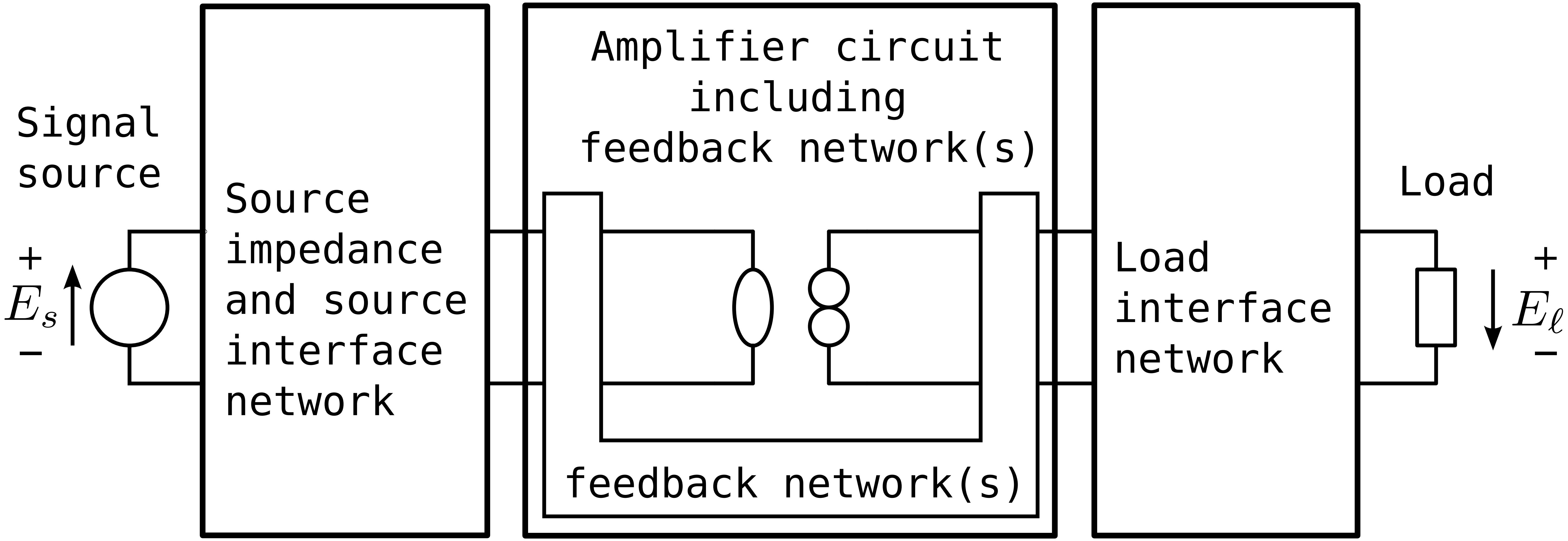
Structured Electronic Design

Noise Design of Input Stage MOS
in Feedback Amplifiers

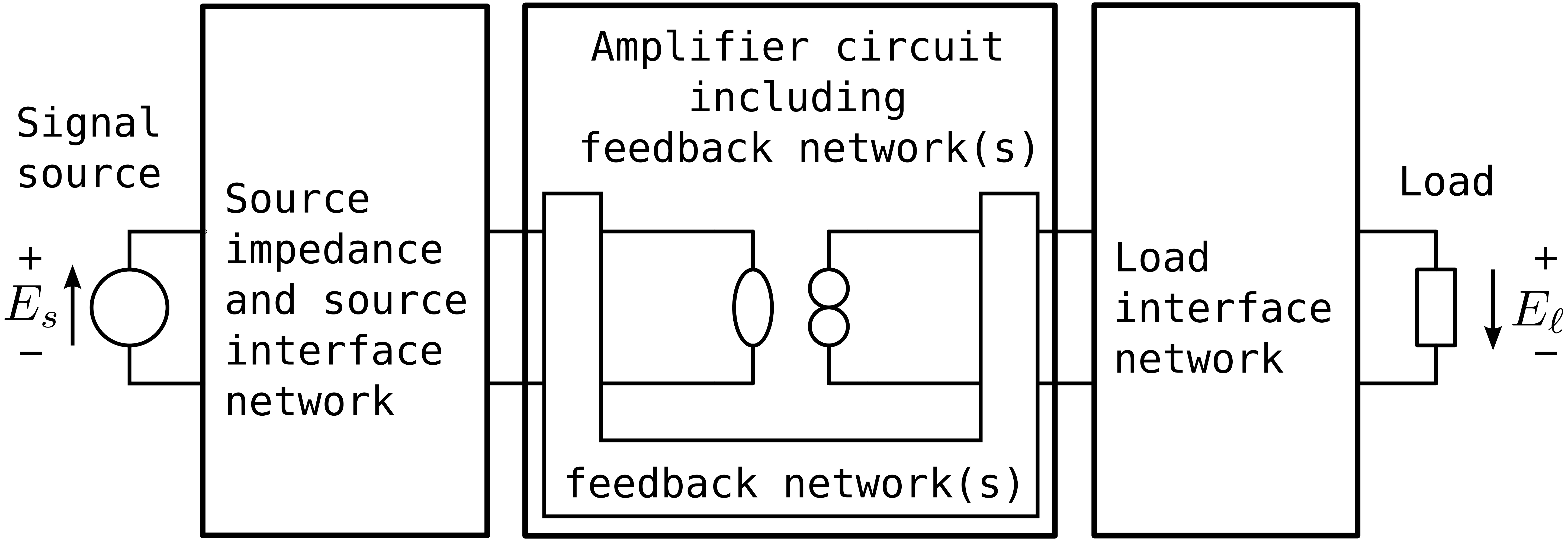
Anton J.M. Montagne

Structure Feedback Amplifier



Known at the start of the controller's noise design

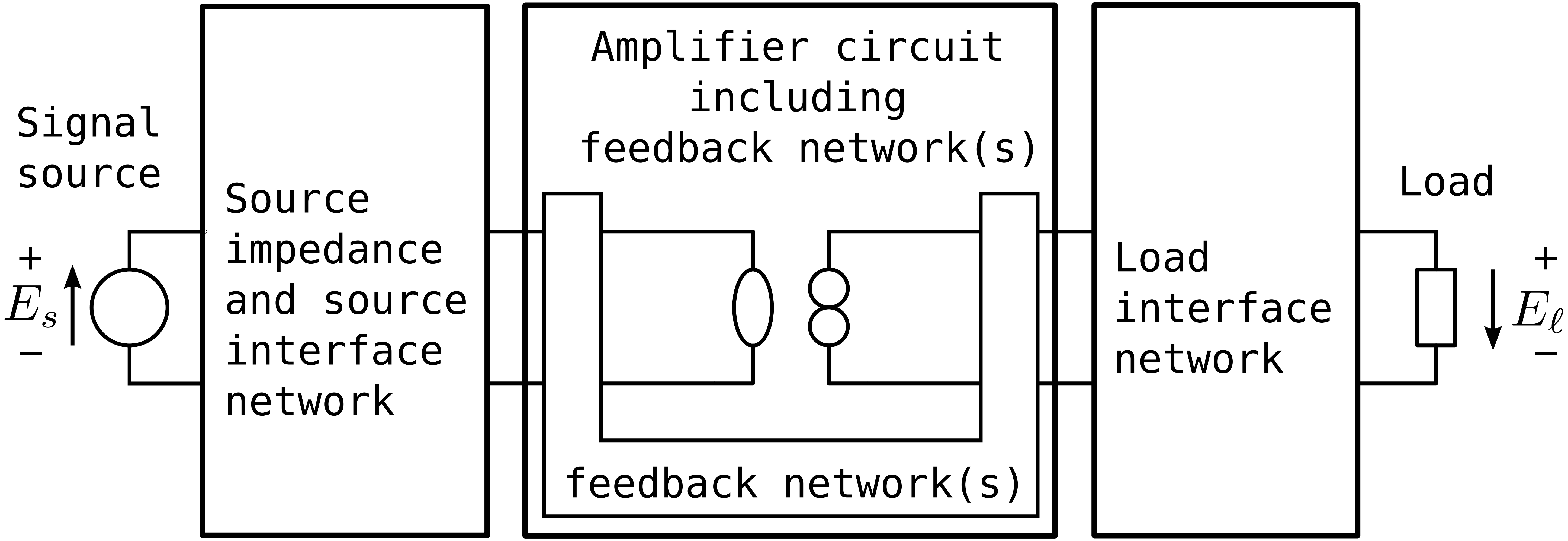
Structure Feedback Amplifier



Known at the start of the controller's noise design

Source impedance

Structure Feedback Amplifier



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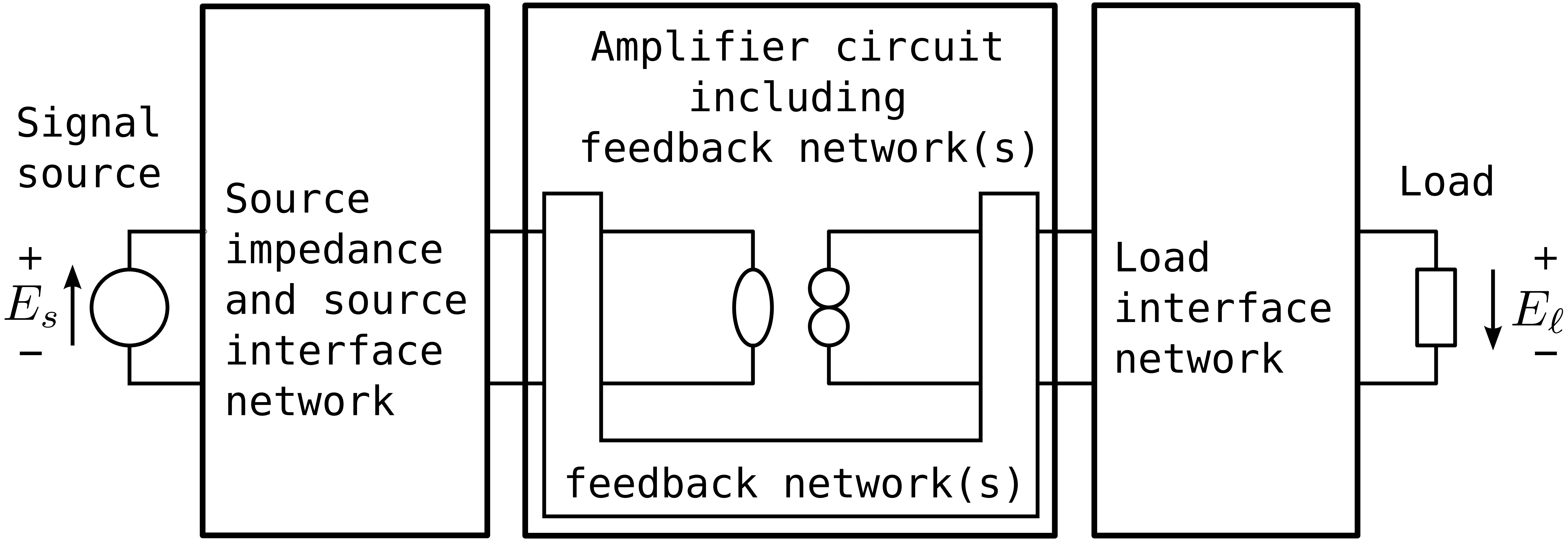
Source impedance

Source interface network

Structure Feedback Amplifier



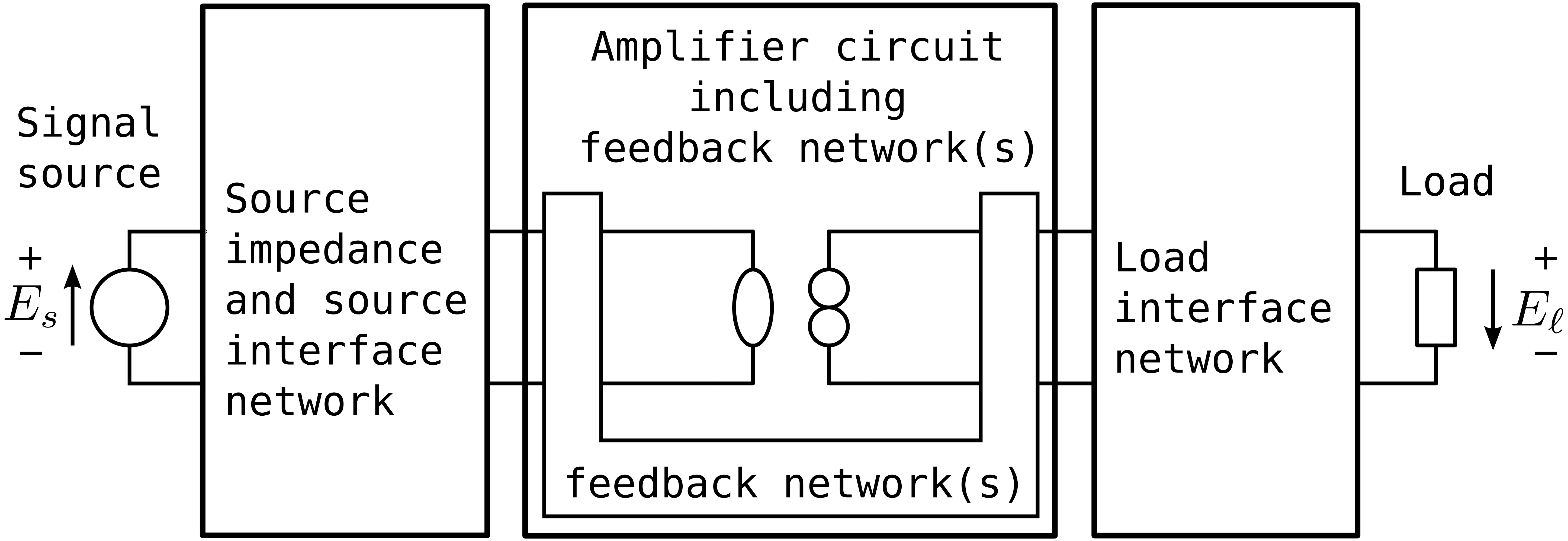
Known at the start of the controller's noise design

Source impedance

Load impedance

Source interface network

Structure Feedback Amplifier

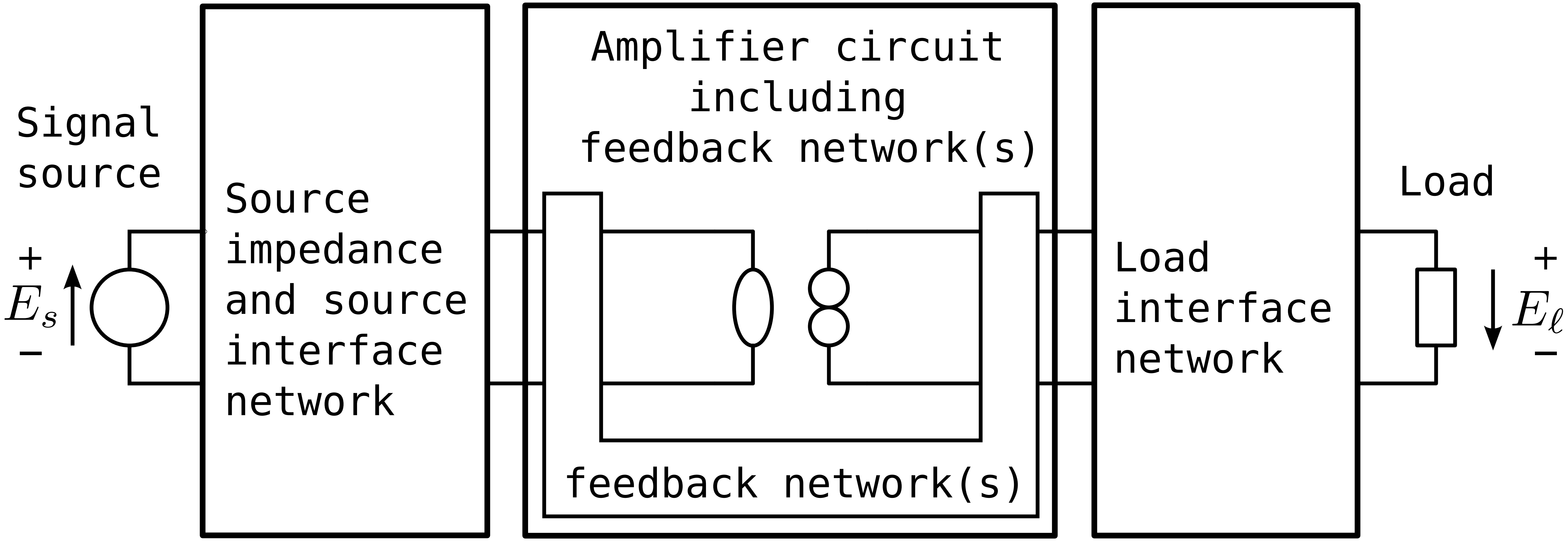


Known at the start of the controller's noise design

Source impedance
Load impedance

Source interface network
Load interface network

Structure Feedback Amplifier

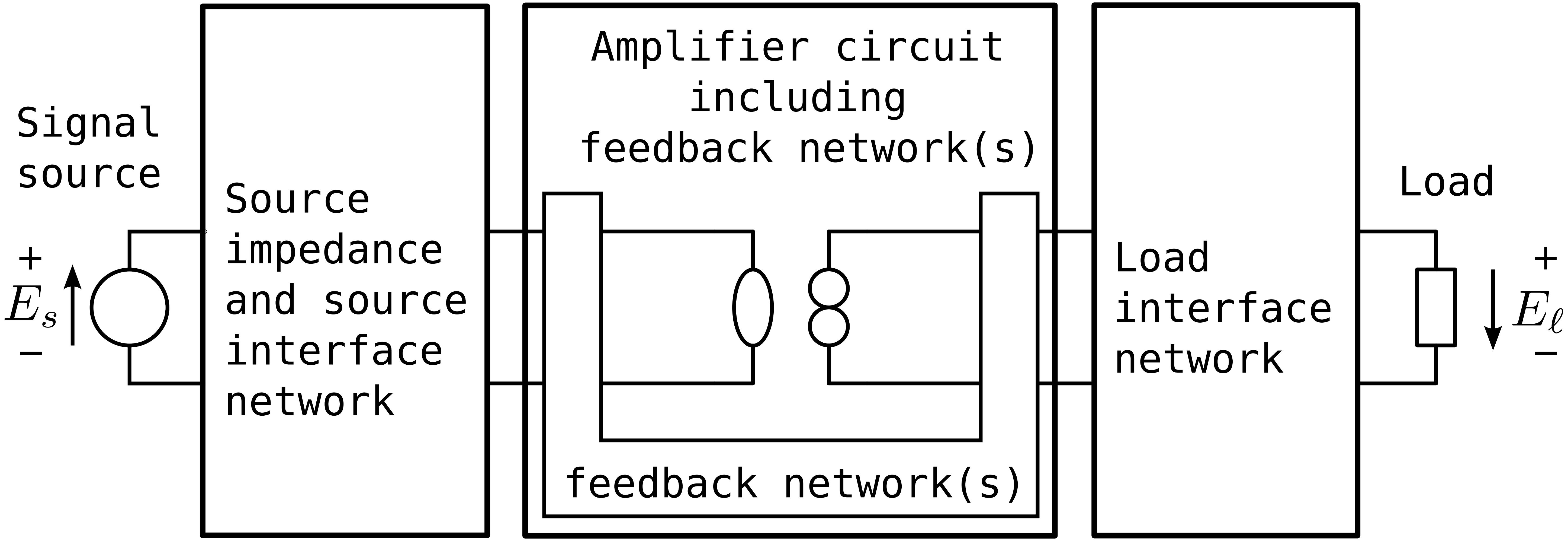


Known at the start of the controller's noise design

Source impedance
Load impedance
Feedback network(s)

Source interface network
Load interface network

Structure Feedback Amplifier



Known at the start of the controller's noise design

Source impedance
Load impedance
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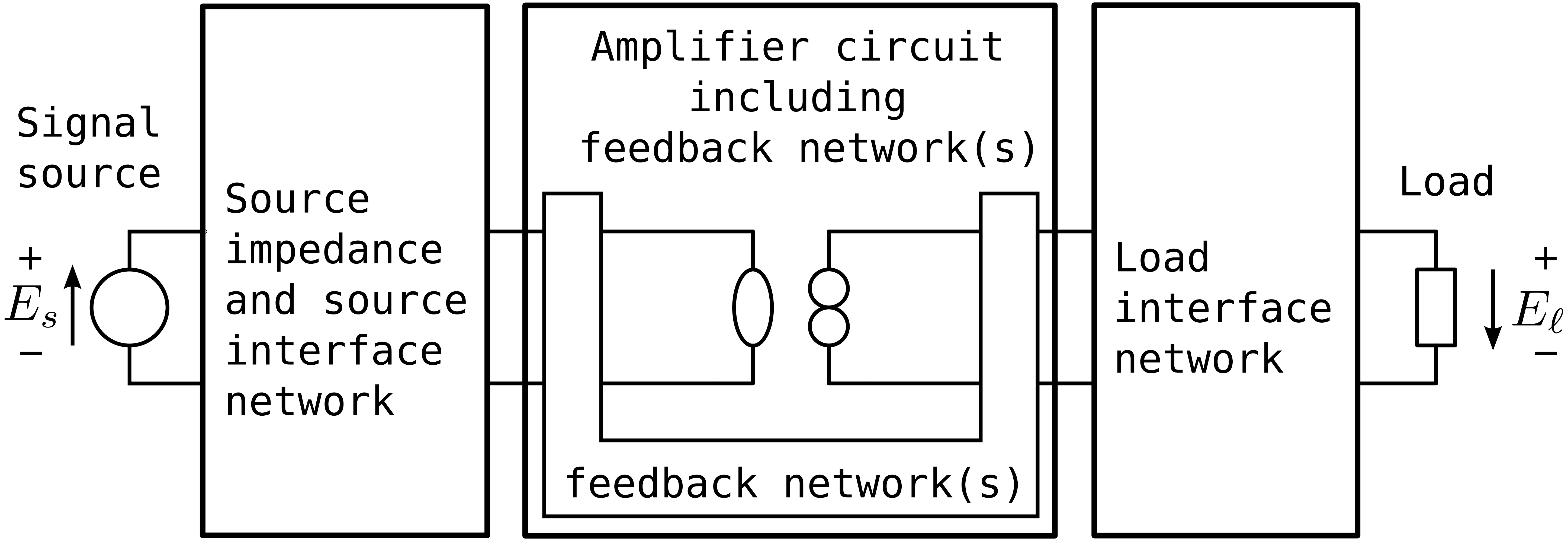
Source interface network
Load interface network
Output noise weighting function

Structure Feedback Amplifier



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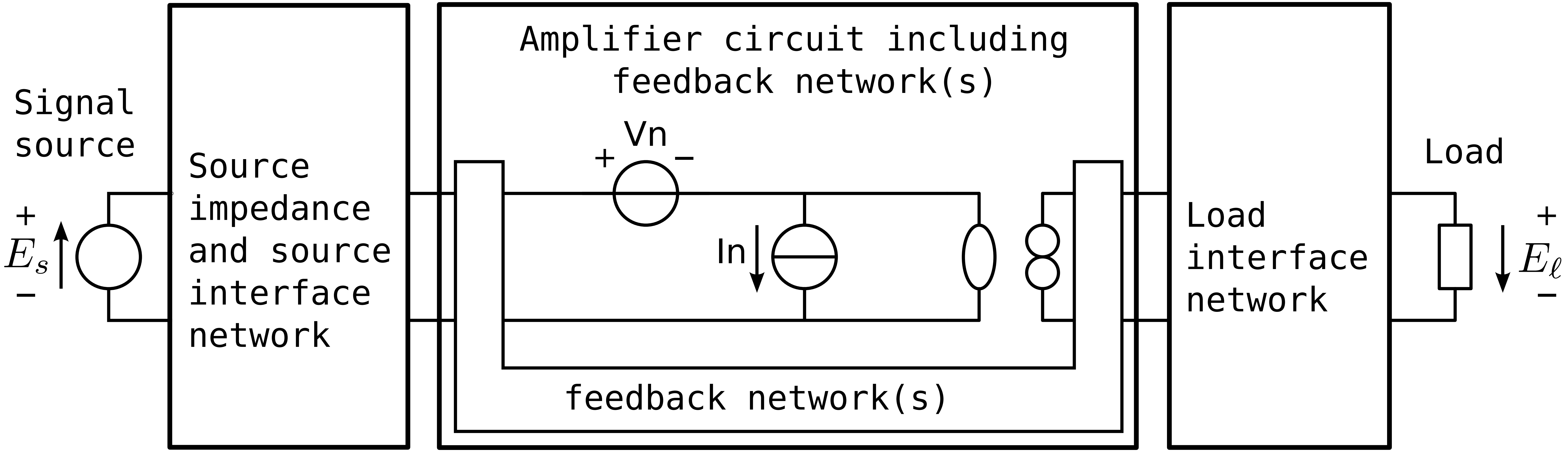
Noise Transfer Functions



