Structured Electronic Design

Operational Amplifiers: modeling

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Modeling techniques

Macro models

Suppliers provide Spice simulation models for operational amplifiers

1. Not all performance aspects have been modeled: see explaining text in de model file
2. Some performance aspects have not been modeled correctly:
   - Equivalent offset voltage modeled with a fixed voltage source
   - Equivalent offset current modeled with a fixed current source
   - Sum of all terminal current does not equal zero: internal current flow to reference node (0)
3. Some macro models are too large for evaluation versions of simulators
4. Always check if relevant performance aspects have been modeled correctly
   - Use test circuits from data sheets as simulation test bench

Simulation demo macro models

Modeling techniques

Modeling individual performance aspects

Create your own models

1. Not all performance aspects need to modeled

   Requirements for static and dynamic voltage and current handling capability
   can be checked with linear models:
   - Plot voltage and current versus time and determine maxima and maximum rate of change

2. Some performance aspects need to be modeled statistically

   Spice can perform Monte Carlo analysis, SLiCAP has statistical description methods
   - Offset voltage and currents have zero mean value, usually their 3-sigma value is specified
   - Input bias current has a nonzero mean value

3. Not all performance aspects need to modeled for each simulation

   Simple simulation models and orthogonal design: each simulation uses its own model

   - Small-signal noise analysis for noise performance
   - DC analysis for static voltage and current handling
   - Statistical analysis for DC operating point
   - Small-signal pole-zero analysis for frequency stability
   - Small-signal dynamic behavior for frequency response
   - Time-domain (transient) analysis for dynamic voltage and current handling

Spice nullor model

Placement:

