) = R_0 \frac{1}{1+s \frac{R_0 G}{2\pi GB}}$$

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