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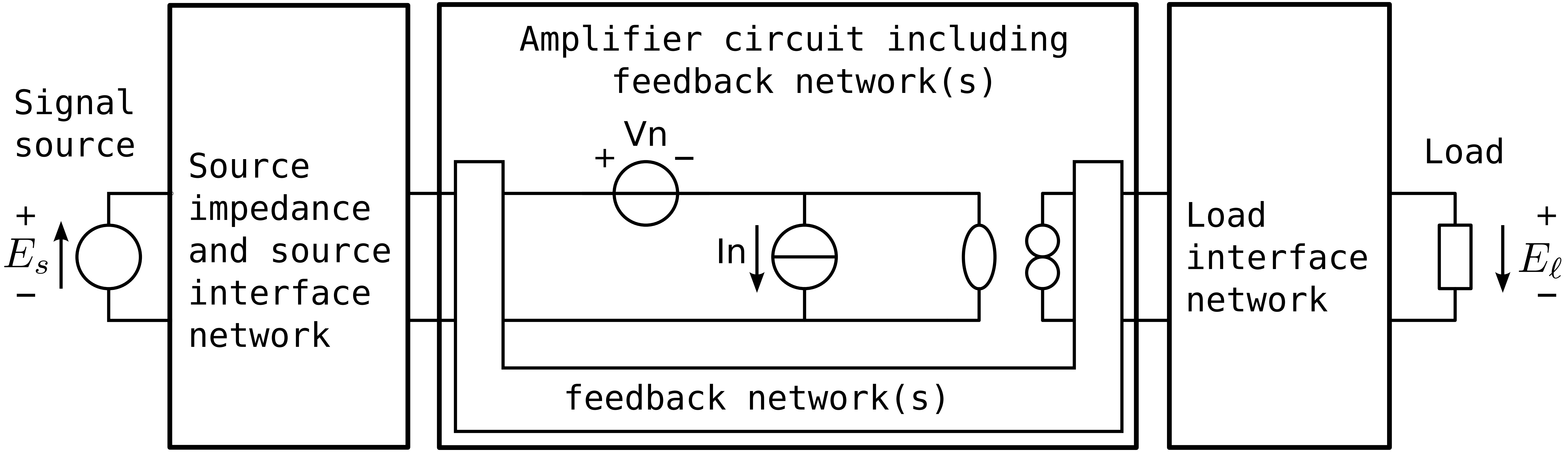
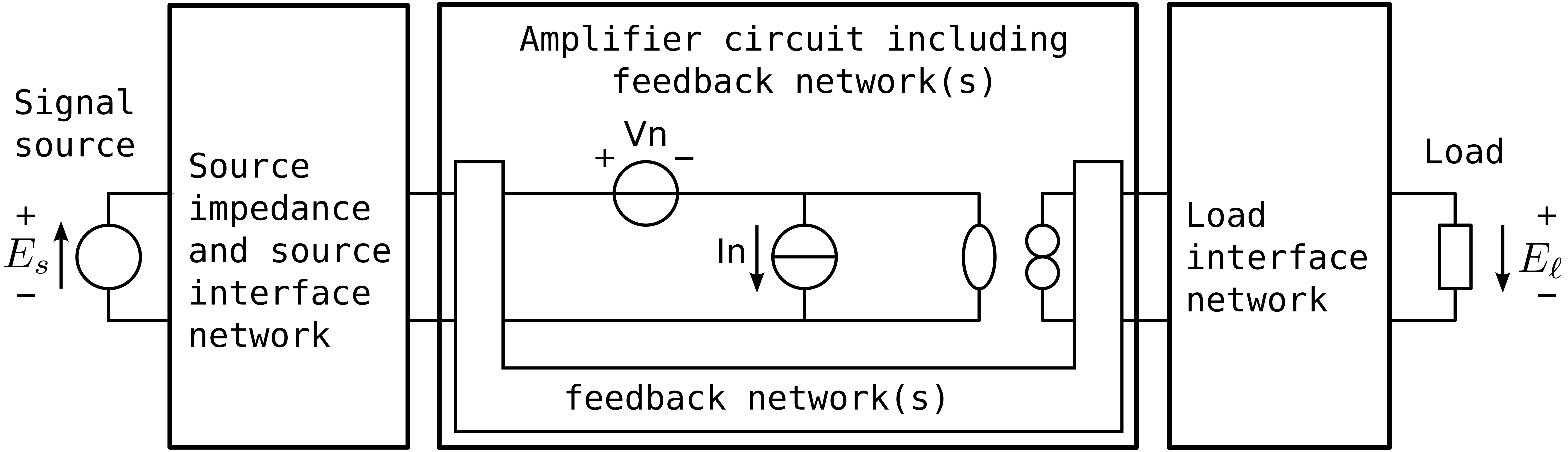


$H_v(f)$: Transfer function from V_n to the output noise e_{ℓ_n}

Noise Transfer Functions



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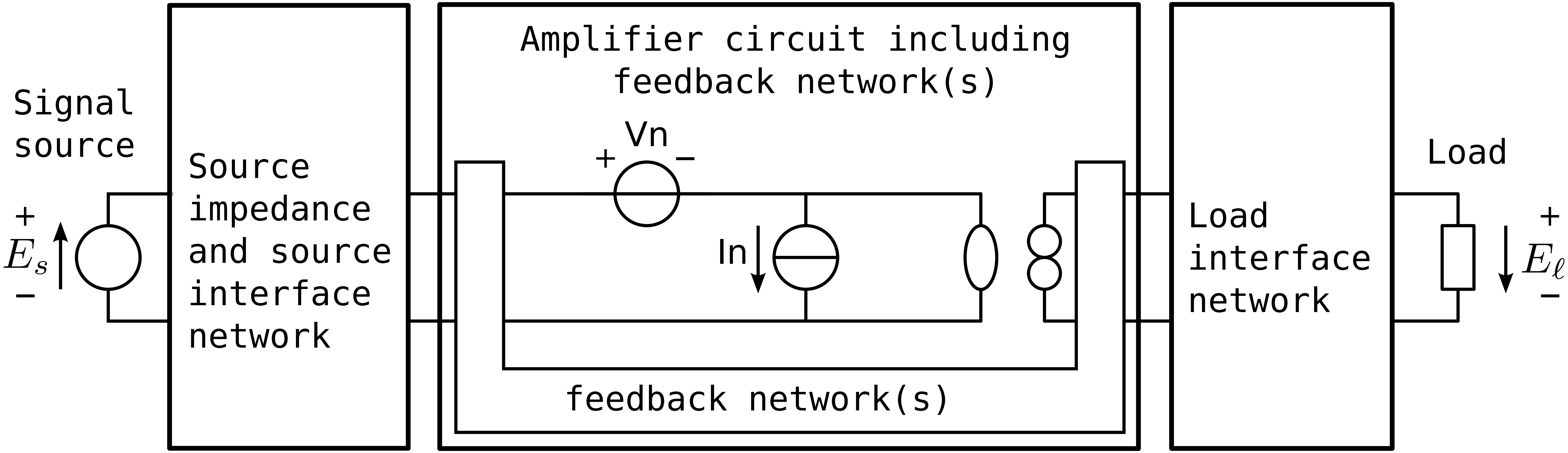

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$\frac{H_i(f)}{H_v(f)} = Z_n(f)$: Driving-point impedance at nullor input.

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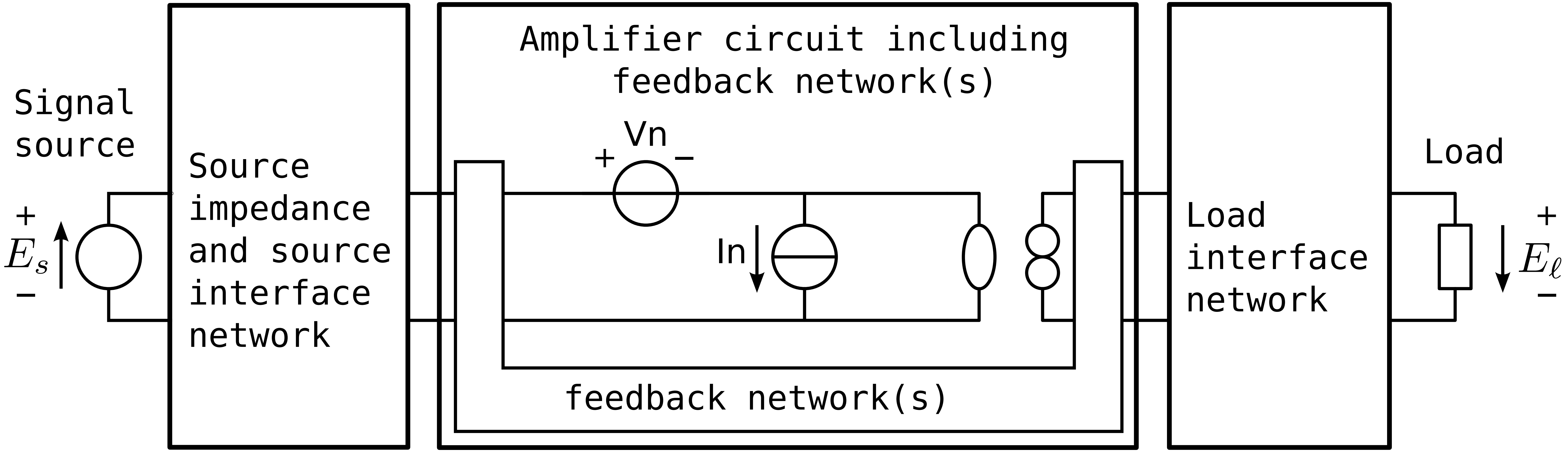

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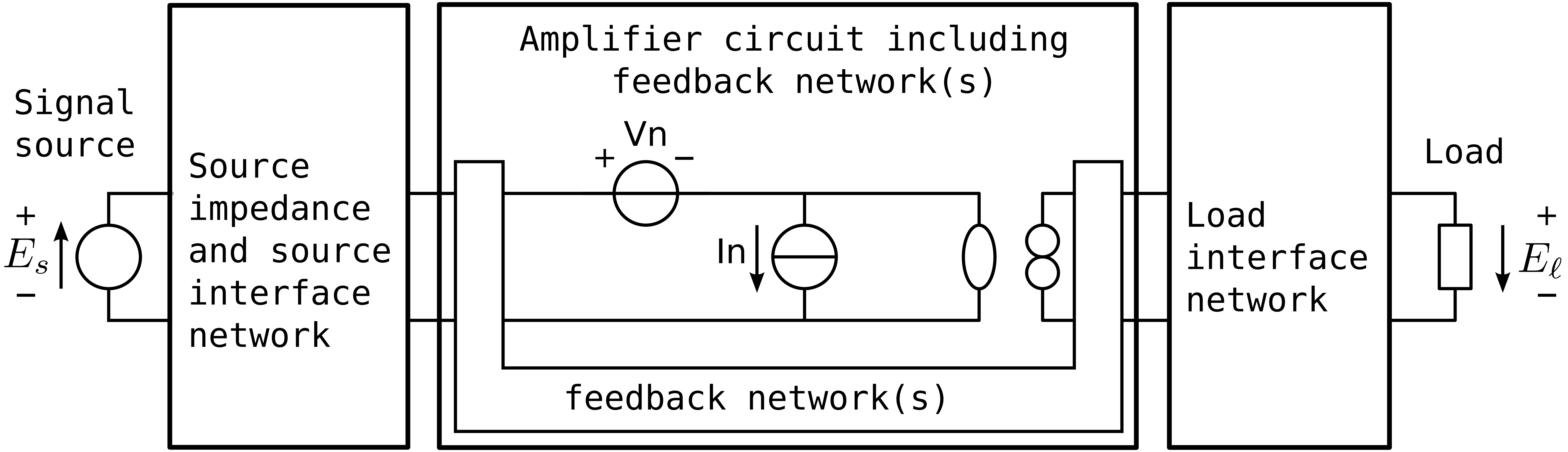

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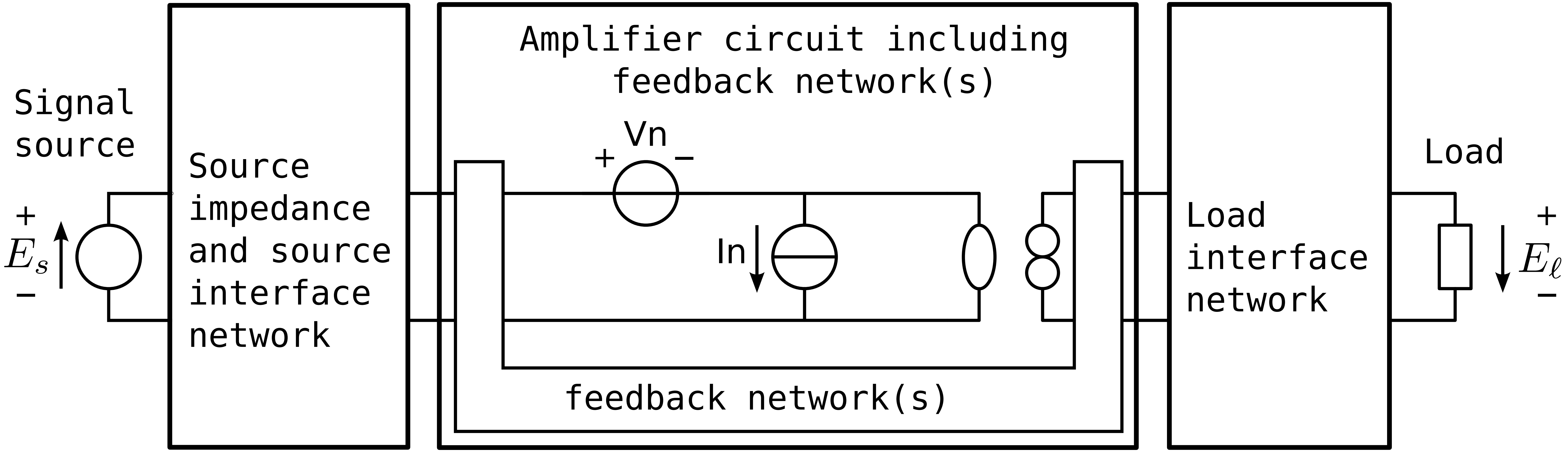

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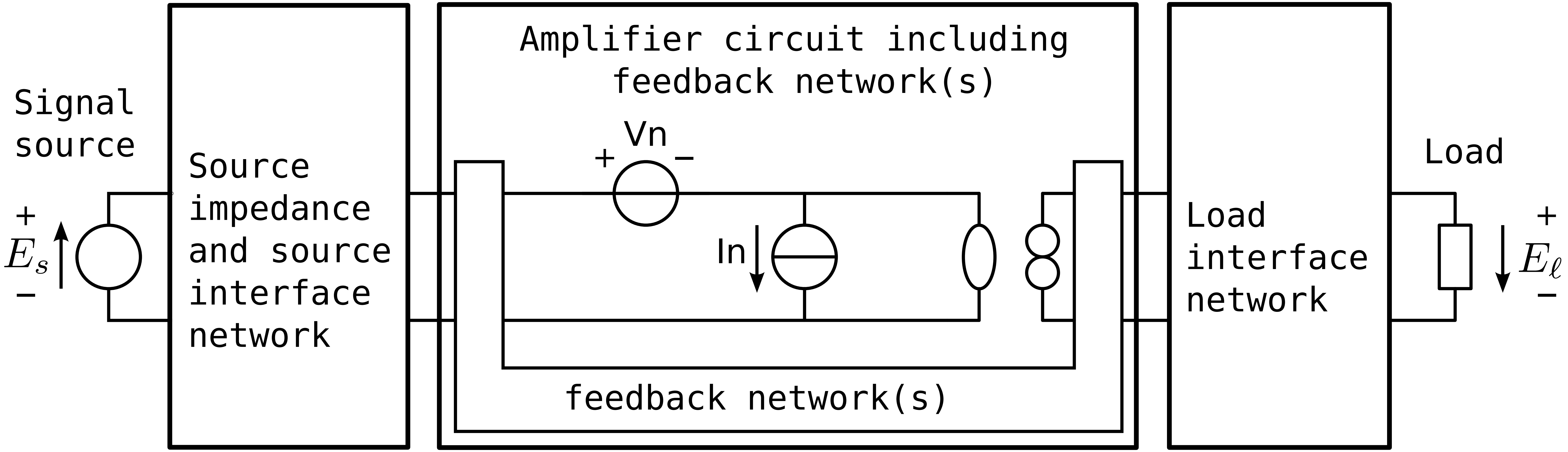
Contribution of Vn to the weighted output noise

Noise Transfer Functions



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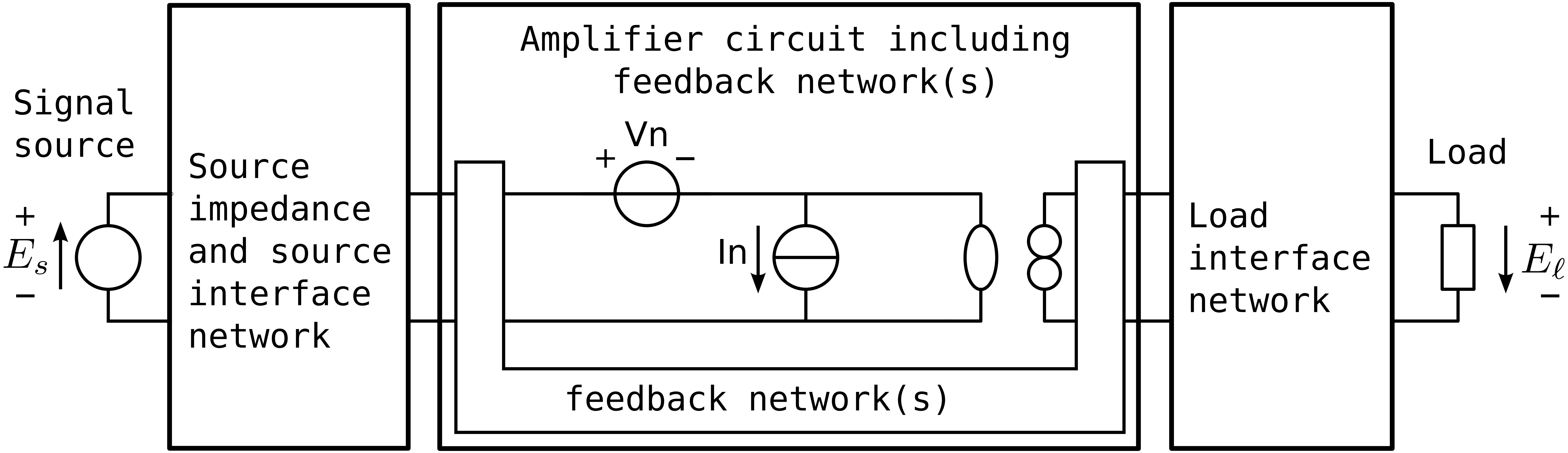
Contribution of Vn to the weighted output noise

Contribution of In to the weighted output noise

Noise Transfer Functions



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Contribution of Vn to the weighted output noise

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Contribution of the source, the feedback and the interface network(s) to the weighted output noise

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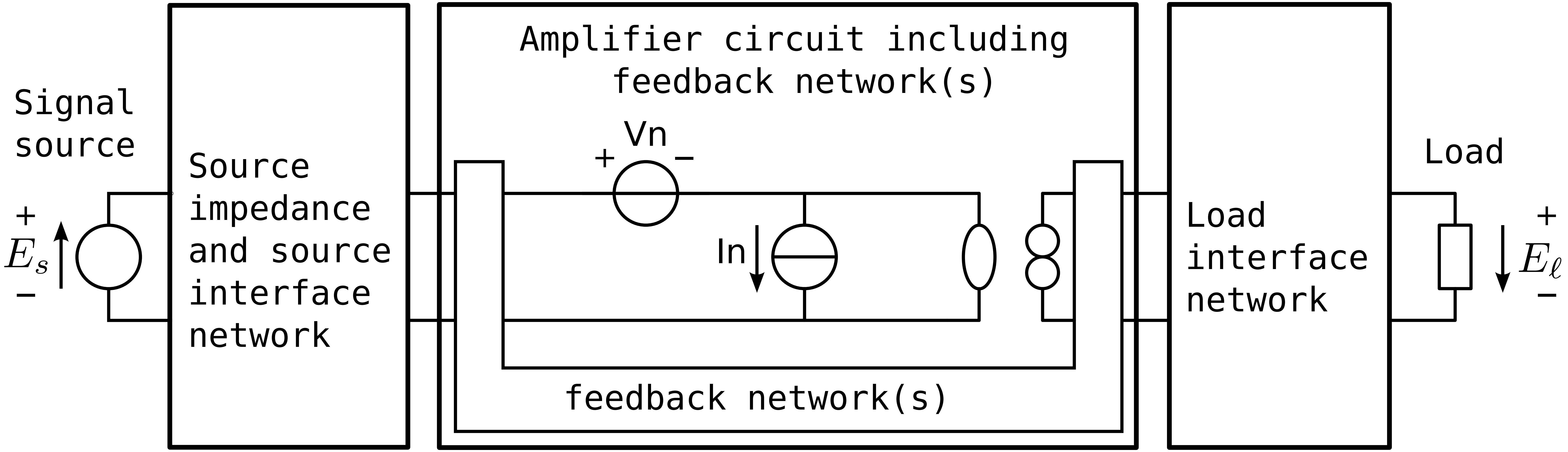

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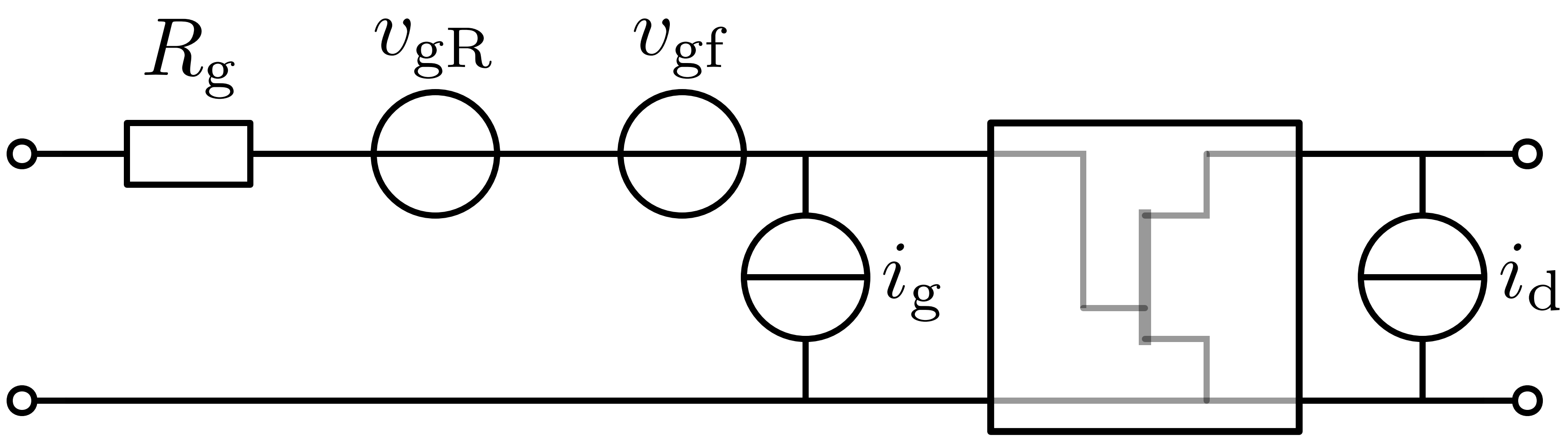
MOS Noise Model