Subcircuit call → `x1 out+ out- in+ in- nullor`

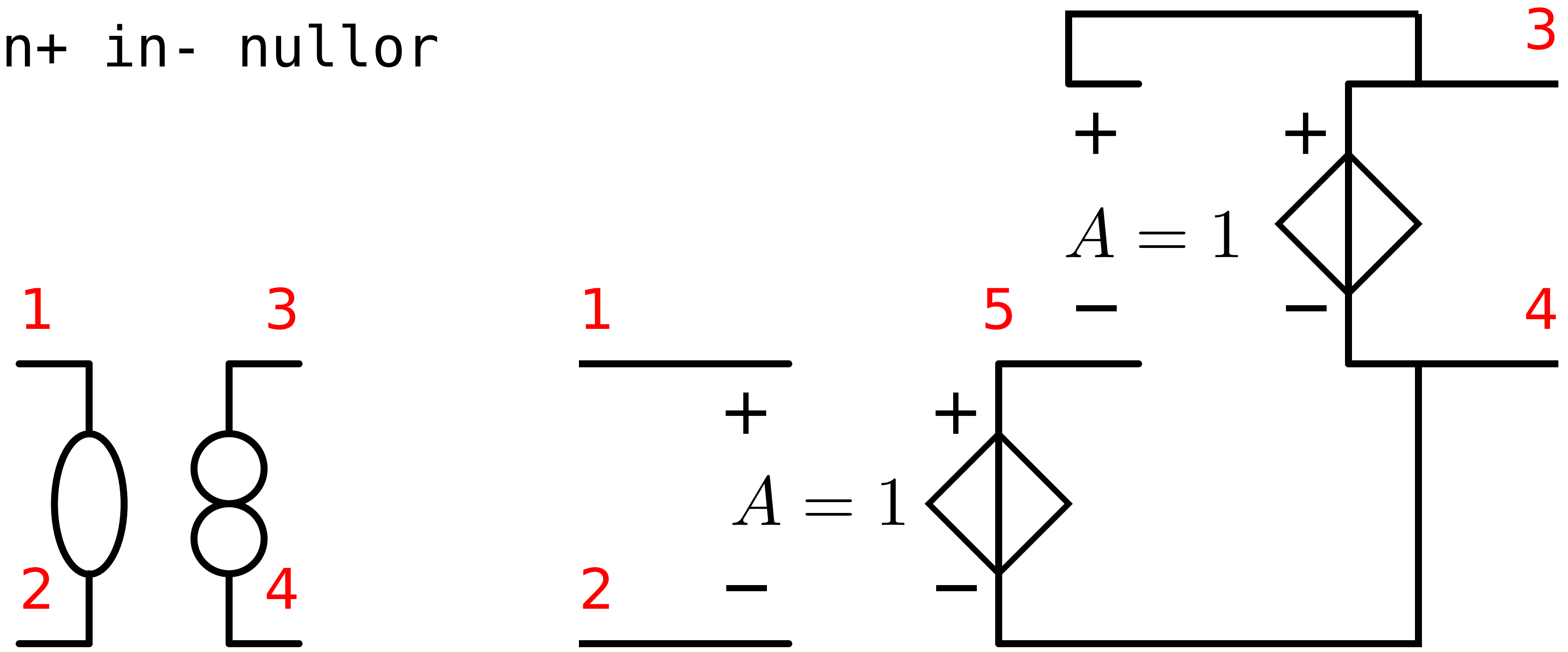


Figure 18.21

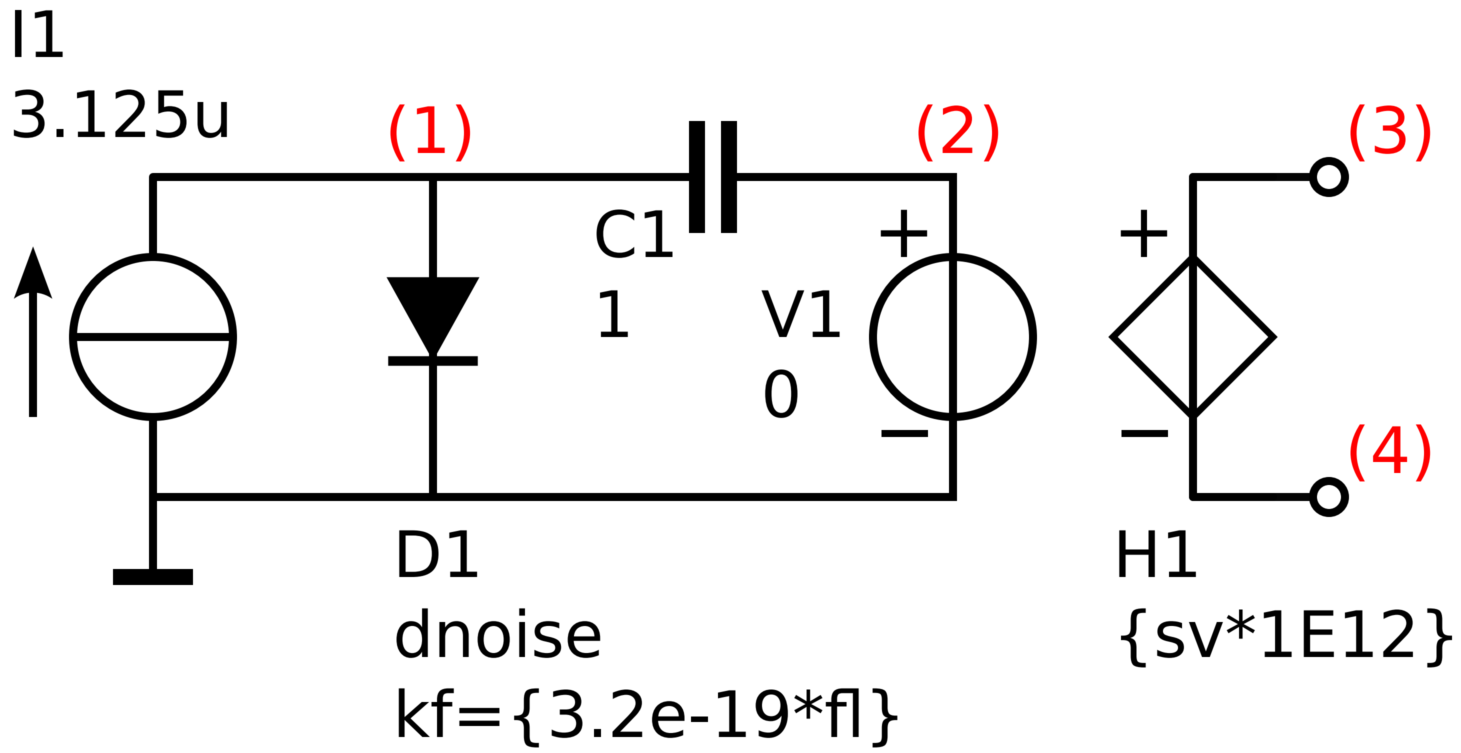
Definition:

VCVS →

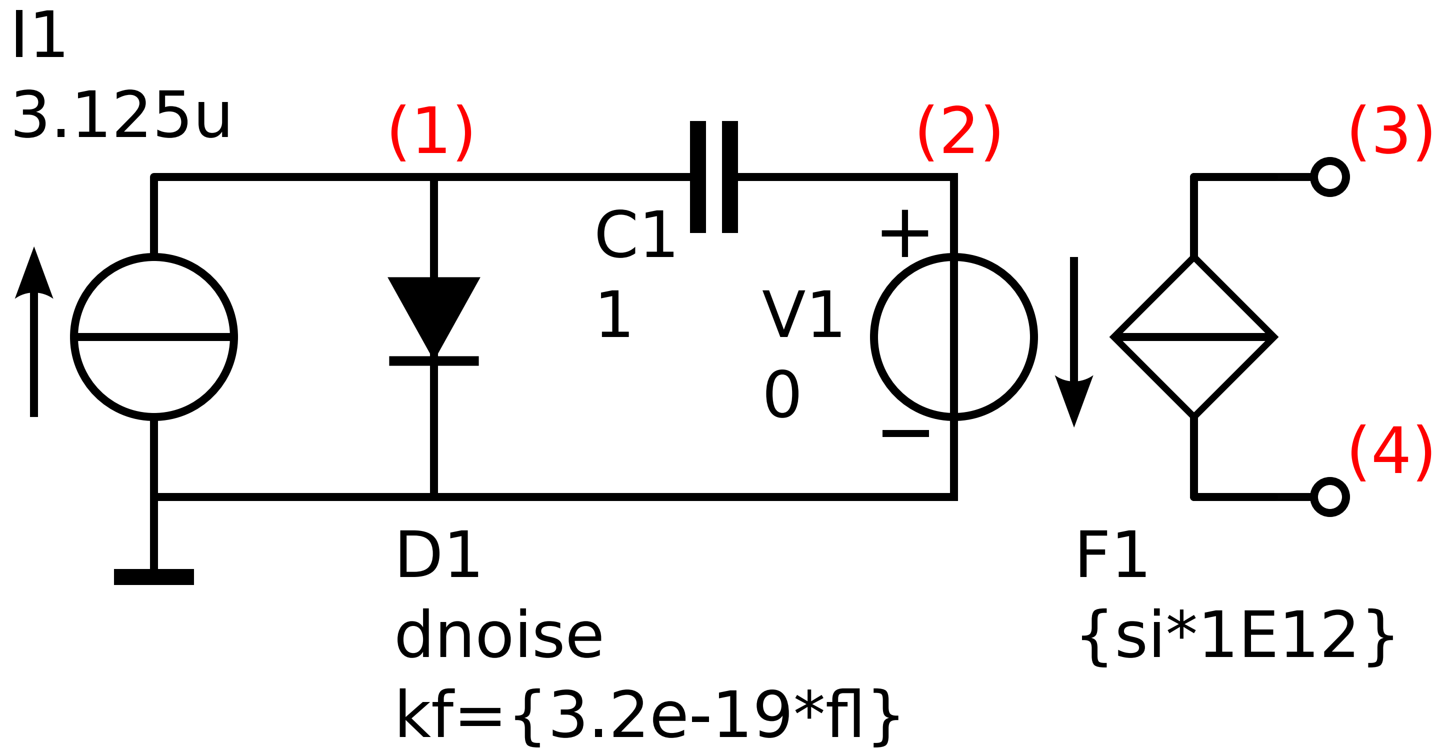
```
.subckt nullor 3 4 1 2
E1 3 4 3 5 1
E2 5 4 1 2 1
.ends
```

