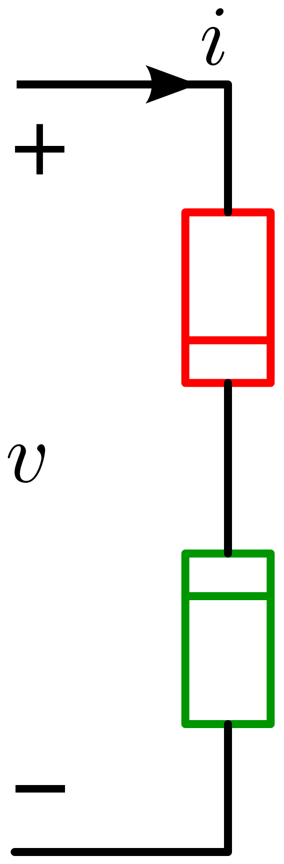
Structured Electronic Design

Balancing of two-terminal elements

Anton J.M. Montagne

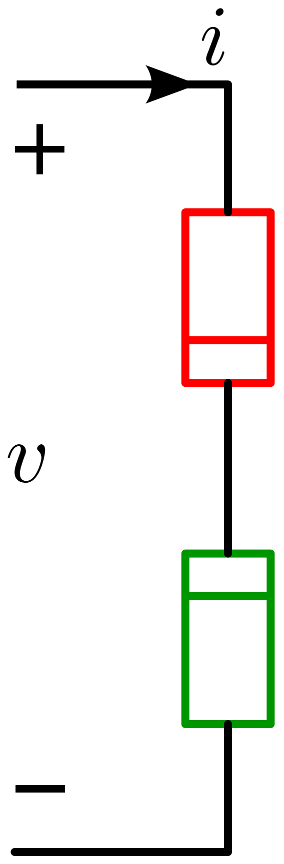
Anti-series and complementary-series connections

Anti-series and complementary-series connections



Anti-series connection of equal elements

Anti-series and complementary-series connections



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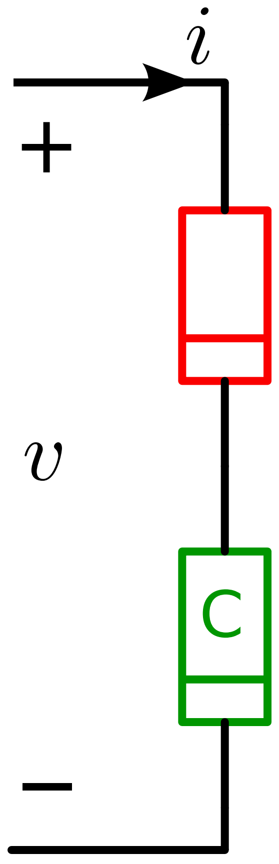
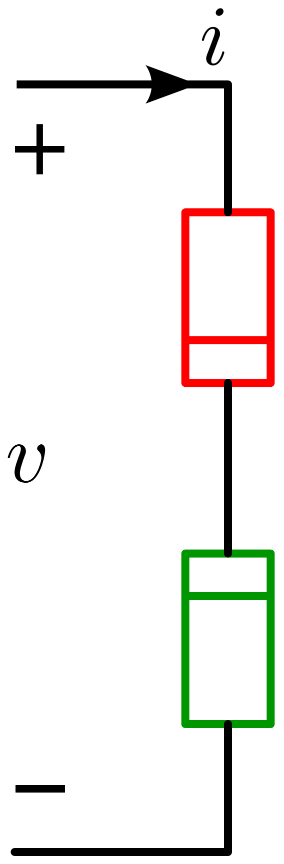


Series connection of complementary elements

Anti-series and complementary-series connections



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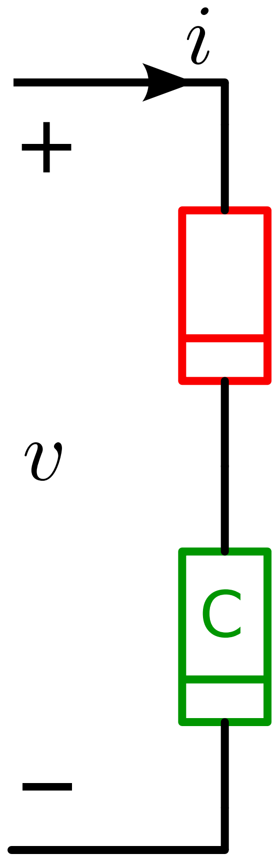