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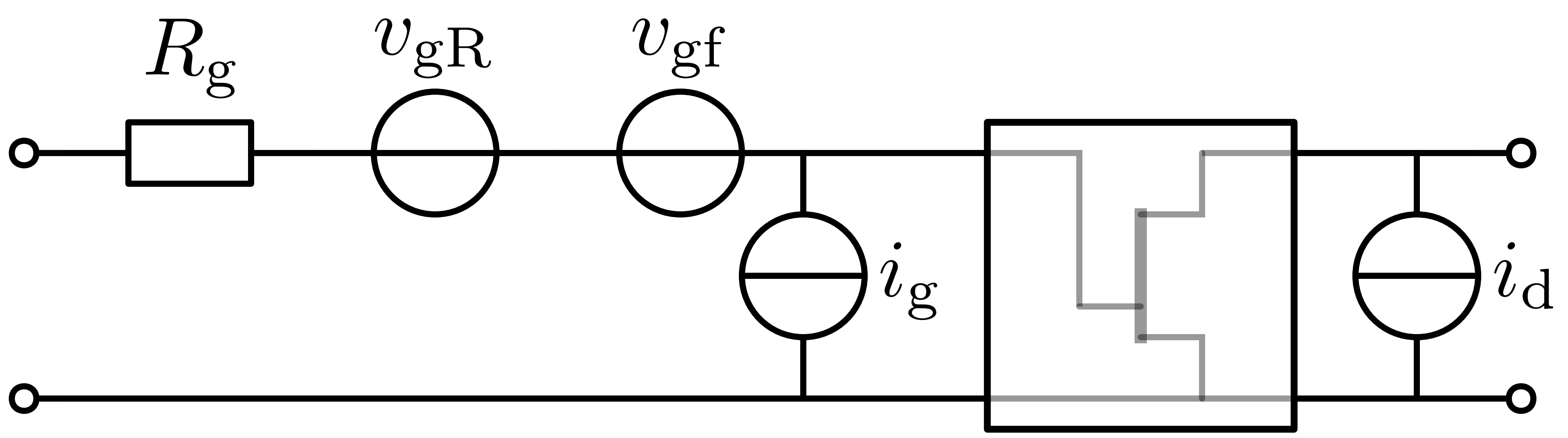
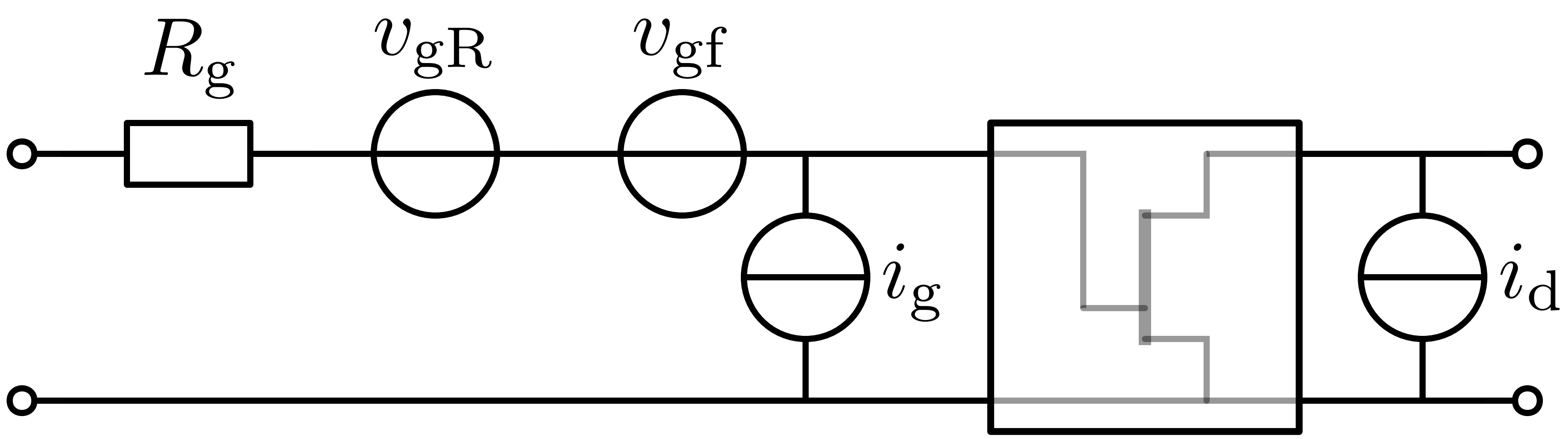


R_g: gate (series) resistance

MOS Noise Model



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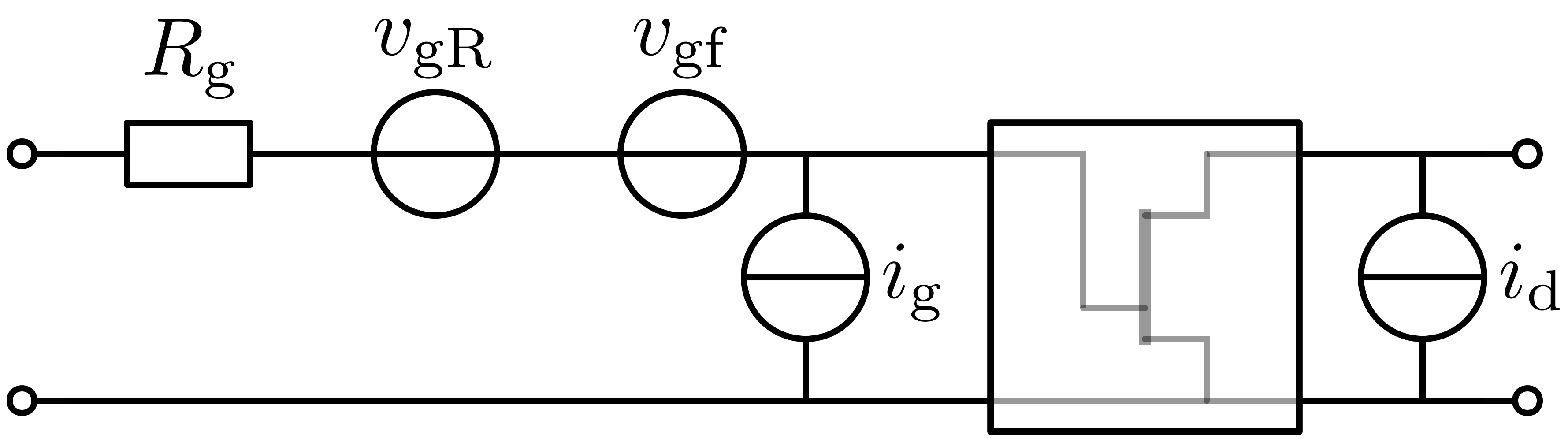

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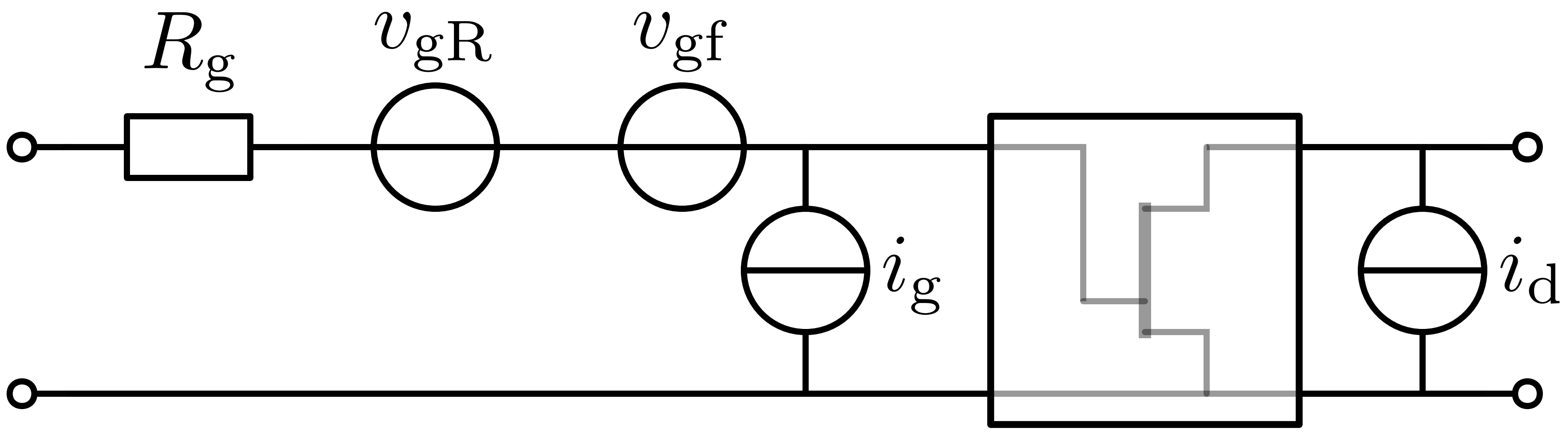

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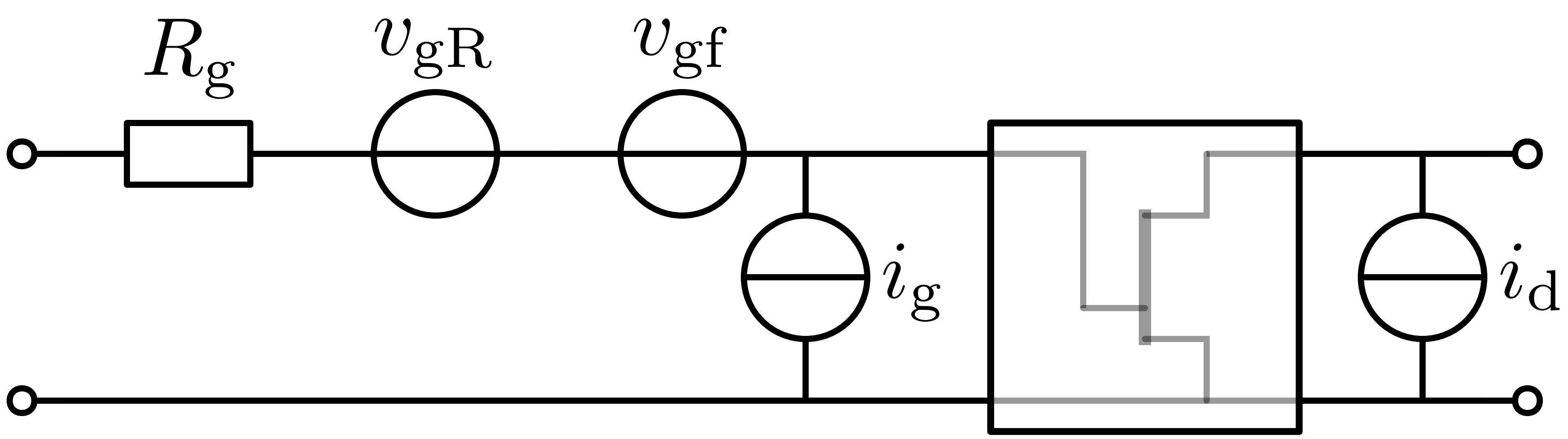

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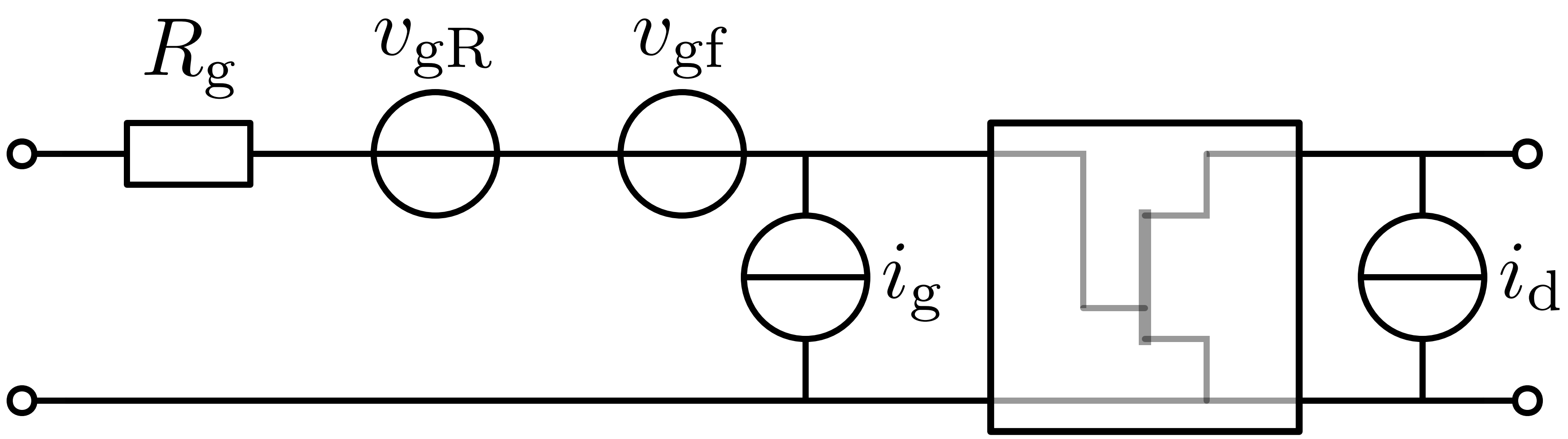

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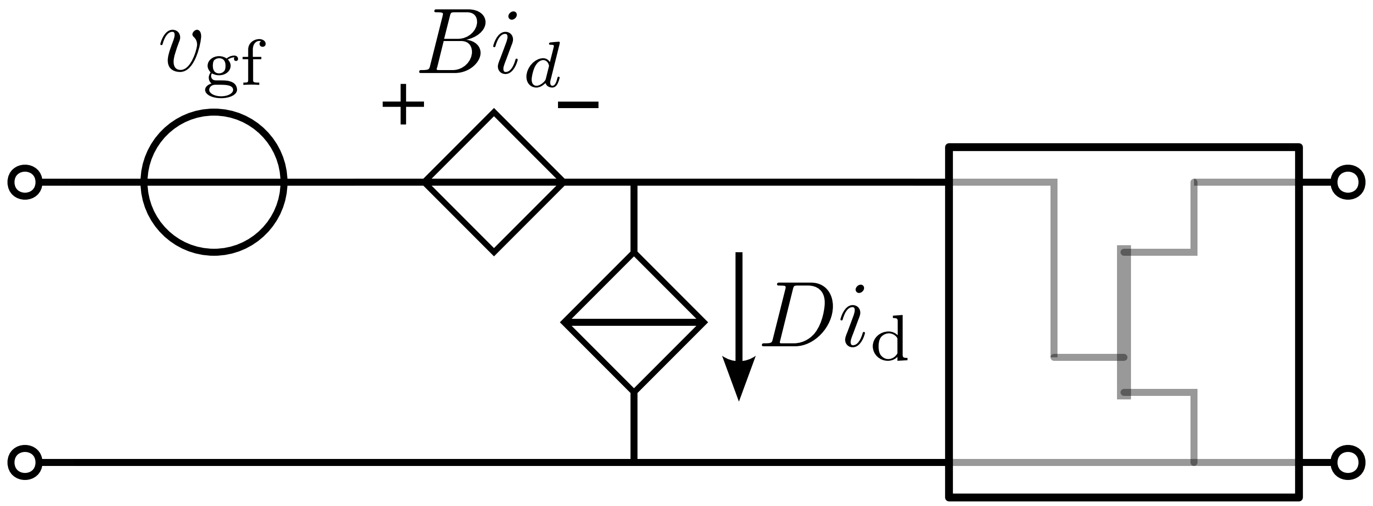
MOS Noise Transformations-1



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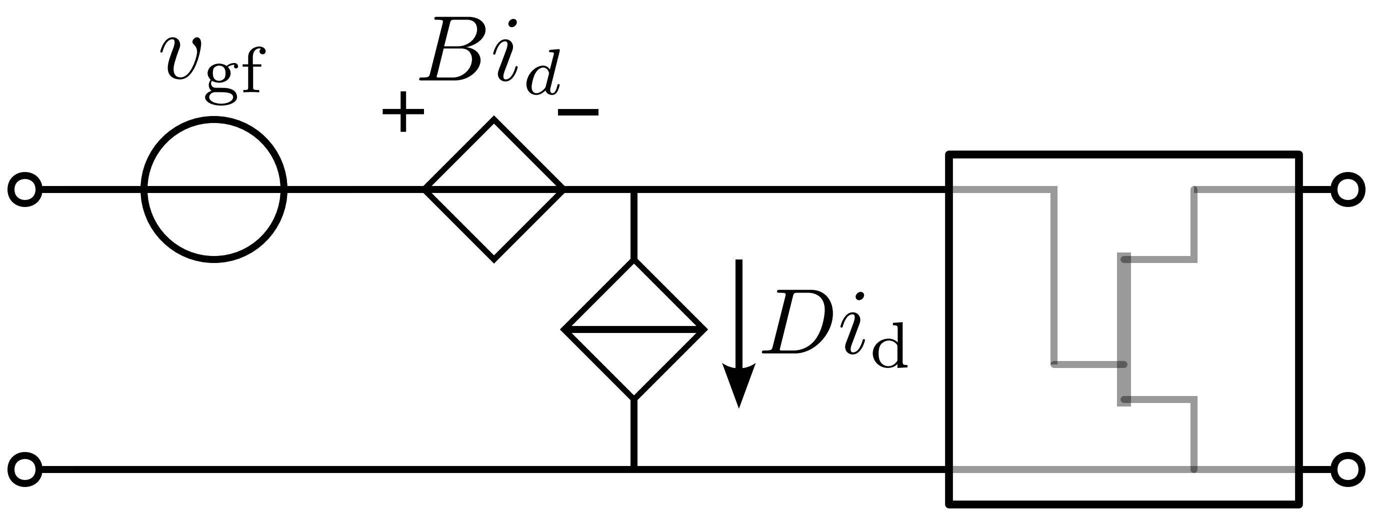

$$B = \frac{1}{j2\pi f c_{\mathrm{dg}} - g_m} \approx \frac{1}{g_m}$$

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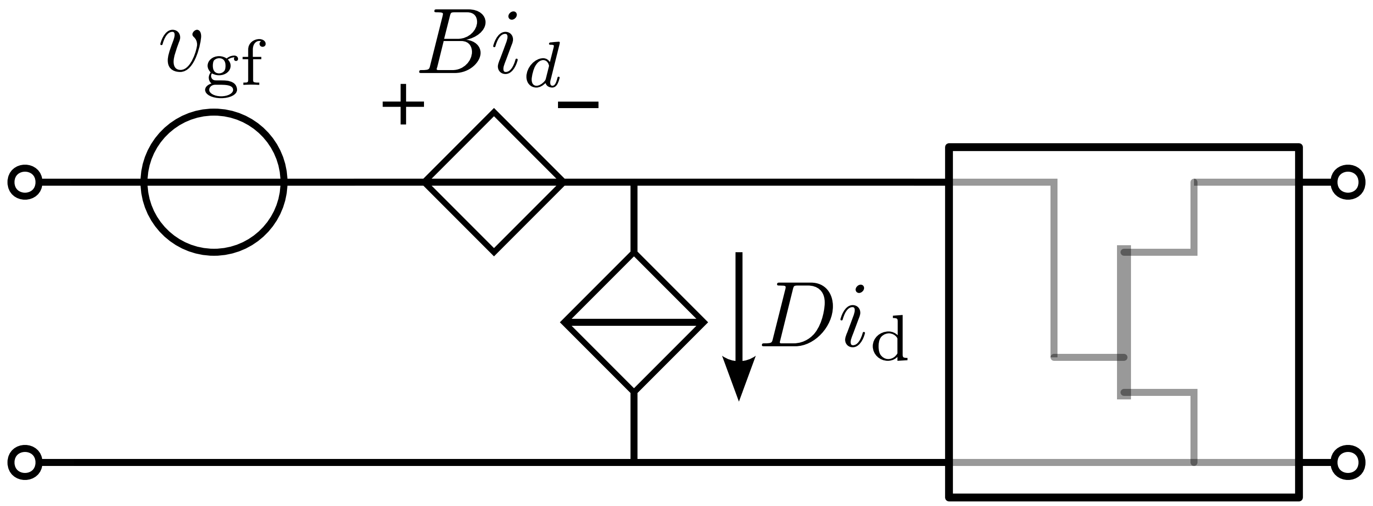

$$B = \frac{1}{j2\pi f c_{\mathrm{dg}} - g_m} \approx \frac{1}{g_m}$$

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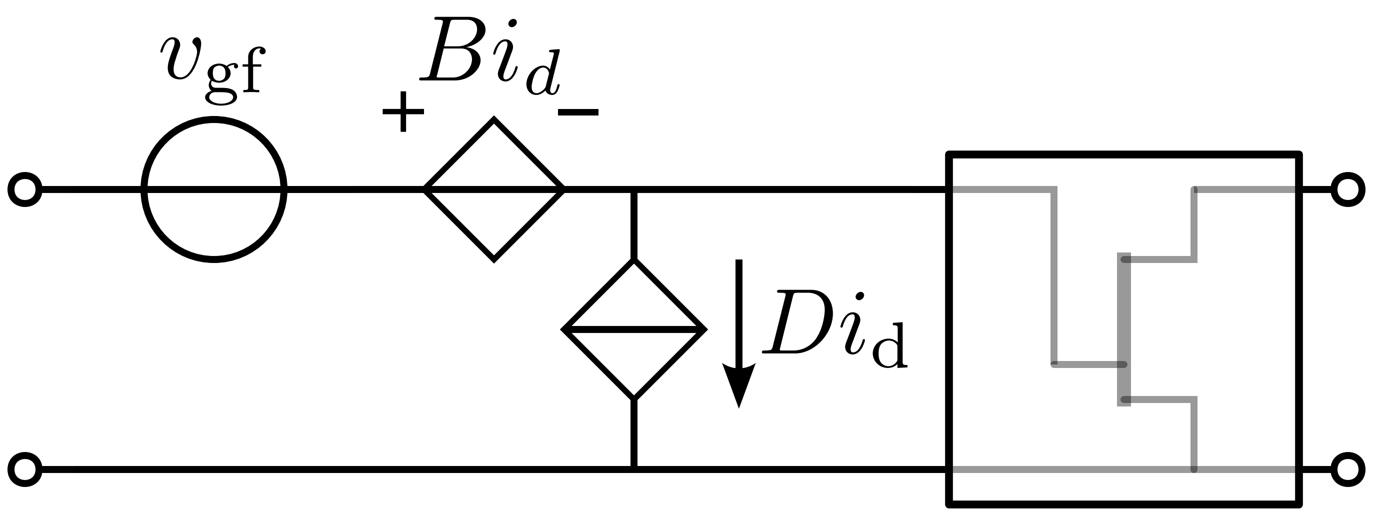

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Negative signs accounted for in the source directions