Modeling techniques

Spice voltage noise source with
floor noise and 1/f noise
(from 0.1mHz and up)



Spice current noise source with
floor noise and 1/f noise
(from 0.1mHz and up)



Diode noise: $$S_i = 2qI_D\left(1 + \frac{\mathrm{KF} I_D^{\mathrm{AF}-1}}{2qf}\right)$$

sv: floor noise spectrum in V/rt(Hz)
si: floor noise spectrum in A/rt(Hz)
fl: corner frequency 1/f noise

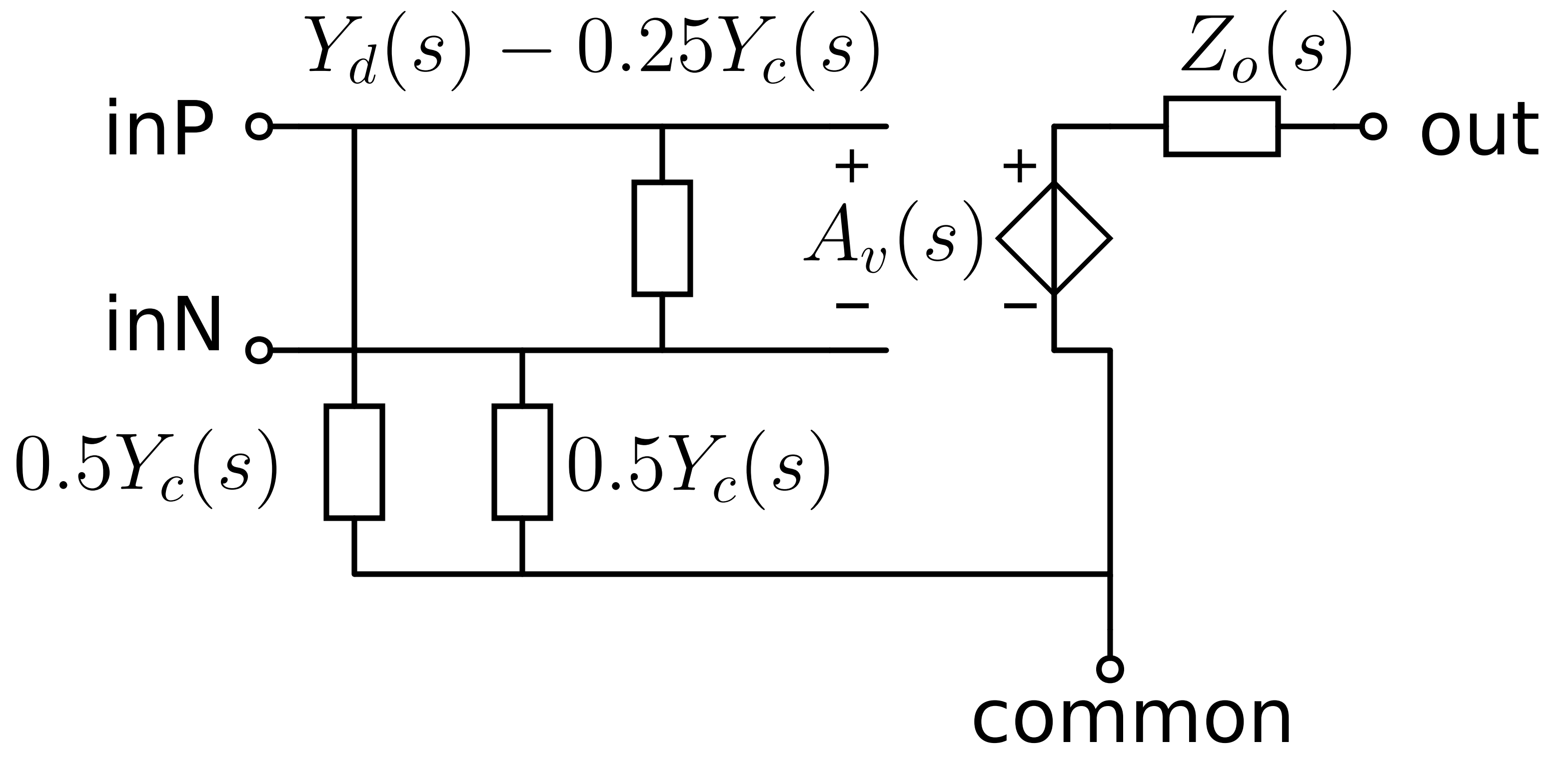
Study: section 8.3.2

Modeling techniques

Small-signal dynamic model voltage-feedback OpAmp

Use active and passive network elements or Laplace blocks

- differential-mode input impedance
- common-mode input impedance
- output impedance
- voltage transfer



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

$$Y_c(s) = G_c + sC_c$$

$$A_v(s) = A_0 \frac{1+b_1 s+b_2 s^2+\cdots b_m s^m}{1+a_1 s+a_2 s^2+\cdots a_n s^n}$$

First order: $A_v(s) = A_0 \frac{1}{1+s\frac{A_0}{2\pi \mathrm{GB}}}$

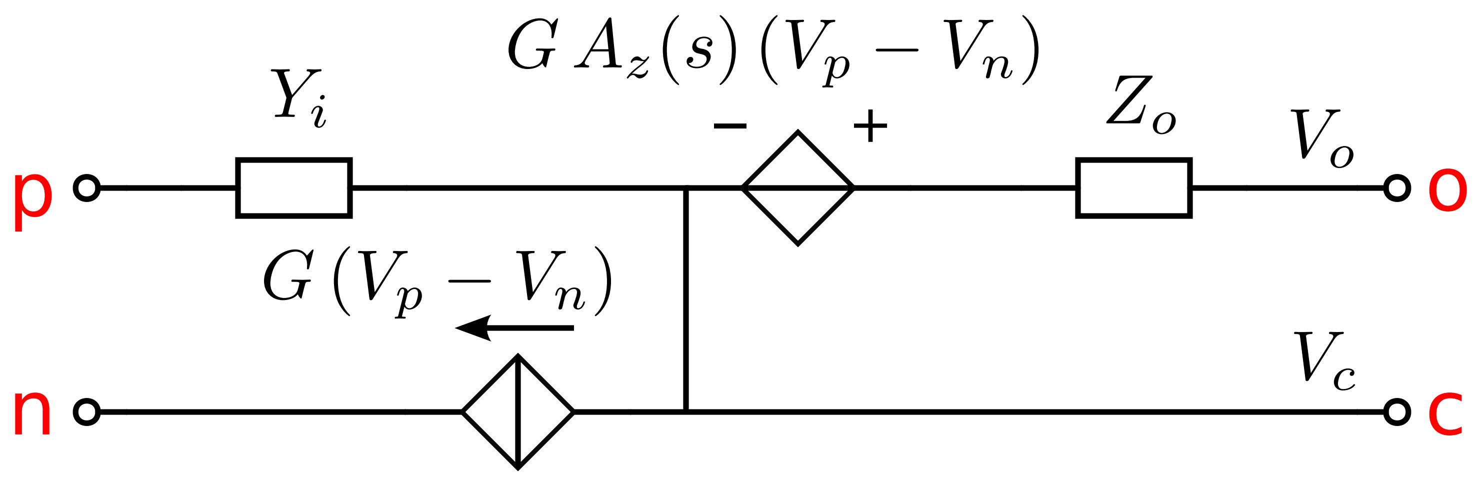
$Z_o(s)$ complex impedance not always specified in data sheet

Modeling techniques

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
- transimpedance output stage



$Y_i(s) = G_i + sC_i$

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

$A_z(s) = Z_0 \frac{1+b_1 s + b_2 s^2 + \cdots b_m s^m}{1+a_1 s + a_2 s^2 + \cdots a_n s^n}$ First order: $A_z(s) = R_0 \frac{1}{1+s\frac{R_0 G}{2\pi \mathrm{GB}}}$