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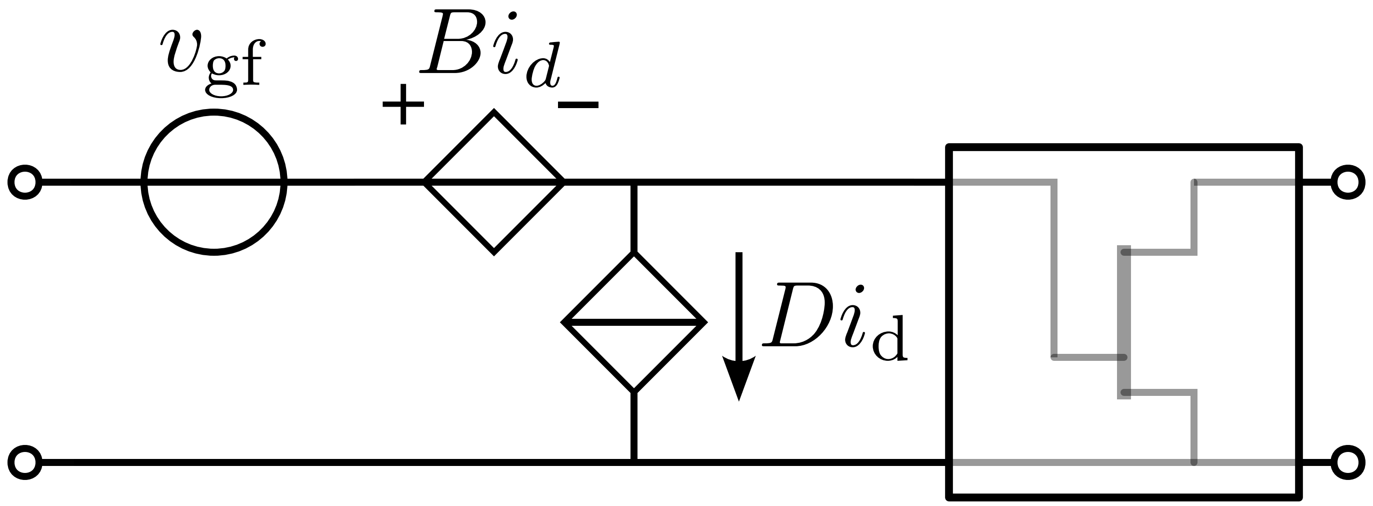

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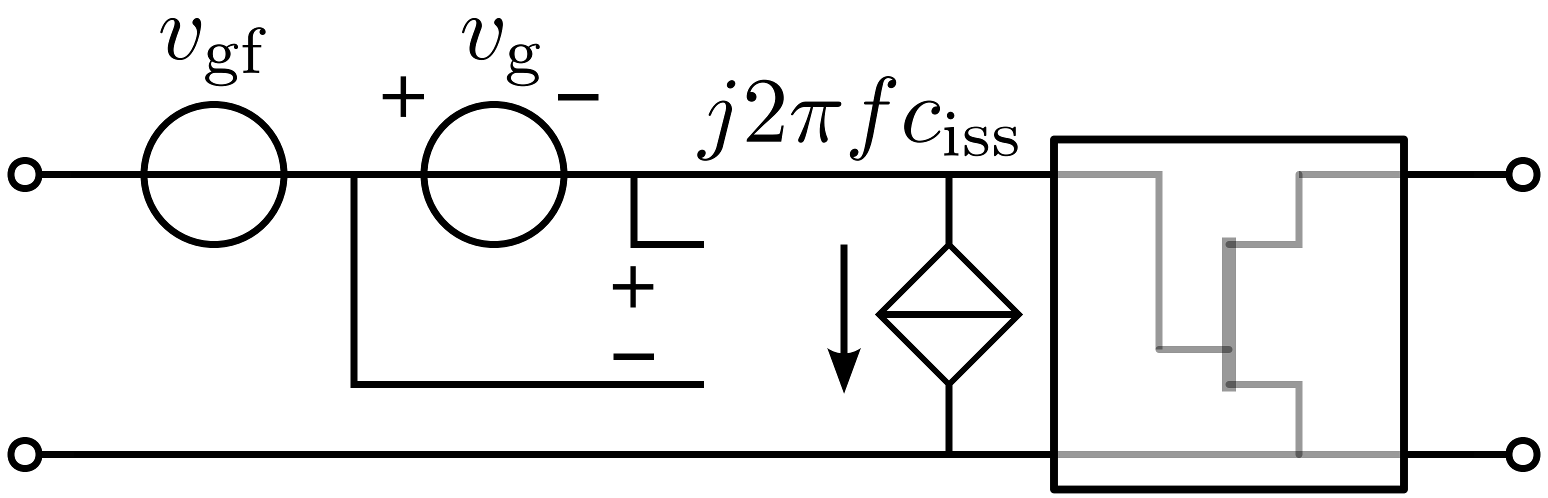

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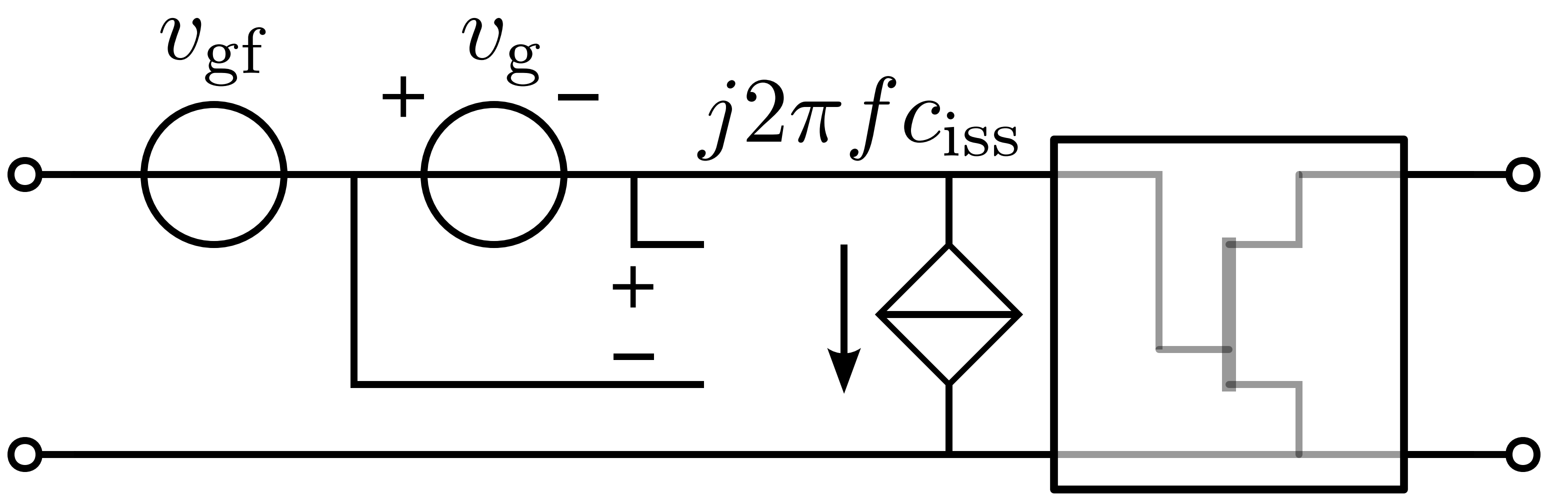

$$S_{v_g} = \frac{4kTn\Gamma}{g_m}$$

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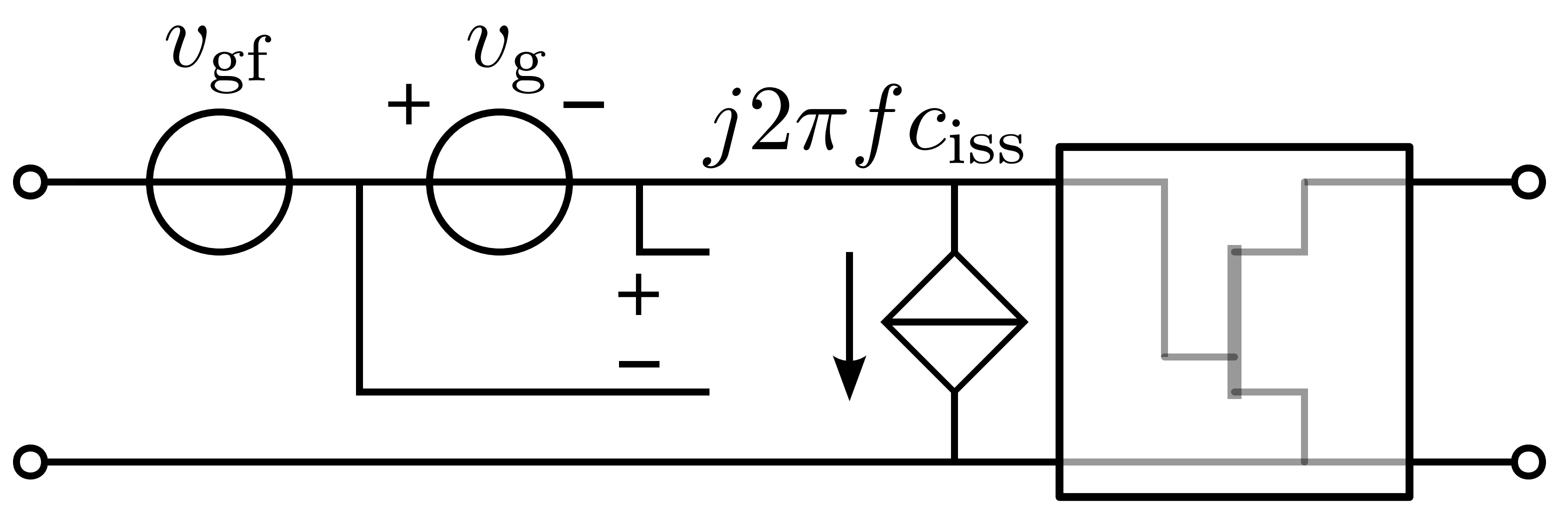

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Ignore the overlap capacitances:
the input capacitance is proportional with the oxide capcitance:

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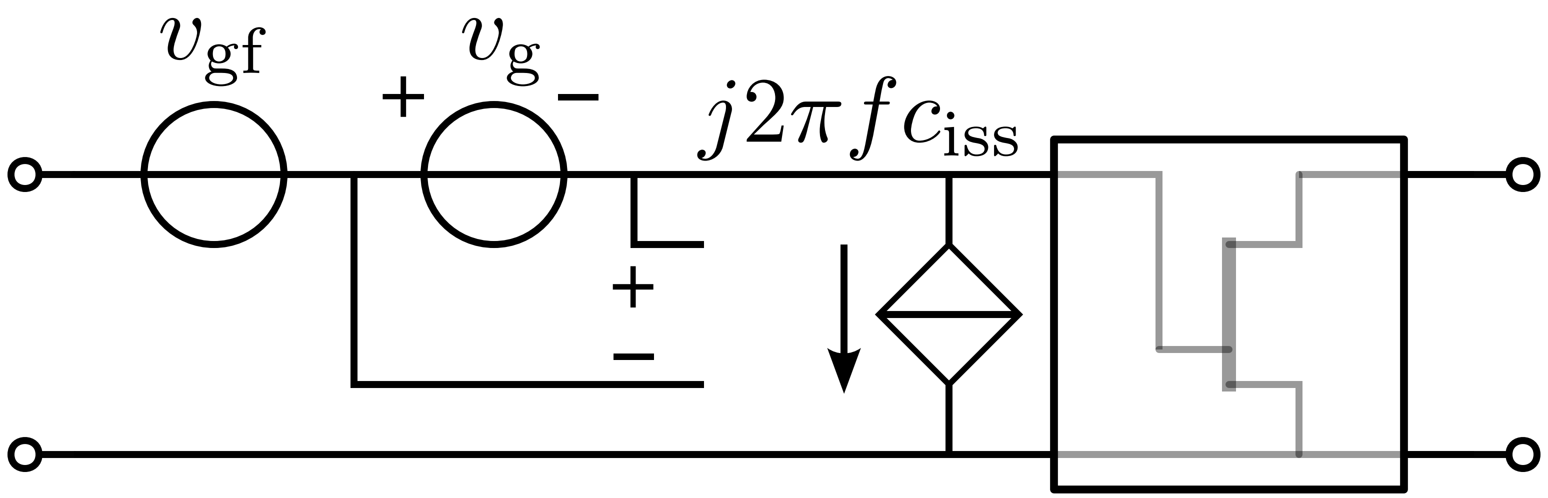

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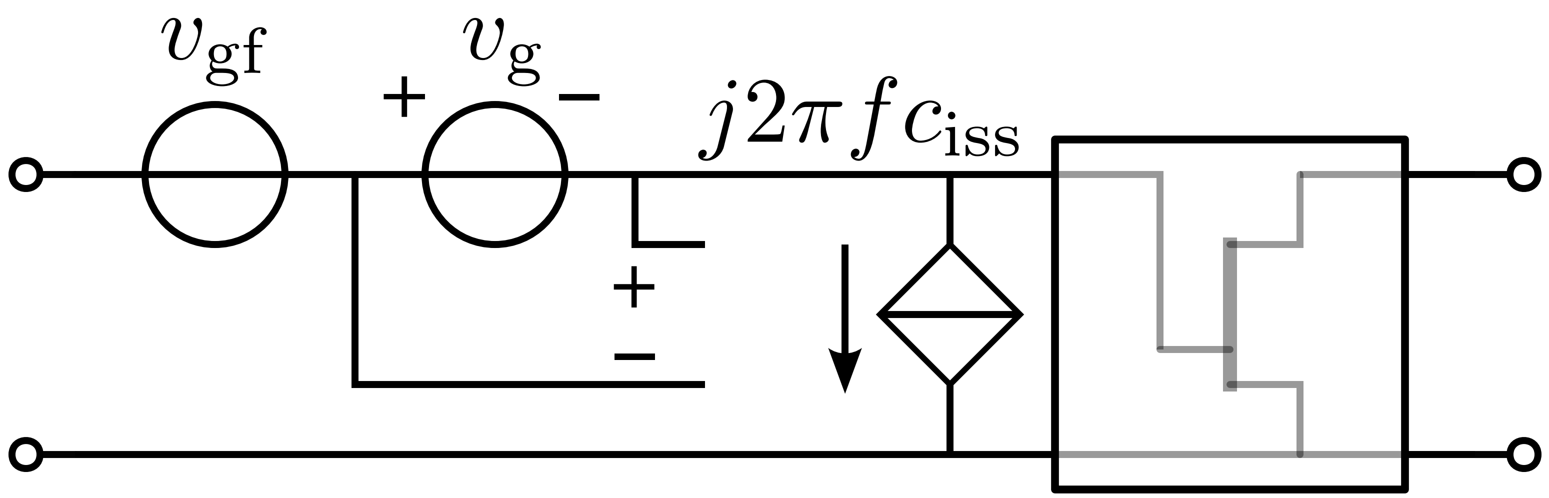

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χ, Γ and K_F depend on the inversion level

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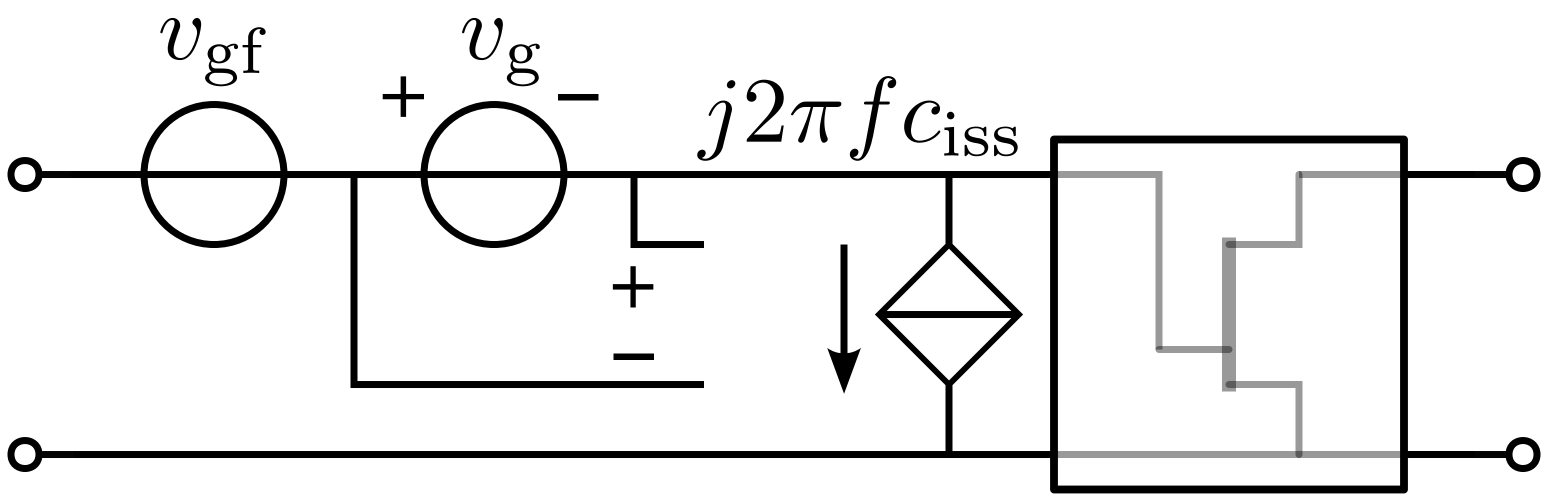

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$\chi = 0.26 \cdots 0.6$ with $IC = 0 \cdots \infty$ and $n = 1.35$

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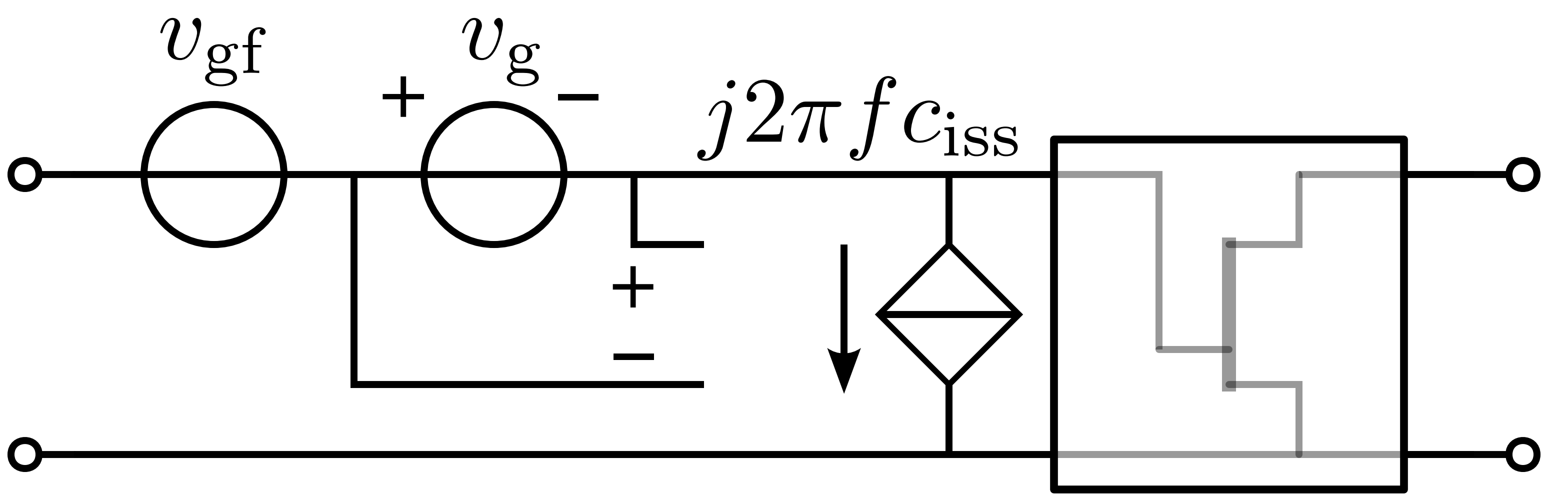

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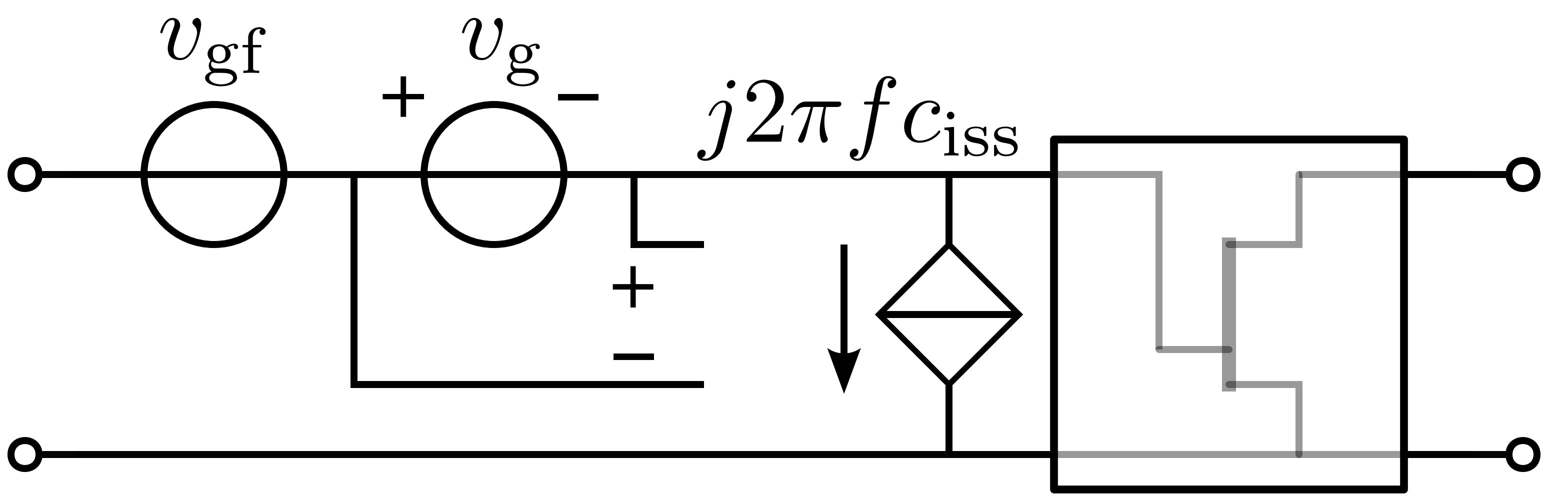

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$\Gamma = \frac{1}{2} \cdots \frac{2}{3}$ with $IC = 0 \cdots \infty$

$$K_F = K_{F0}\left(1 + \frac{V_{\rm EFF}}{V_{\rm KF}}\right)^2 \qquad V_{\rm KF} = 0.2 \cdots 2$$

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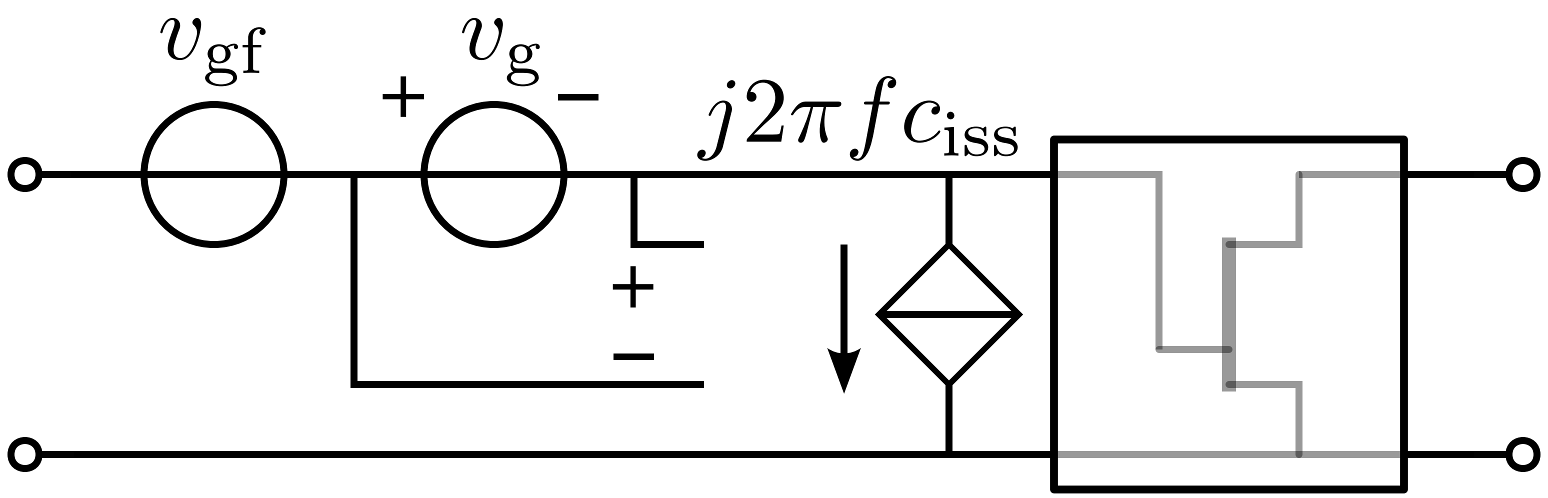

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$$c_{\text{iss}} = \chi WLC_{\text{OX}} \qquad S_{v_{gf}} = \frac{K_F}{C_{\text{OX}}^2 WLf^{\text{AF}}} \approx \frac{\chi K_F}{C_{\text{OX}} c_{\text{iss}} f^{\text{AF}}} \ \text{V}^2/\text{Hz}$$

χ, Γ and K_F depend on the inversion level

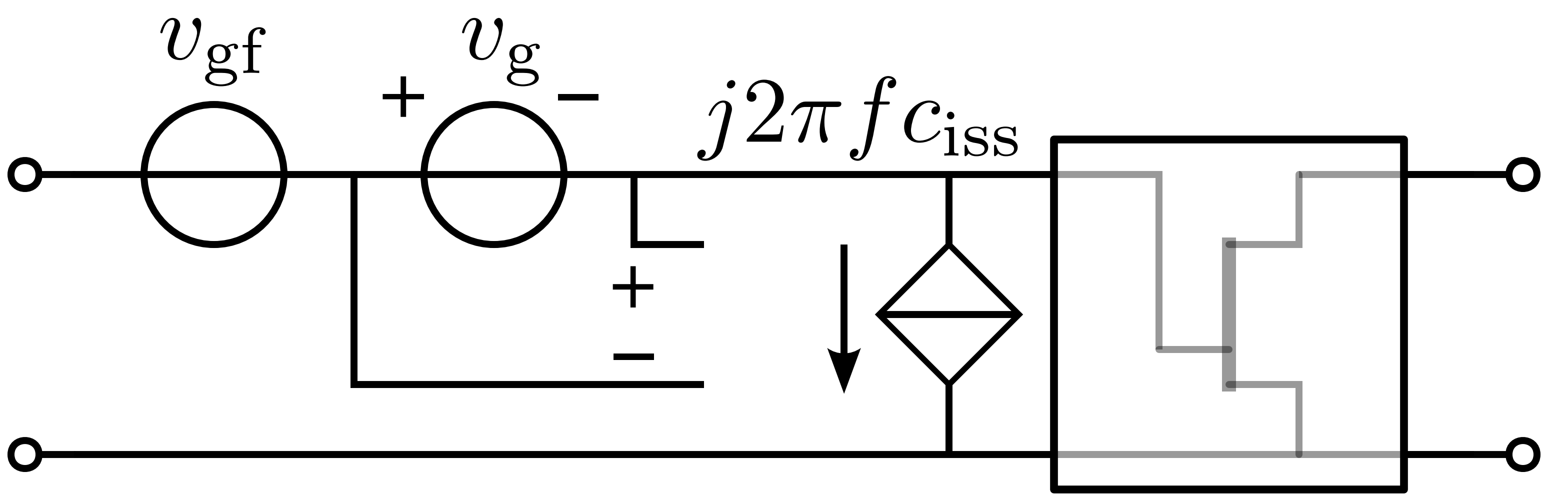
$\chi = 0.26 \cdots 0.6$ with $IC = 0 \cdots \infty$ and $n = 1.35$

$\Gamma = \frac{1}{2} \cdots \frac{2}{3}$ with $IC = 0 \cdots \infty$

$$K_F = K_{F0}\left(1 + \frac{V_{\text{EFF}}}{V_{\text{KF}}}\right)^2 \qquad V_{\text{KF}} = 0.2 \cdots 2$$

S_{v_g} and $S_{v_{gf}}$ are now expressed in the MOS design parameters g_m and c_{iss}

MOS Noise Transformations-2



$$S_{v_g} = \frac{4kTn\Gamma}{g_m}$$

Ignore the overlap capacitances:
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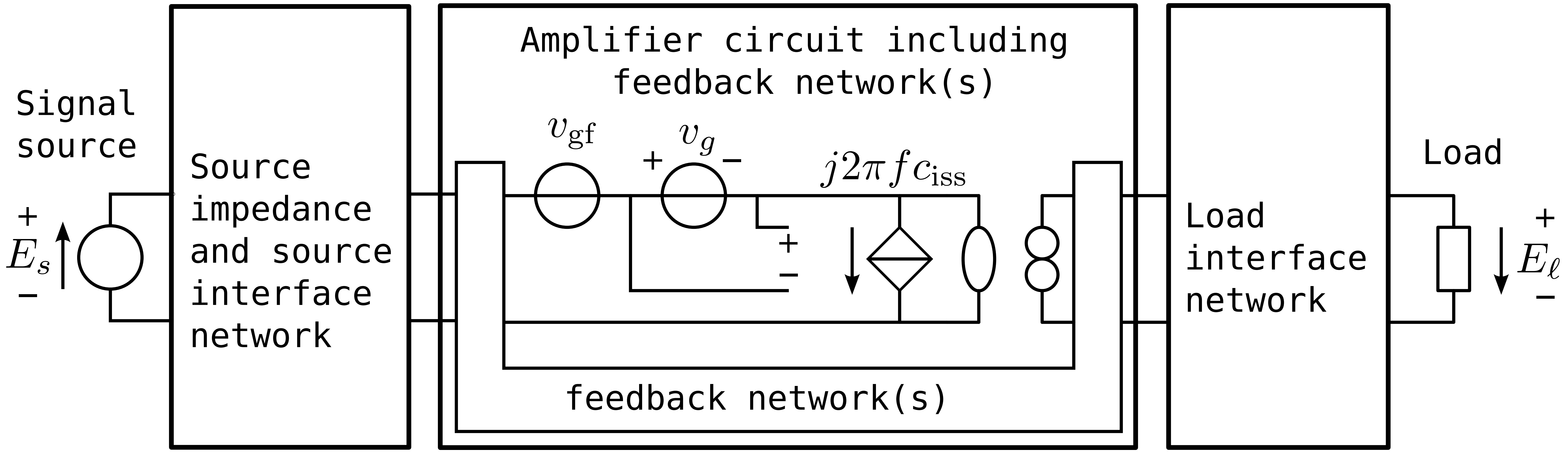
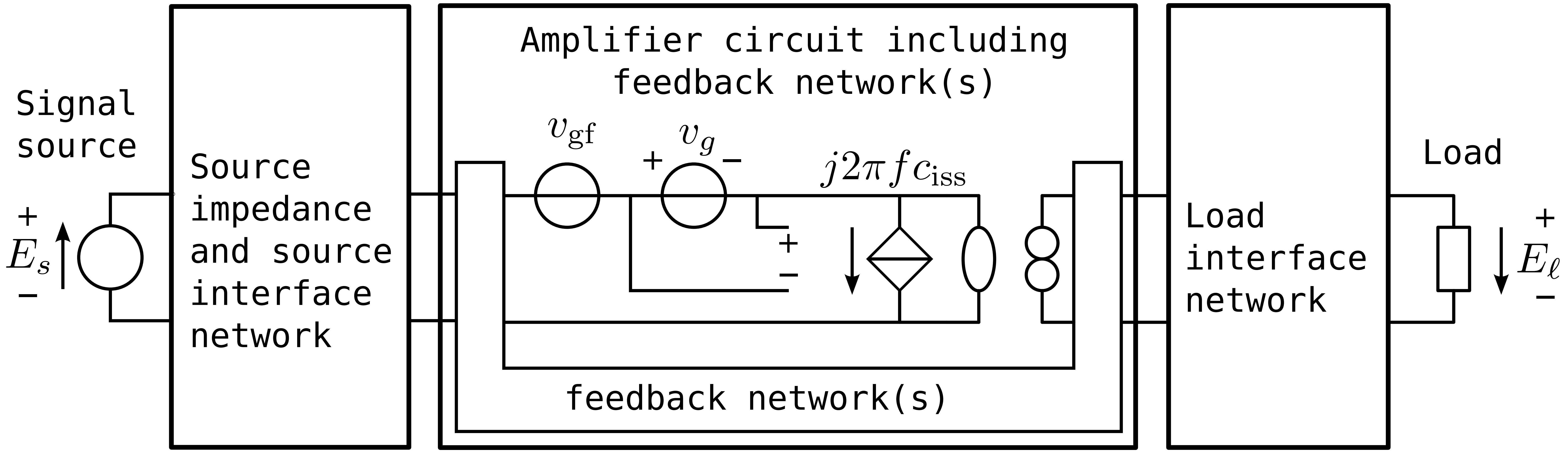
Feedback amplifier MOS Noise

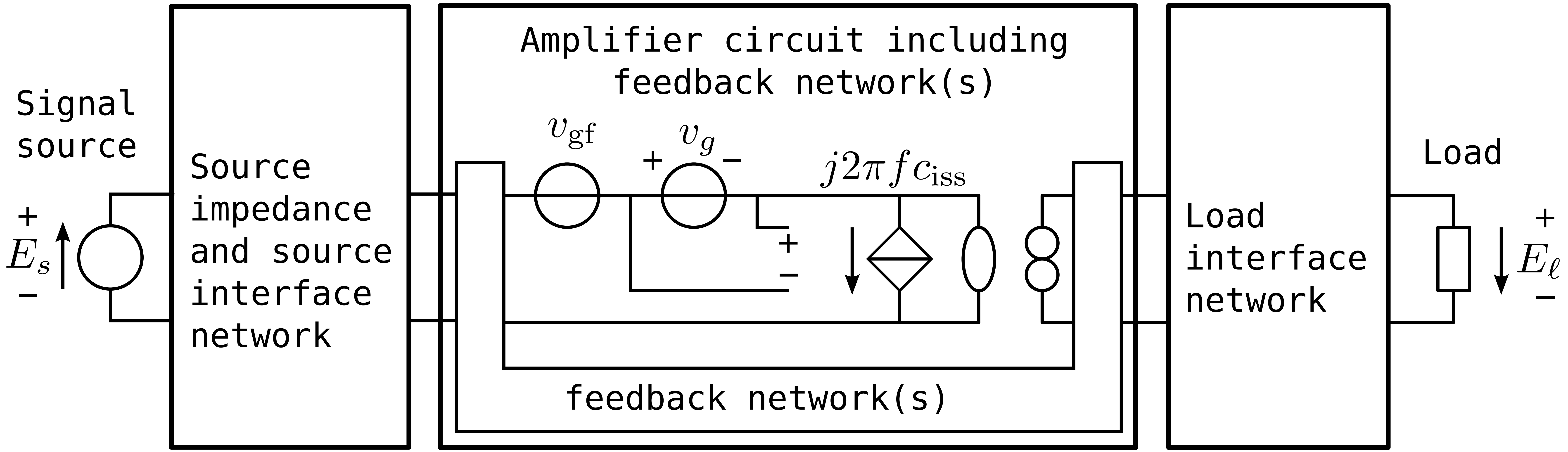


Feedback amplifier MOS Noise



$$S_{v_g} = \frac{4kTn\Gamma}{g_m} \qquad \mathrm{V^2/Hz}$$

Feedback amplifier MOS Noise



$$S_{v_g} = \frac{4kTn\Gamma}{g_m} \quad \mathrm{V^2/Hz}$$

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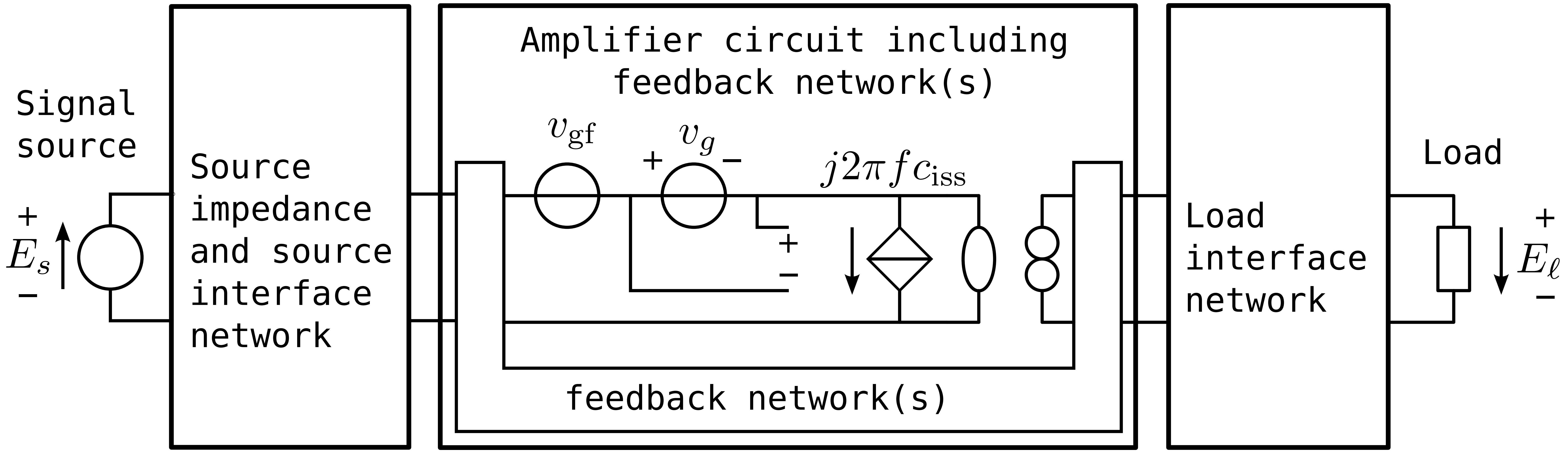
Feedback amplifier MOS Noise



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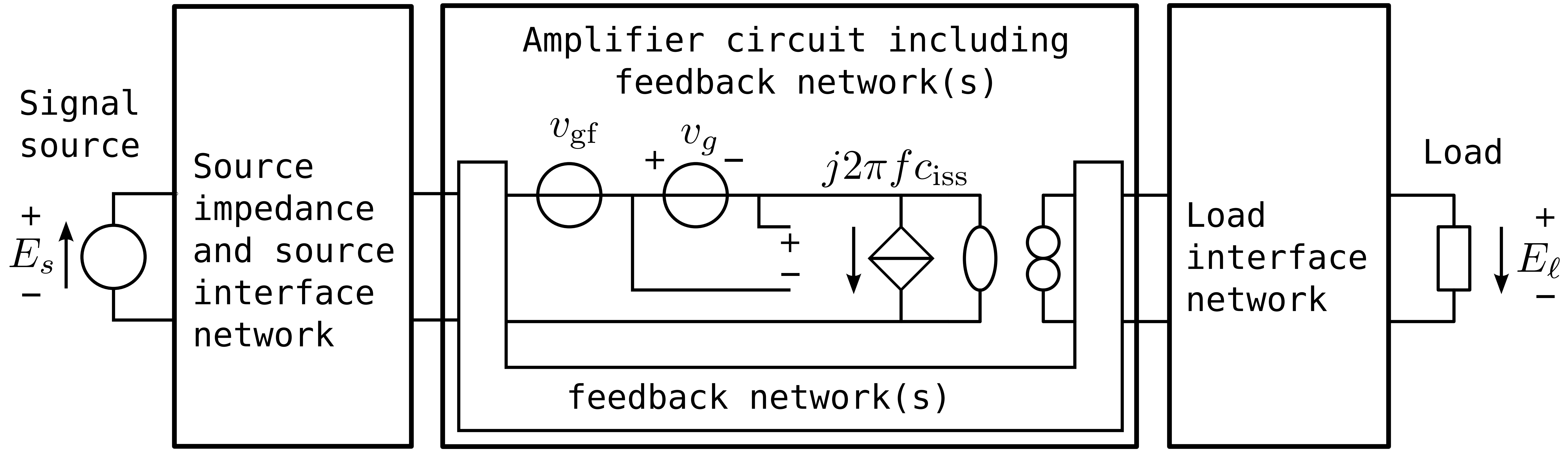
Next step: determine MOS parameters g_m and c_{iss} at a given inversion level

Feedback amplifier MOS Noise



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Next step: determine MOS parameters g_m and c_{iss} at a given inversion level

Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

$$S_{e\ell} = \frac{\chi K_F}{C_{\mathrm{OX}}} \frac{1}{c_{\mathrm{iss}} f^{\mathrm{AF}}} |H_{\mathrm{v}}|^2 + \frac{4kTn\Gamma}{g_m} |H_{\mathrm{v}} + H_{\mathrm{i}} 2\pi j f c_{iss})|^2 + S_0$$

Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

$$S_{e\ell} = \frac{\chi K_F}{C_{\mathrm{OX}}} \frac{1}{c_{\mathrm{iss}} f^{\mathrm{AF}}} |H_{\mathrm{v}}|^2 + \frac{4kTn\Gamma}{g_m} |H_{\mathrm{v}} + H_{\mathrm{i}} 2\pi j f c_{iss})|^2 + S_0$$

$$S_{e\ell} = \frac{1}{c_{iss}} \frac{\chi K_F |H_{\mathrm{v}}|^2}{C_{OX} f^{\mathrm{AF}}}$$

Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

$$S_{e\ell} = \frac{\chi K_F}{C_{\mathrm{OX}}} \frac{1}{c_{\mathrm{iss}} f^{\mathrm{AF}}} |H_{\mathrm{v}}|^2 + \frac{4kTn\Gamma}{g_m} |H_{\mathrm{v}} + H_{\mathrm{i}} 2\pi j f c_{iss})|^2 + S_0$$

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Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

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Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

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$$e_\ell^2 = \int_0^\infty |W_f|^2 S_{e\ell} df$$

Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

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Feedback amplifier MOS noise design equation

Unweighted output noise spectrum

$$S_{e\ell} = \frac{\chi K_F}{C_{\mathrm{OX}}}\frac{1}{c_{\mathrm{iss}} f^{\mathrm{AF}}}|H_{\mathrm{v}}|^2 + \frac{4kTn\Gamma}{g_m}|H_{\mathrm{v}} + H_{\mathrm{i}} 2\pi j f c_{iss})|^2 + S_0$$

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Feedback amplifier MOS noise design equation

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$$\gamma = 16kTn\Gamma\pi \int_0^\infty f|W_f|^2[\Im(H_\mathrm{v})\Re(H_\mathrm{i}) - \Re(H_\mathrm{v})\Im(H_\mathrm{i})]df = -16kTn\Gamma\pi \int_0^\infty f|W_f|^2\Im(Z_n)|H_\mathrm{v}|^2 df$$

Feedback amplifier MOS noise design equation

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Coefficients $\alpha \cdots \epsilon$ have numeric values at the start of the MOS noise design.

Feedback amplifier MOS noise design equation

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Feedback amplifier MOS noise design equation

Total squared weighted output noise:

$$e_\ell^2 = \alpha \frac{1}{c_{iss}} + \beta \frac{1}{g_m} + \gamma \frac{c_{iss}}{g_m} + \delta \frac{c_{iss}^2}{g_m} + \epsilon$$

Feedback amplifier MOS noise design equation

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MOS contribution to squared weighted output noise:

$$e_{\ell M}^{2}=\alpha\frac{1}{c_{iss}}+\beta\frac{1}{g_m}+\gamma\frac{c_{iss}}{g_m}+\delta\frac{c_{iss}^{2}}{g_m}$$

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Remember coefficients depend on inversion level!

Relation between transconductance and input capacitance to meet requirement:

$$g_m \geq \frac{c_{\mathrm{iss}}}{e_{\ell M}^2 c_{\mathrm{iss}} - \alpha} \left(\beta + \gamma c_{\mathrm{iss}} + \delta c_{\mathrm{iss}}^2\right)$$

Feedback amplifier MOS noise design equation

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Minimum can be below technological minimum set by the minimum channel width and length.

Feedback amplifier MOS noise design equation

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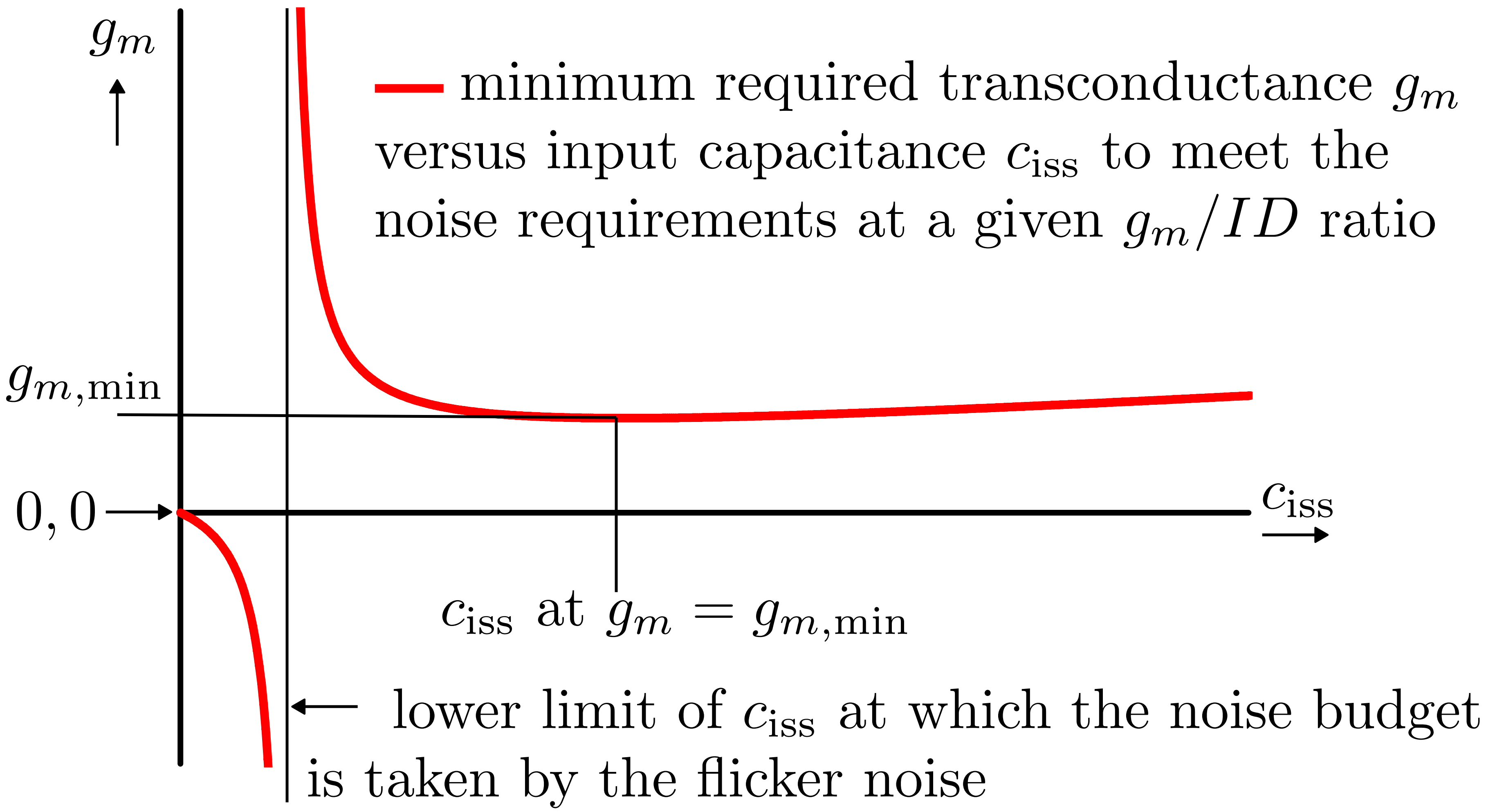

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Feasibility of the noise design

Total squared weighted output noise:

$$e_\ell^2 = \alpha\frac{1}{c_{iss}} + \beta\frac{1}{g_m} + \gamma\frac{c_{iss}}{g_m} + \delta\frac{c_{iss}^2}{g_m} + \epsilon$$

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NOT FEASIBLE: If ϵ exeeds the requirement for the total squared weighted output noise.

Feasibility of the noise design

Total squared weighted output noise:

$$e_\ell^2 = \alpha \frac{1}{c_{iss}} + \beta \frac{1}{g_m} + \gamma \frac{c_{iss}}{g_m} + \delta \frac{c_{iss}^2}{g_m} + \epsilon$$

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NOT FEASIBLE:

If ϵ exeeds the requirement for the total squared weighted output noise.

If $f_T = \frac{g_m}{2\pi c_{\mathrm{iss}}}$ is too low:

Feasibility of the noise design

Total squared weighted output noise:

$$e_\ell^2 = \alpha\frac{1}{c_{iss}} + \beta\frac{1}{g_m} + \gamma\frac{c_{iss}}{g_m} + \delta\frac{c_{iss}^2}{g_m} + \epsilon$$

MOS contribution to squared weighted output noise:

$$e_{\ell M}^2 = \alpha\frac{1}{c_{iss}} + \beta\frac{1}{g_m} + \gamma\frac{c_{iss}}{g_m} + \delta\frac{c_{iss}^2}{g_m}$$

NOT FEASIBLE:

If ϵ exeeds the requirement for the total squared weighted output noise.

If $f_T = \frac{g_m}{2\pi c_{\mathrm{iss}}}$ is too low:

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From transconductance and capacitance to current and geometry

$$c_{\mathrm{iss}} = \chi C_{\mathrm{OX}} W L + W \left(C_{\mathrm{GSO}} + C_{\mathrm{GDO}} \right) + 2 L C_{\mathrm{GBO}}$$

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Example

Transimpedance integrator with capacitive source

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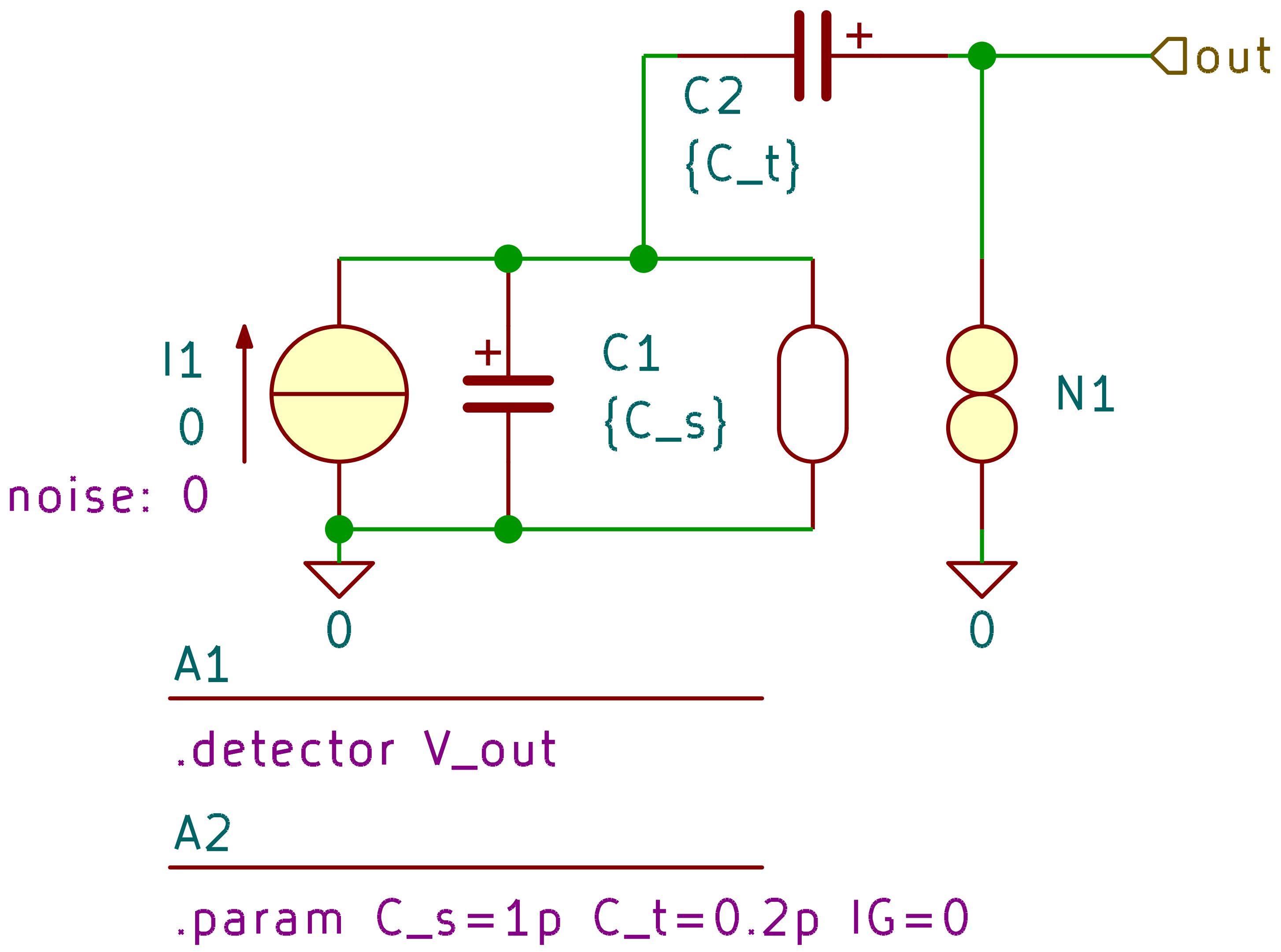

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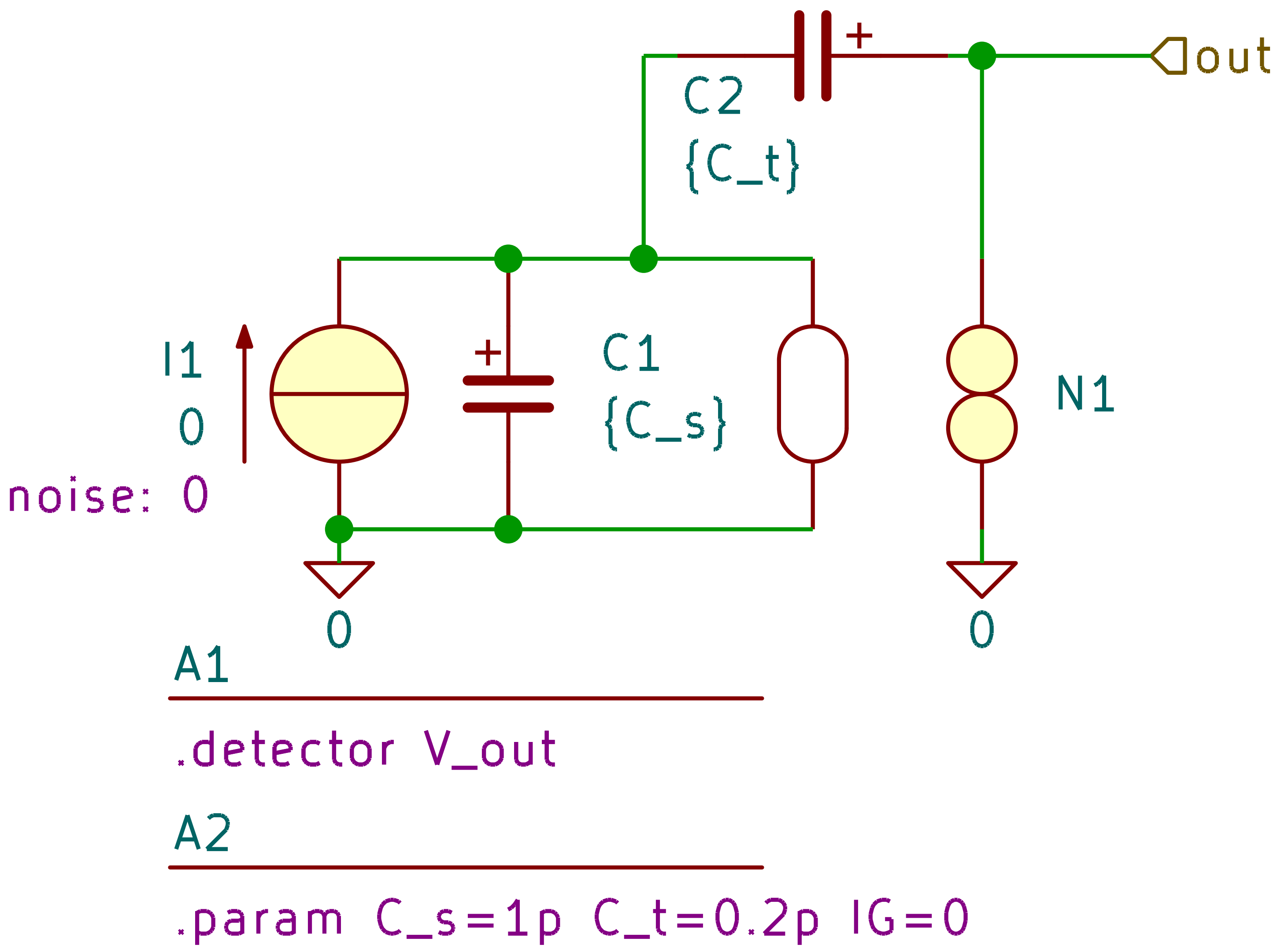
Transimpedance integrator with capacitive source



Coefficients of the symbolic noise equition (determined with SLiCAP):

term	**coefficient**
$\frac{1}{c_{iss}}$	$\alpha = \int_{f_{min}}^{f_{max}} \frac{K_F \chi f^{-A_F} (C_s+C_t)^2}{C_{OX} C_t^2}\, df$
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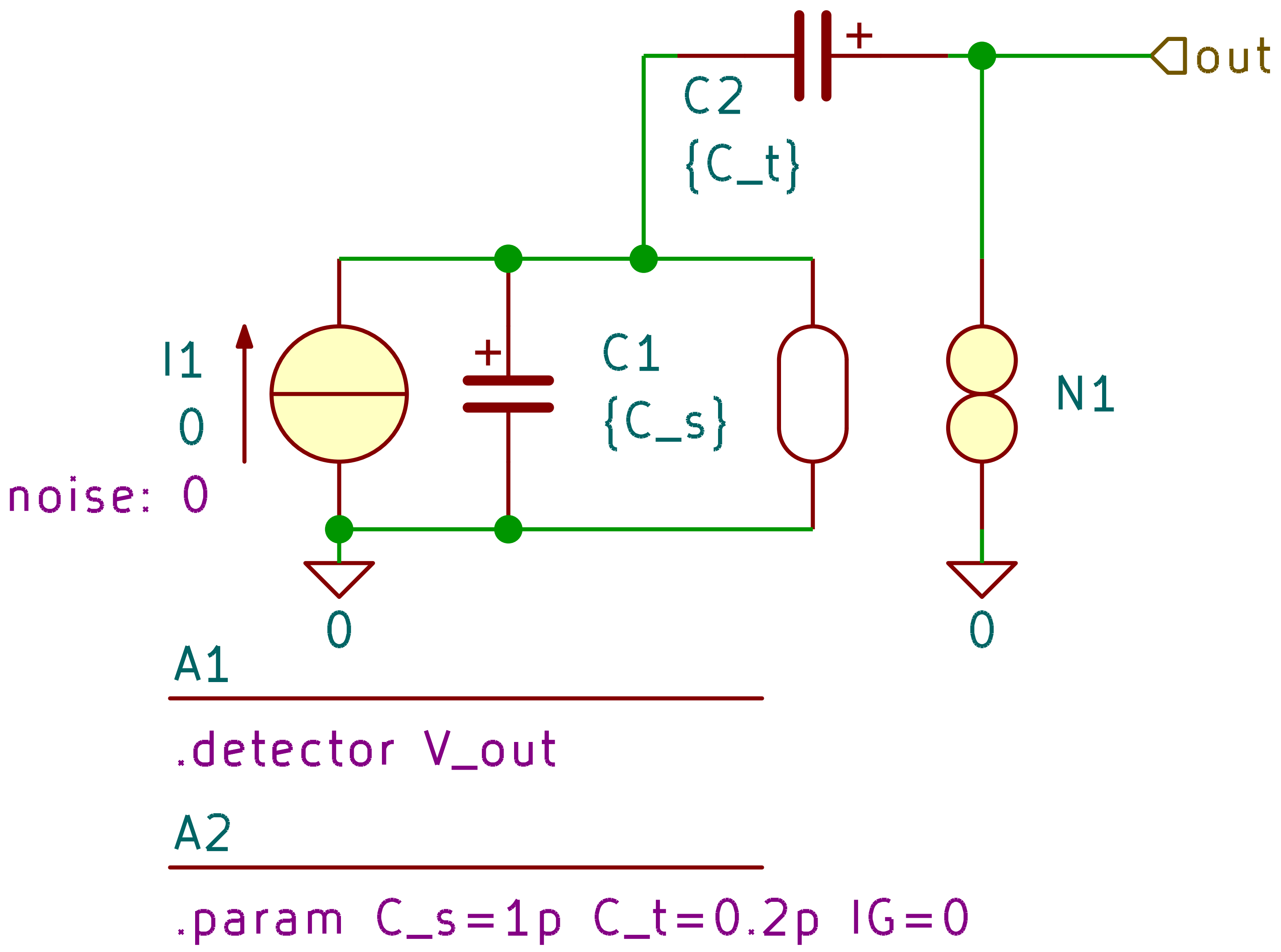

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If we ignore flicker noise:

$$c_{\mathrm{issOpt}} = \sqrt{\frac{\beta}{\delta}} = C_s + C_t = 1.2 \text{ pF}$$

$$v_{n_{\mathrm{out}}}^2 = \frac{16kTn\Gamma}{g_m} \left(\frac{C_s+C_t}{C_t} \right)^2 (f_{\max} - f_{\min})$$

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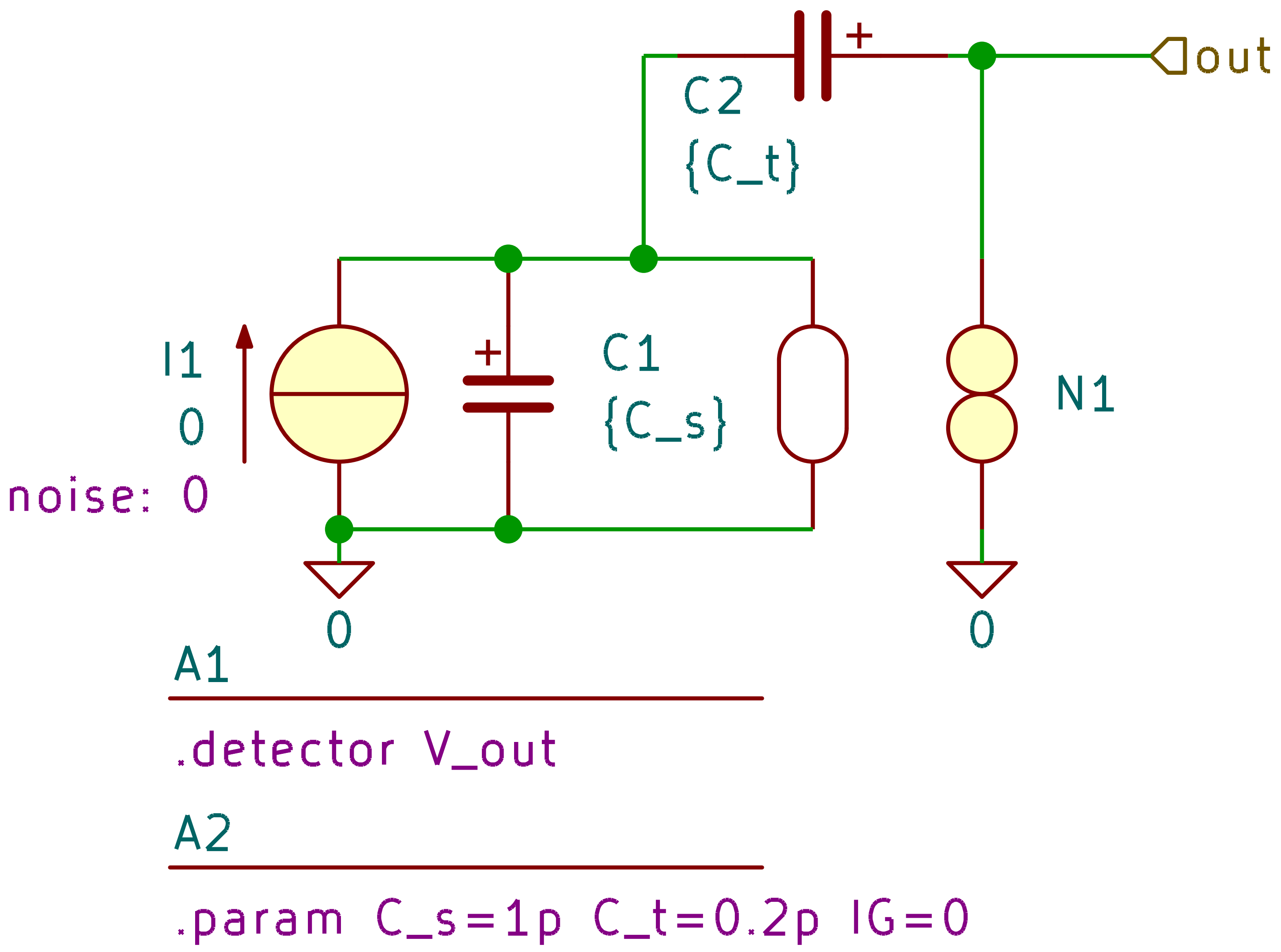

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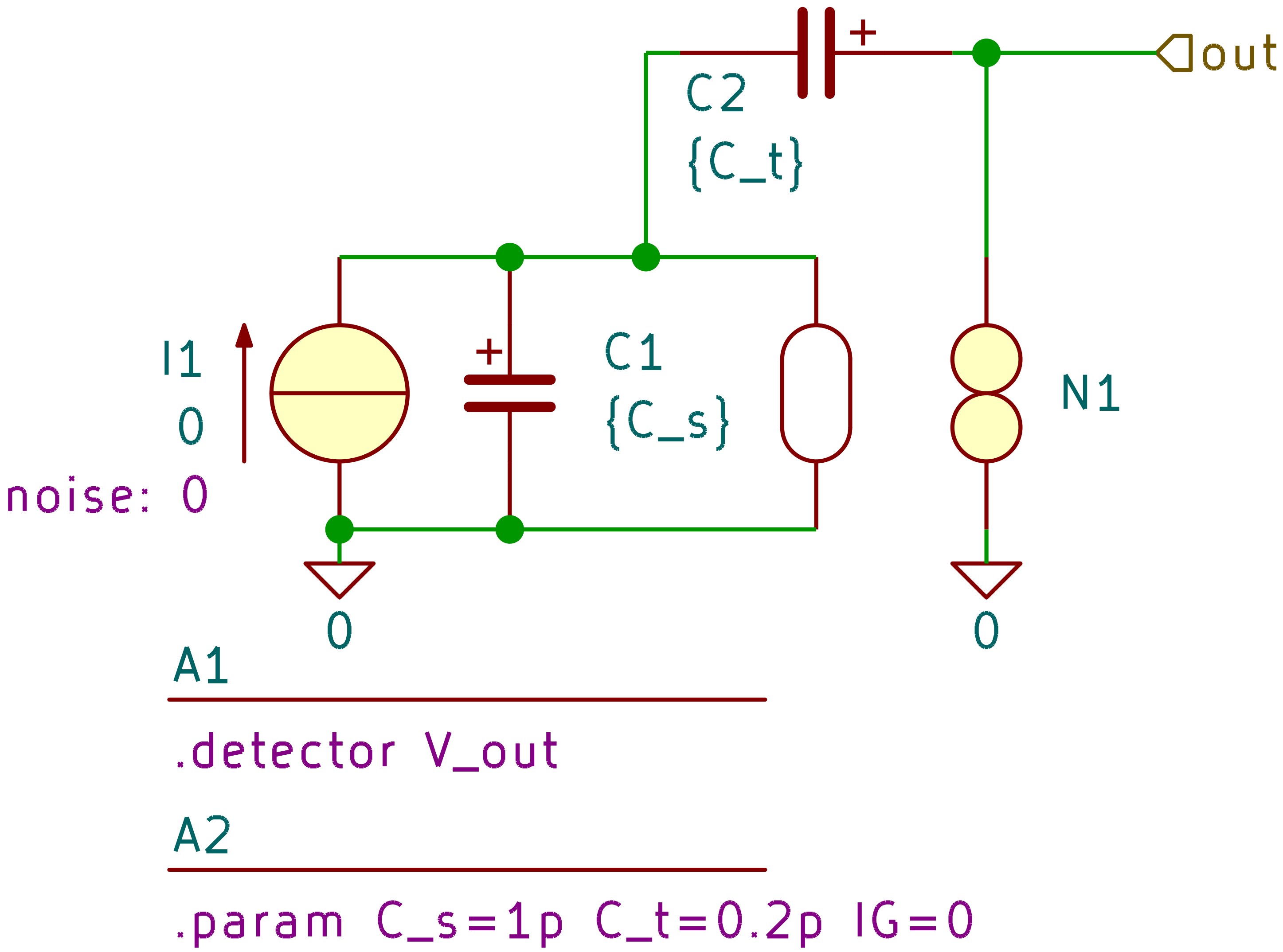
SLiCAP design automation

SLiCAP design automation

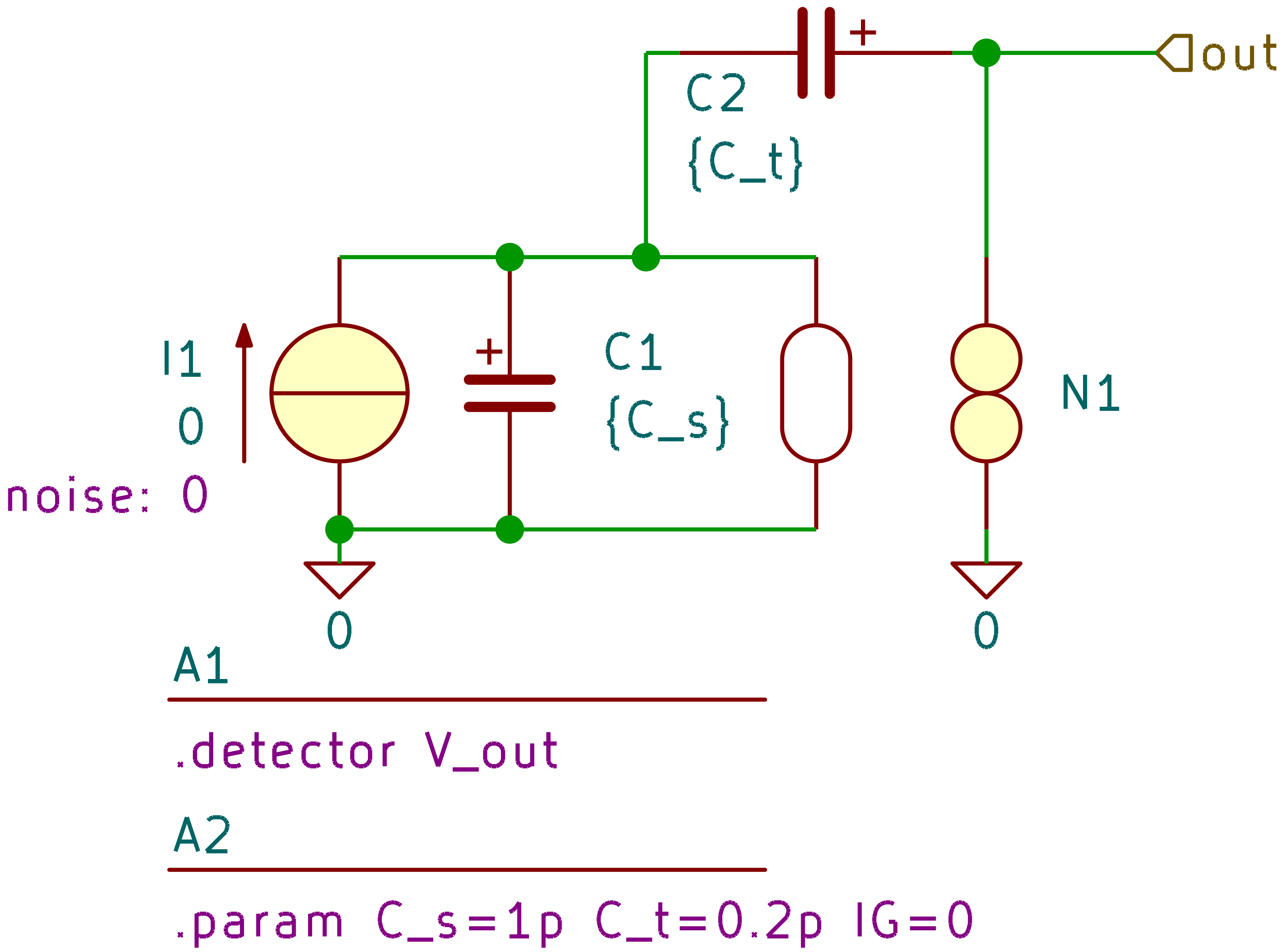
1. Select CMOS process and fit EKV parameters to BSIM

SLiCAP design automation



1. Select CMOS process and fit EKV parameters to BSIM
2. Create KiCAD amplifier circuit with nullor as controller

SLiCAP design automation



1. Select CMOS process and fit EKV parameters to BSIM
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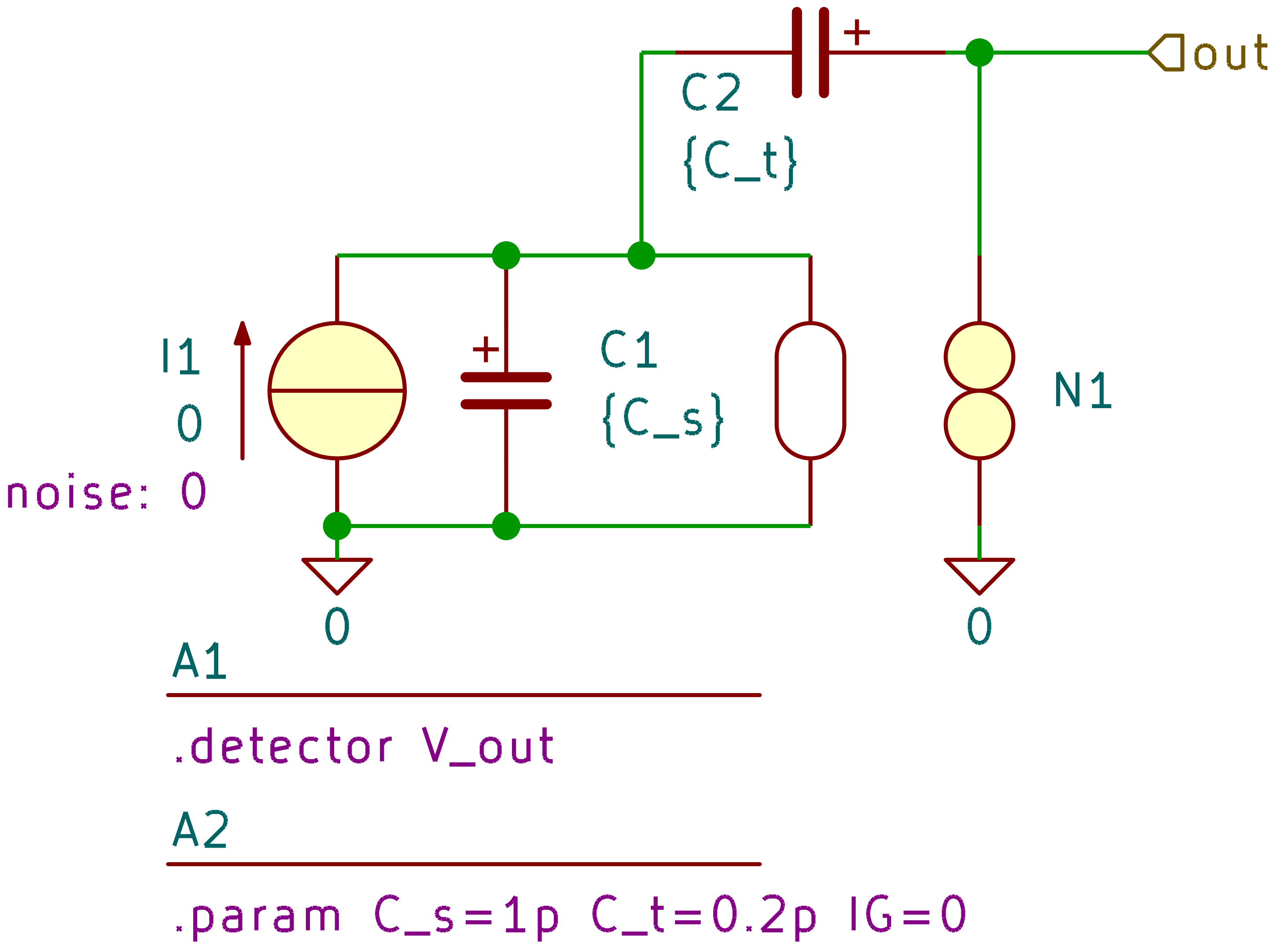
3. Define noise requirements (frequency range and budgets)

SLiCAP design automation



1. Select CMOS process and fit EKV parameters to BSIM
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3. Define noise requirements (frequency range and budgets)
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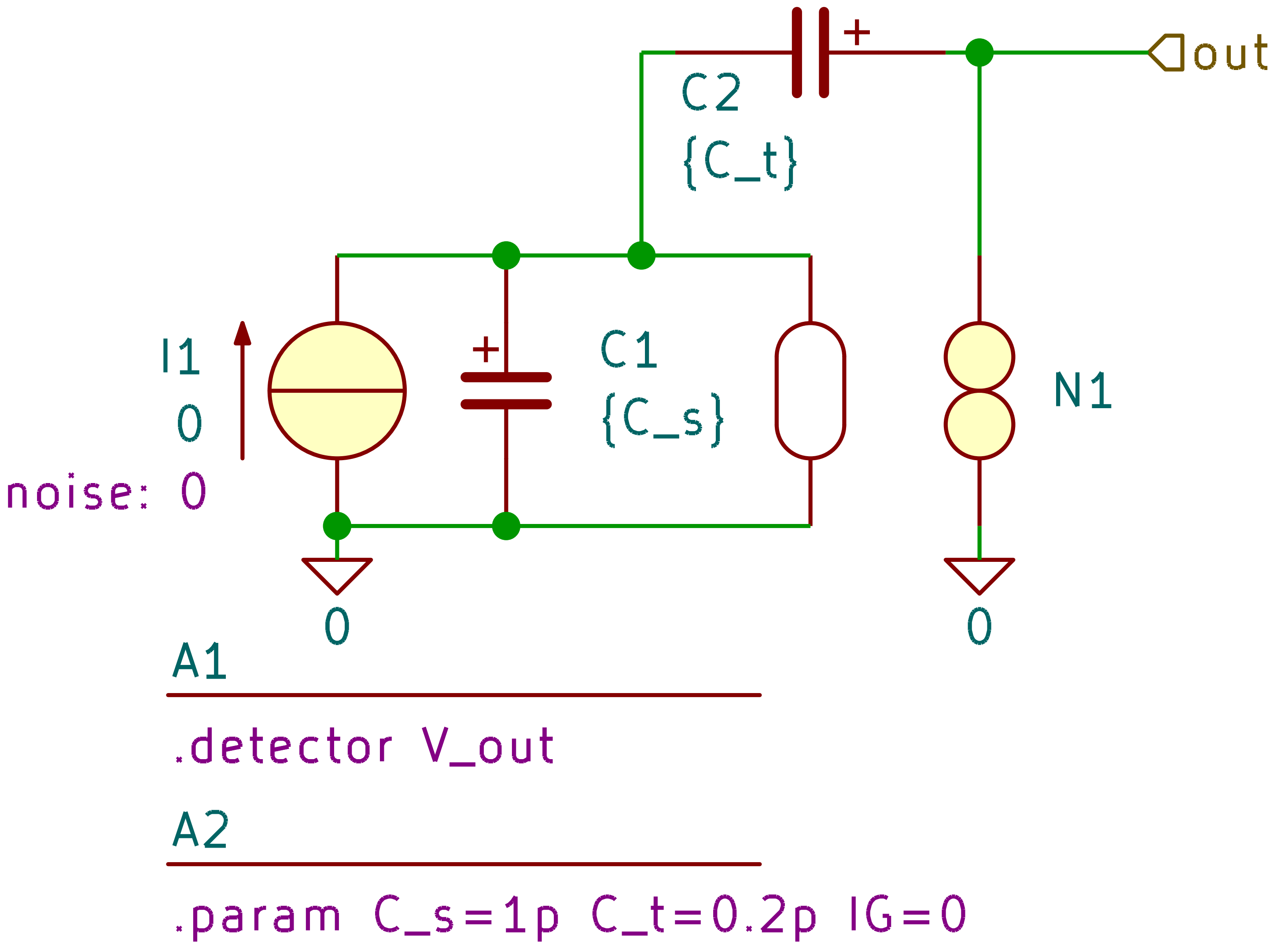
SLiCAP design automation



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5. Define circuit requirements
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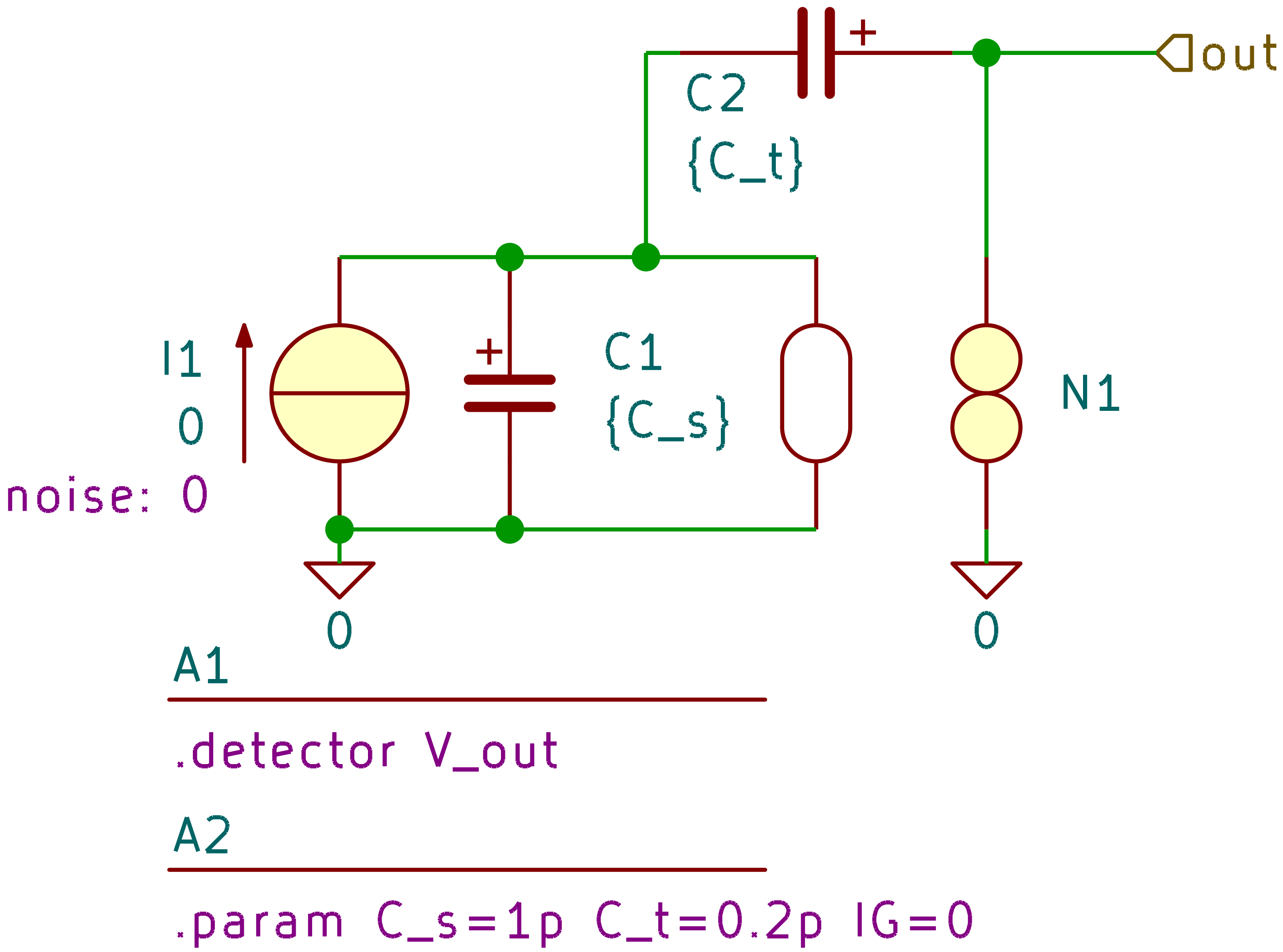
SLiCAP design automation



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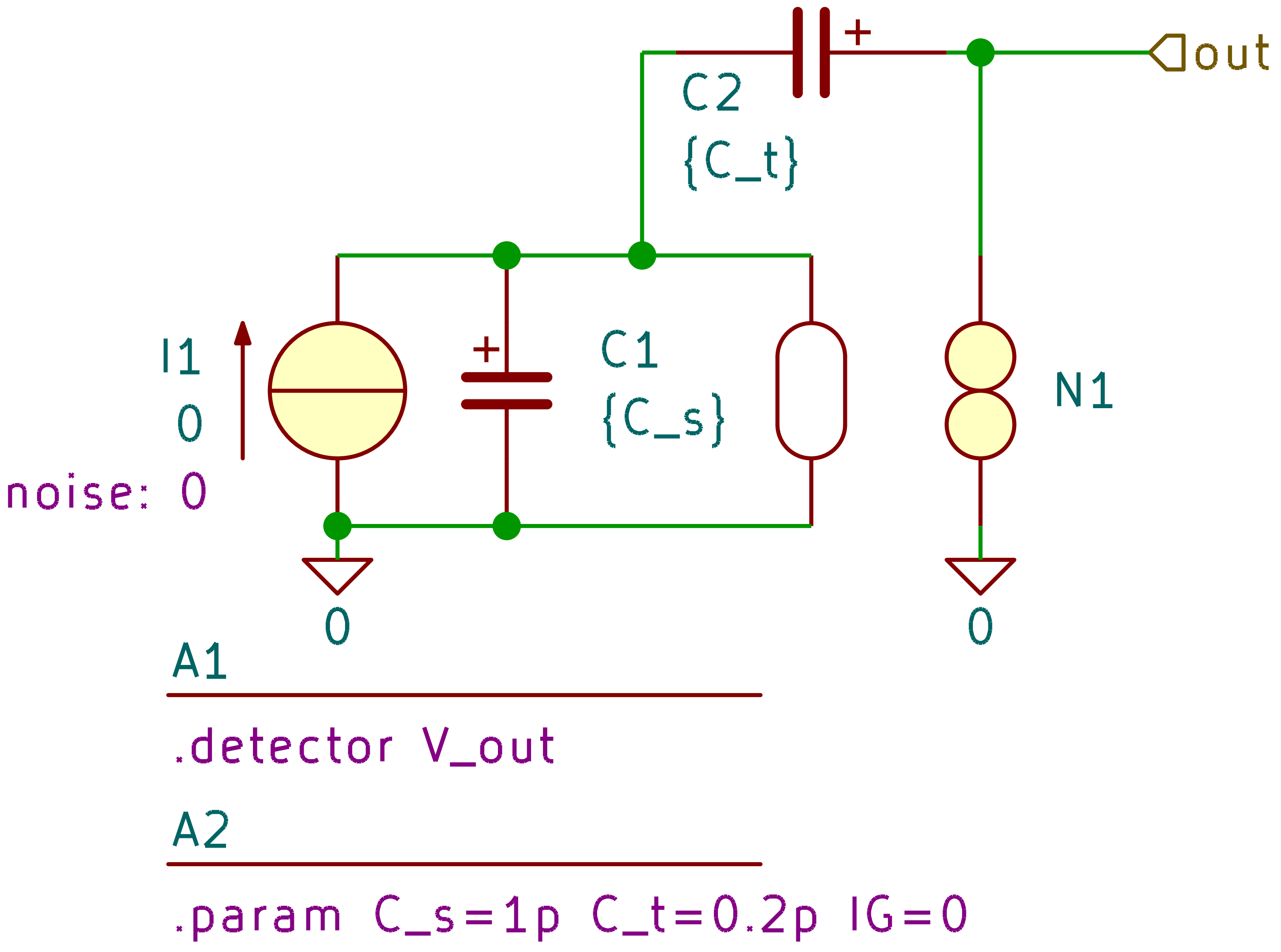
6. Run the design automation script

SLiCAP design automation



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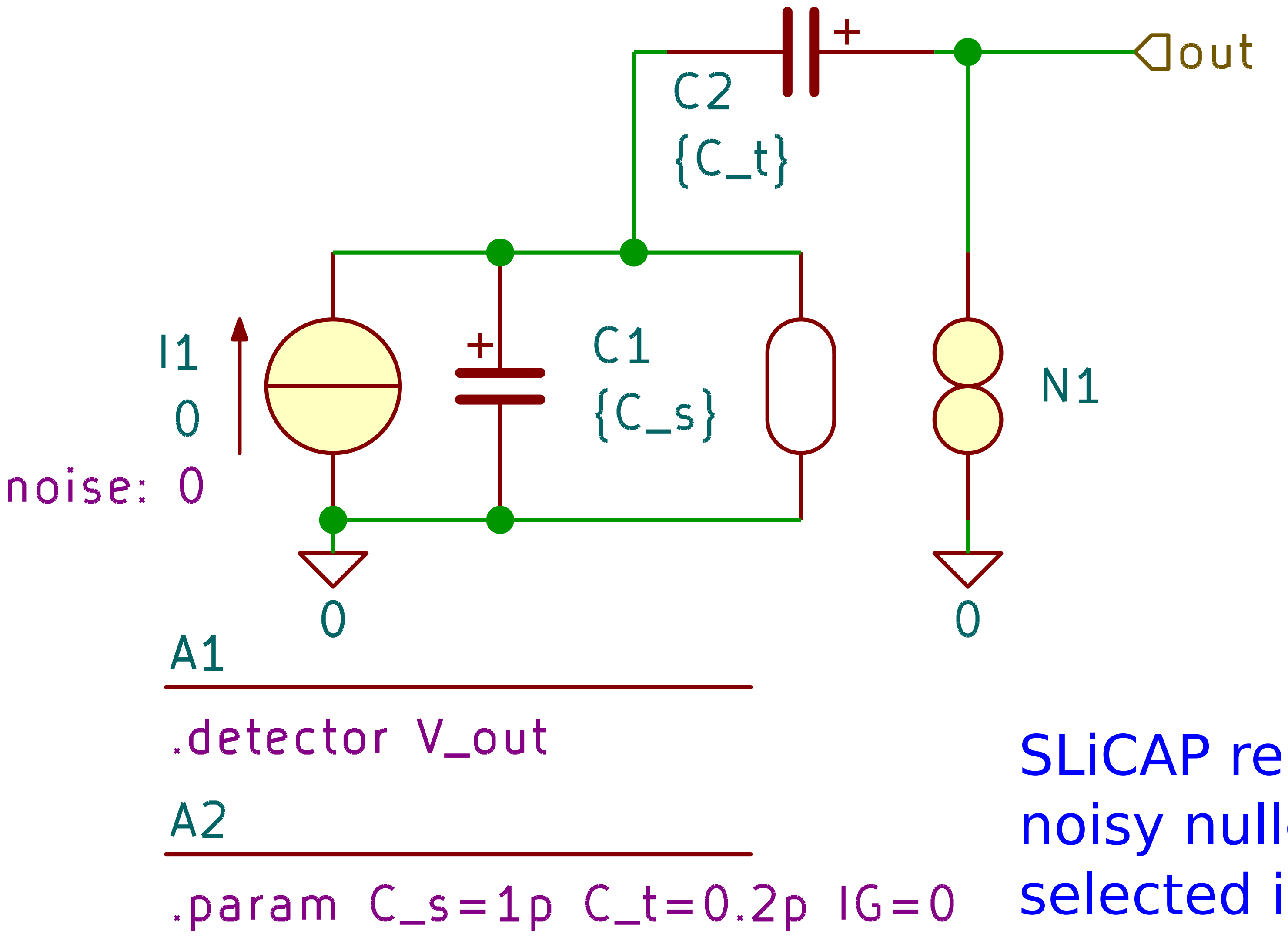
7. Select one valid option for design

SLiCAP design automation



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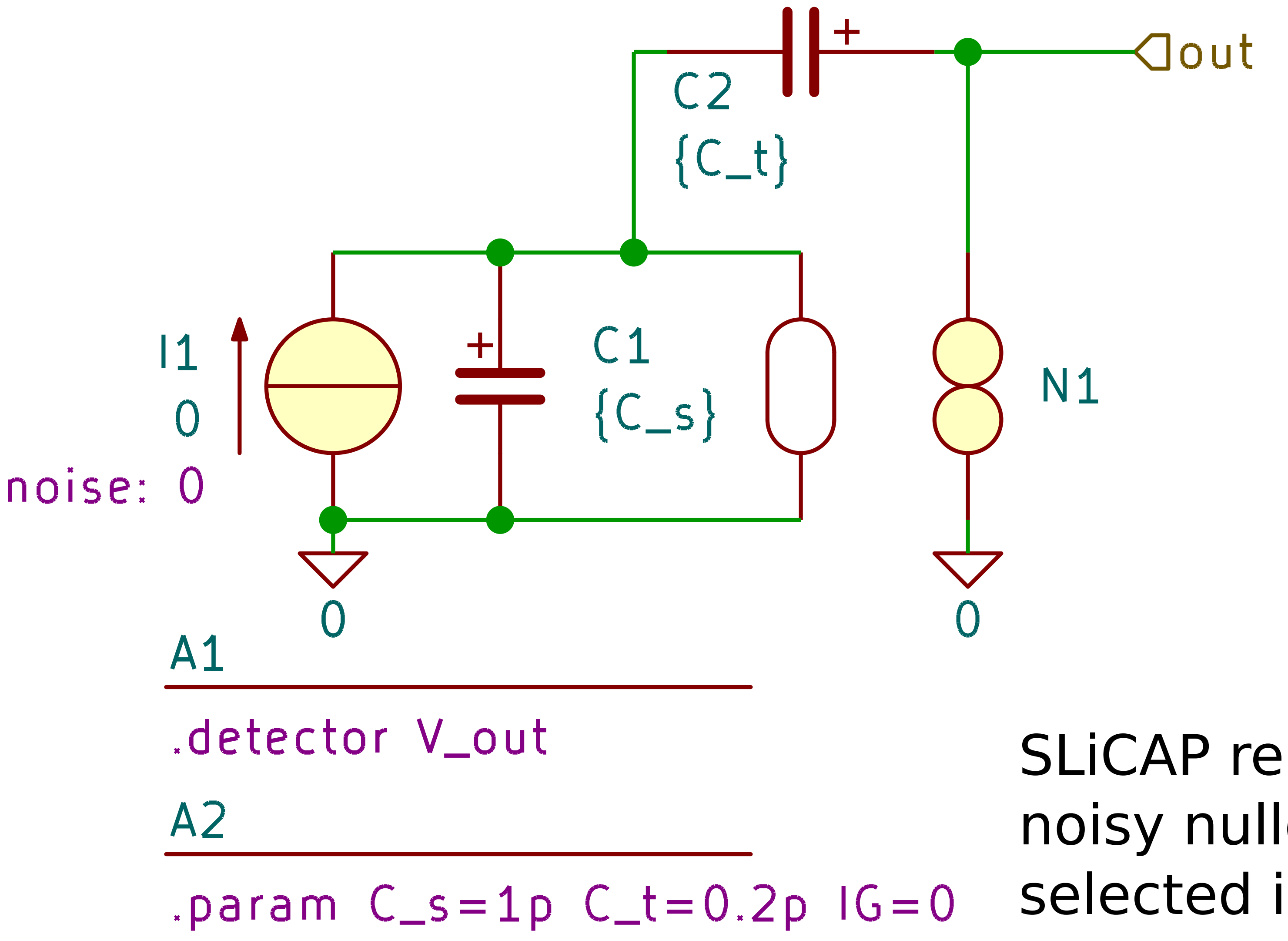
SLiCAP replaces the nullor with an N-channel or a P-channel noisy nullor and evaluates W, L, and I_{DS} for six scenarios for the selected inversion coefficient or gm/ID ratio:

SLiCAP design automation



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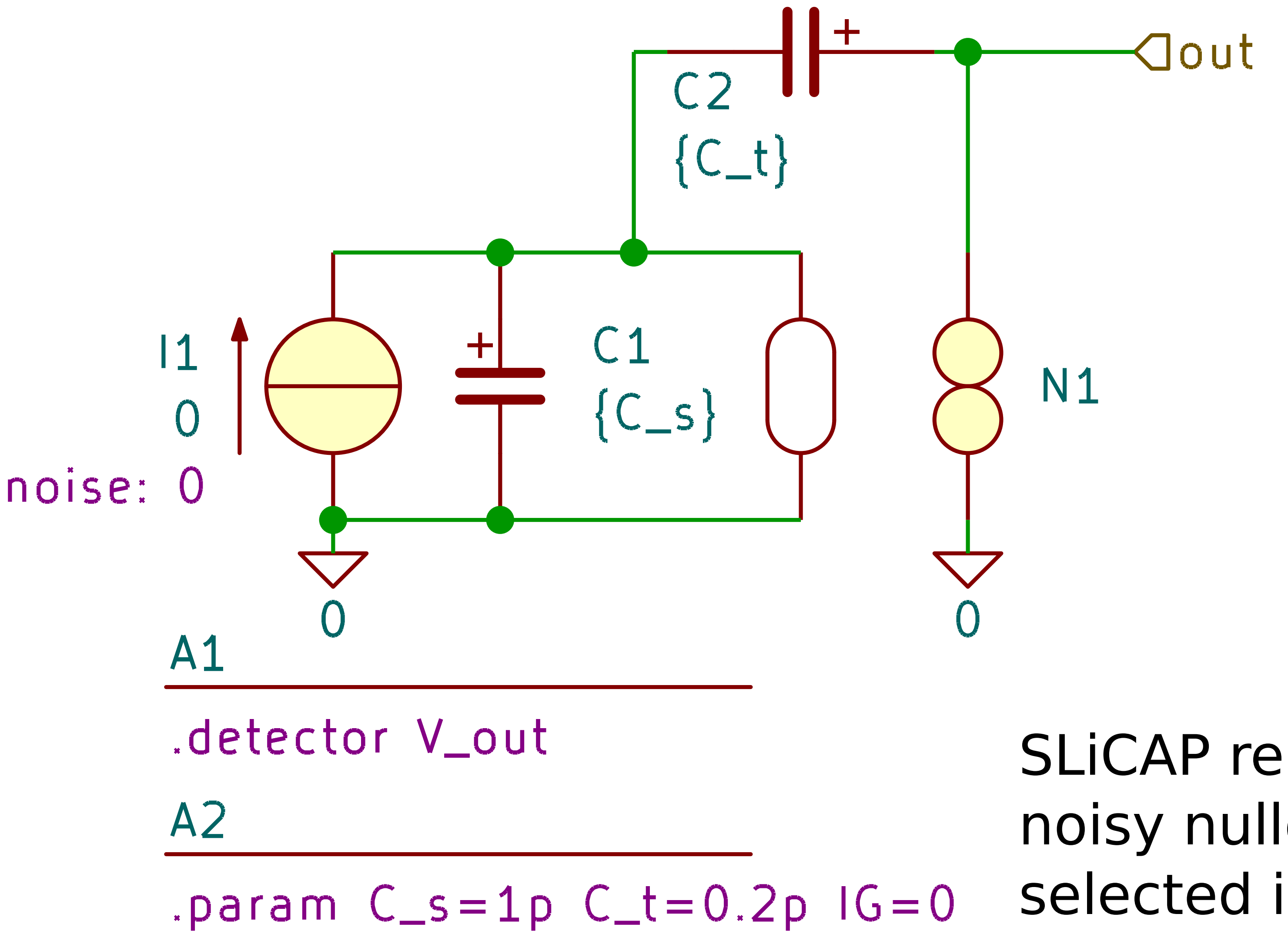
1. Mininum noise at maximum inversion level

SLiCAP design automation



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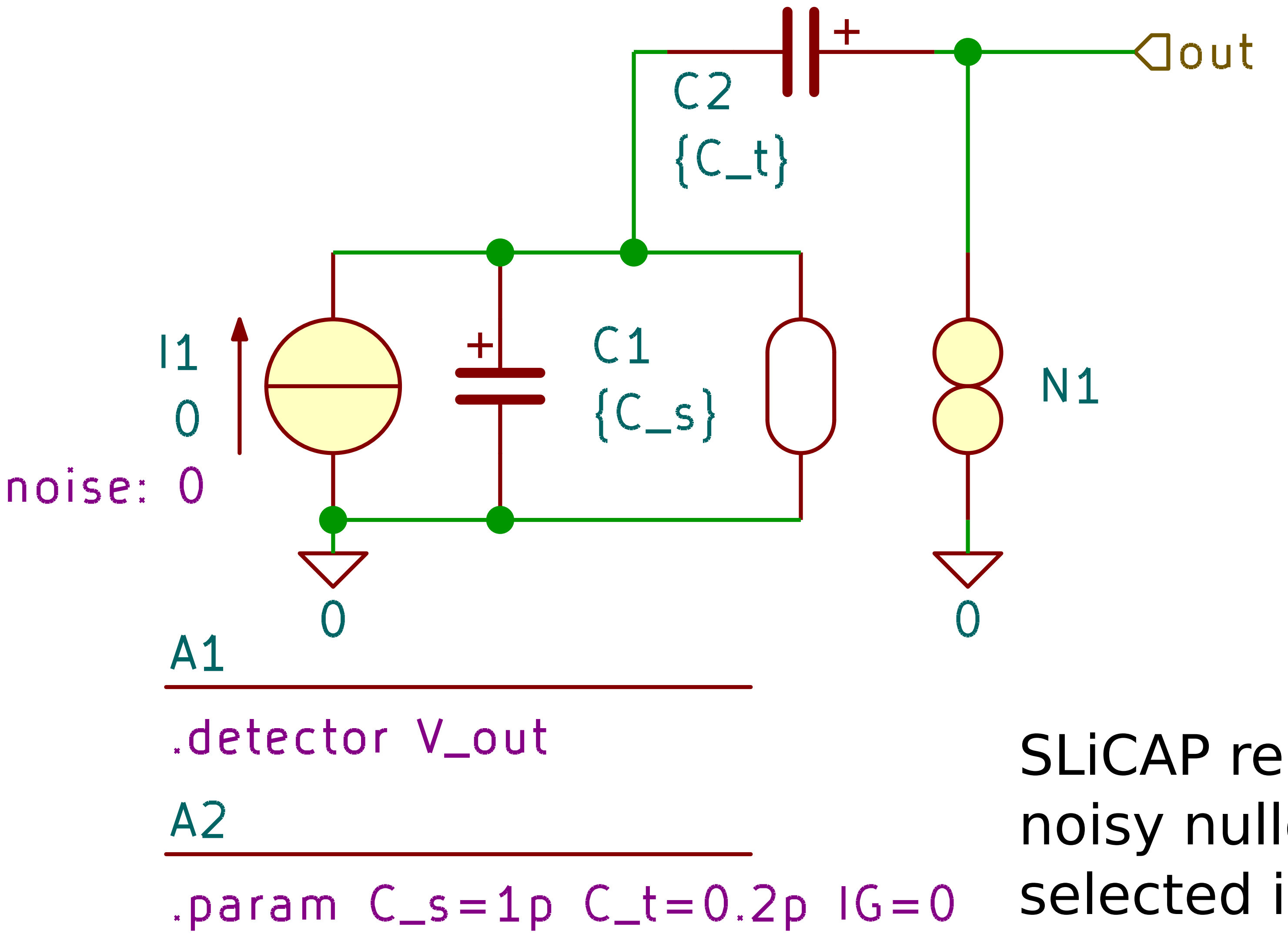
3. Define noise requirements (frequency range and budgets)
4. Define technology requirements
   (channel type, minimum and maximum geometry)
5. Define circuit requirements
   (inversion coefficient or gm/ID ratio, and current budget)
6. Run the design automation script
7. Select one valid option for design

SLiCAP replaces the nullor with an N-channel or a P-channel noisy nullor and evaluates W, L, and I_{DS} for six scenarios for the selected inversion coefficient or gm/ID ratio:

1. Mininum noise at maximum inversion level
2. Minimum current to meet the noise specification

SLiCAP design automation



1. Select CMOS process and fit EKV parameters to BSIM
2. Create KiCAD amplifier circuit with nullor as controller
3. Define noise requirements (frequency range and budgets)
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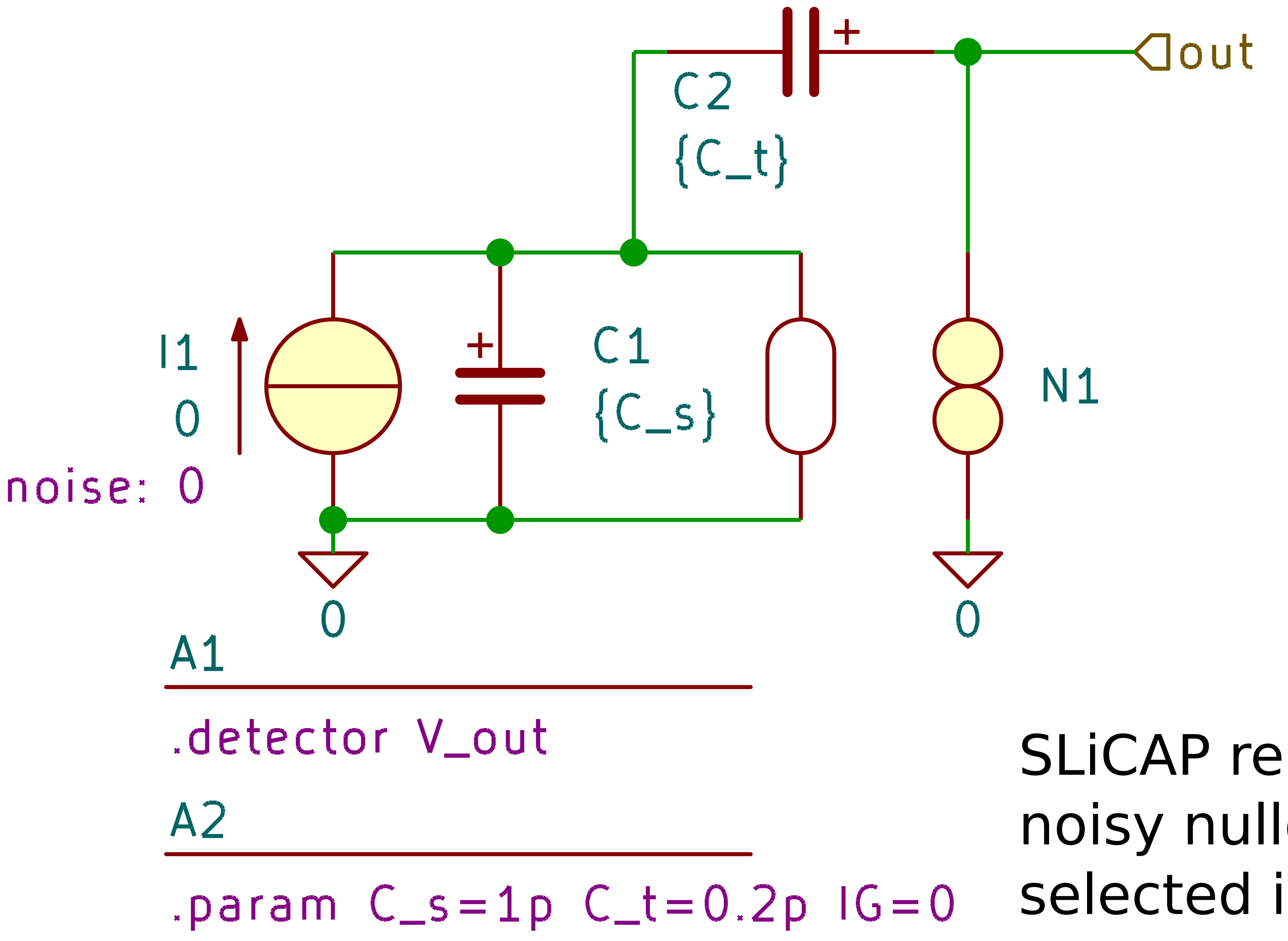
2. Minimum current to meet the noise specification
3. Minimum cut-off frequency to meet the noise specification

SLiCAP design automation



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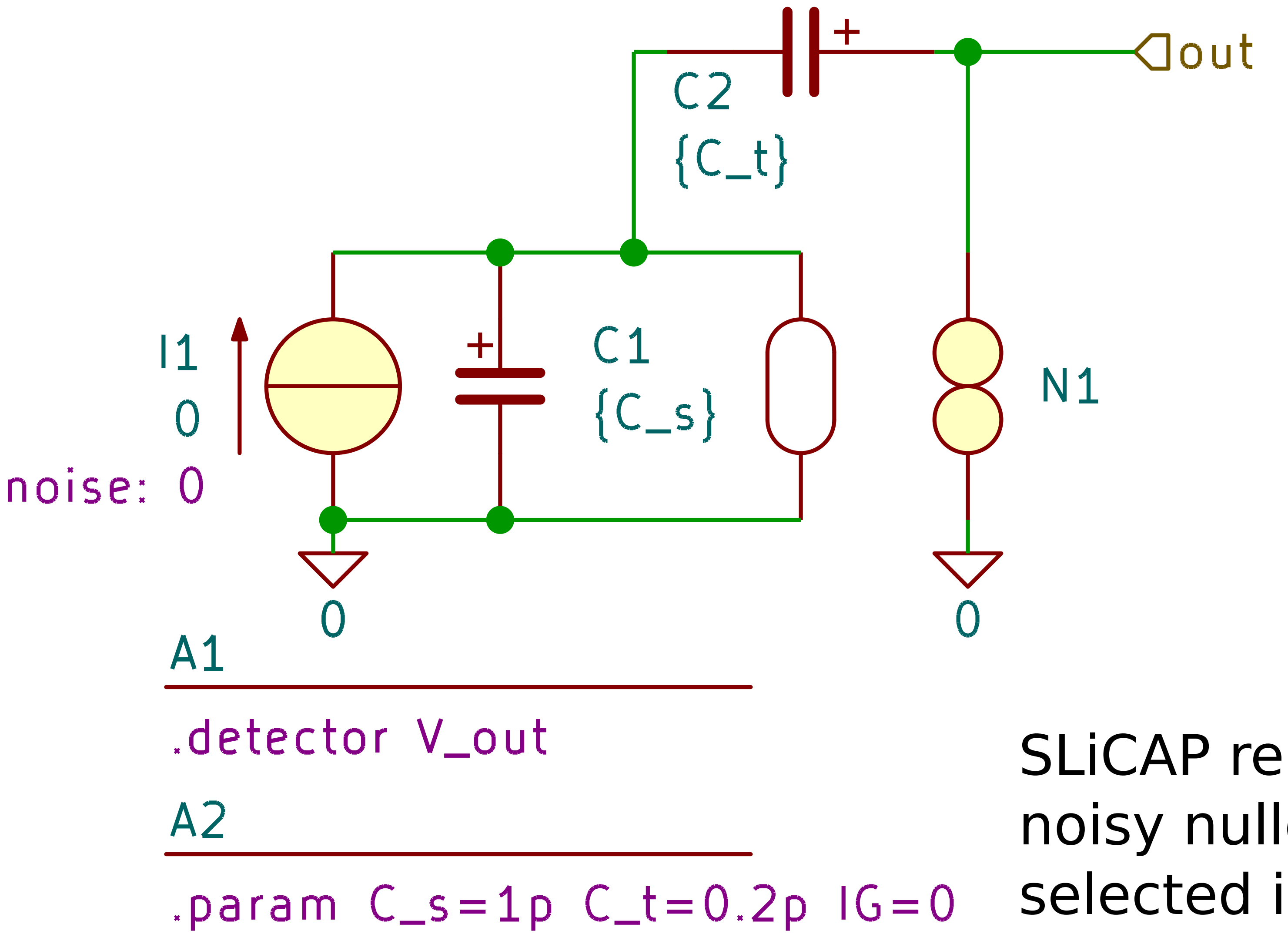
1. Mininum noise at maximum inversion level
2. Minimum current to meet the noise specification
3. Minimum cut-off frequency to meet the noise specification
4. Minimum product of g_m and c_{iss} to meet the noise specification

SLiCAP design automation



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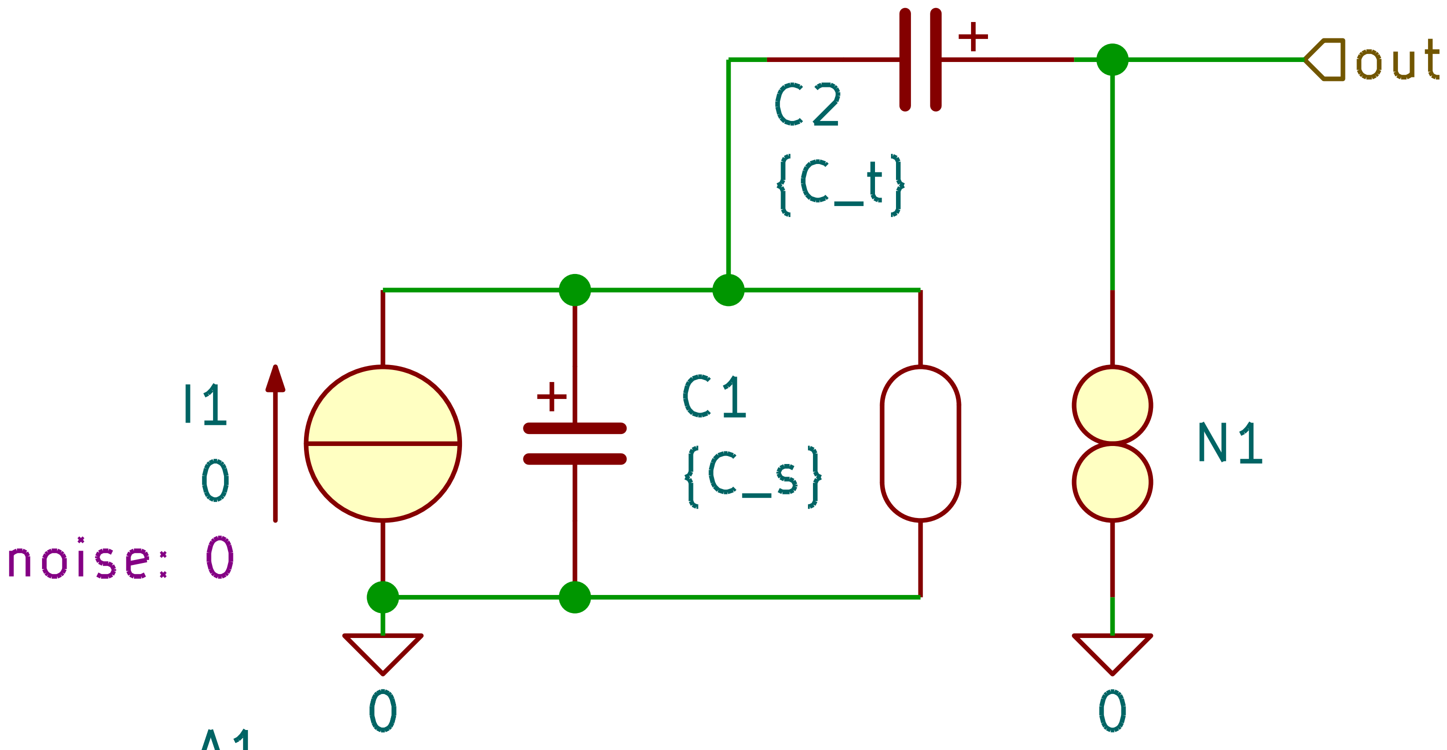
2. Minimum current to meet the noise specification
3. Minimum cut-off frequency to meet the noise specification
4. Minimum product of g_m and c_{iss} to meet the noise specification
5. Minimum area at a given current budget to meet the noise specification

SLiCAP design automation



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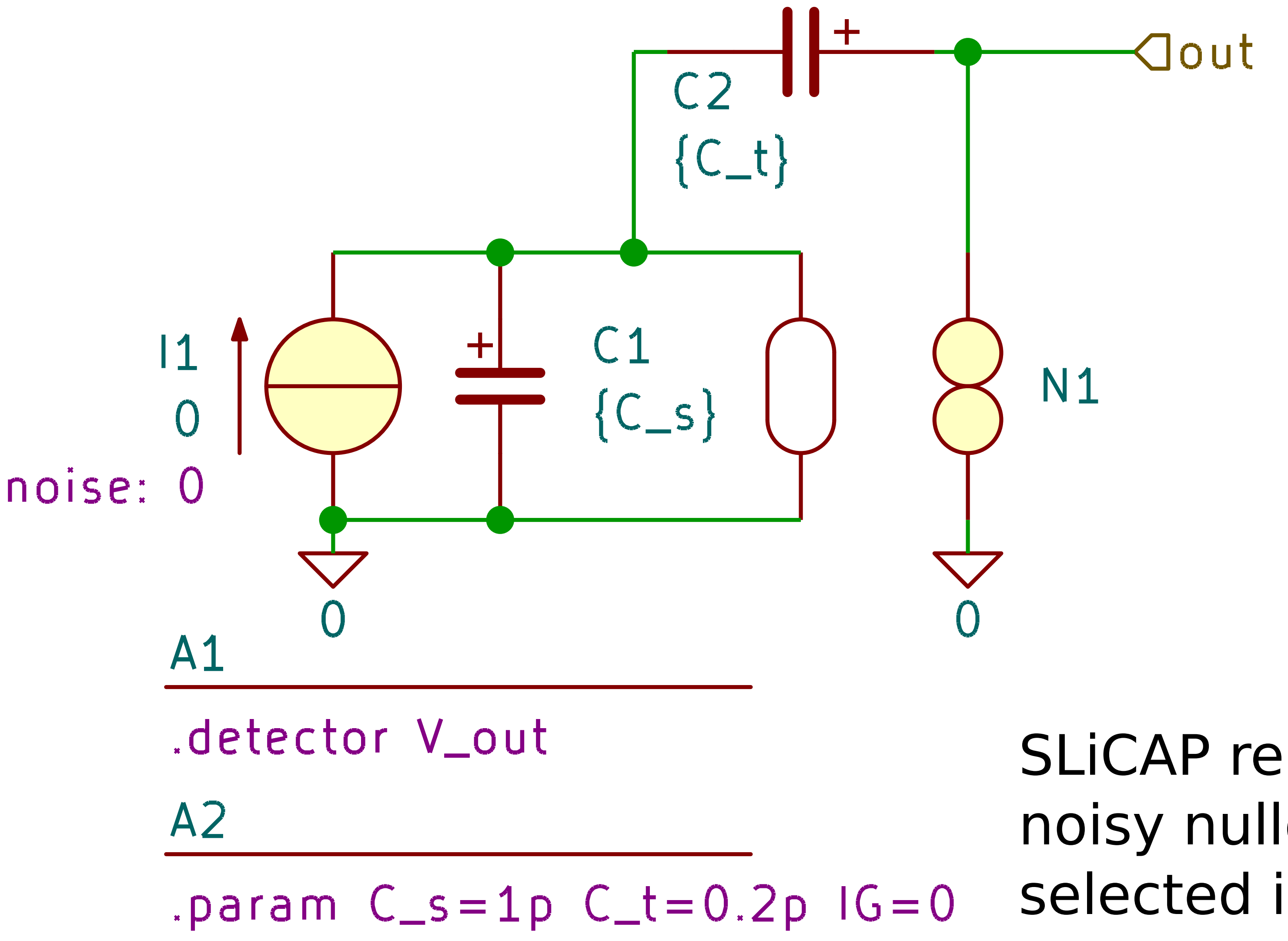
SLiCAP replaces the nullor with an N-channel or a P-channel noisy nullor and evaluates W, L, and I_{DS} for six scenarios for the selected inversion coefficient or gm/ID ratio:

1. Mininum noise at maximum inversion level
2. Minimum current to meet the noise specification
3. Minimum cut-off frequency to meet the noise specification
4. Minimum product of g_m and c_{iss} to meet the noise specification
5. Minimum area at a given current budget to meet the noise specification
6. Maximum area at a given current budget to meet the noise specification

SLiCAP design automation



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