Series
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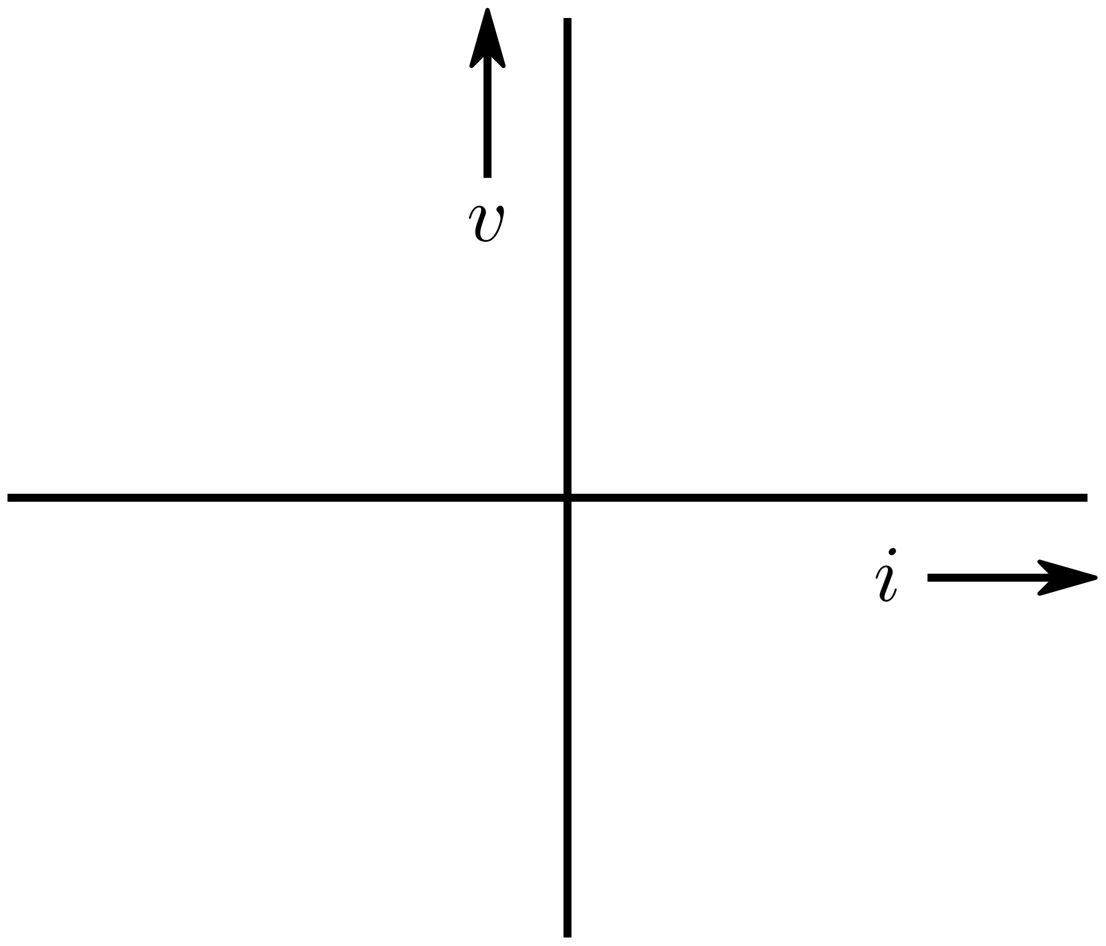

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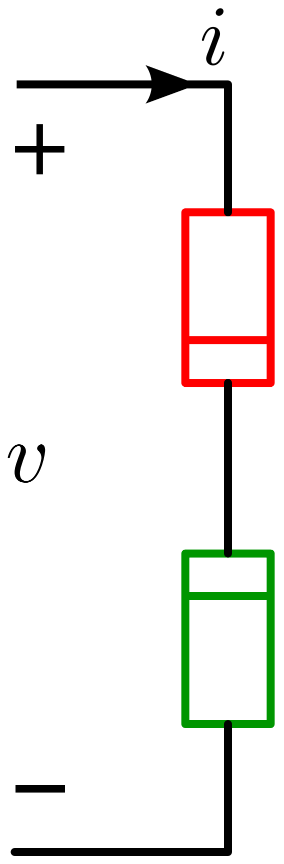

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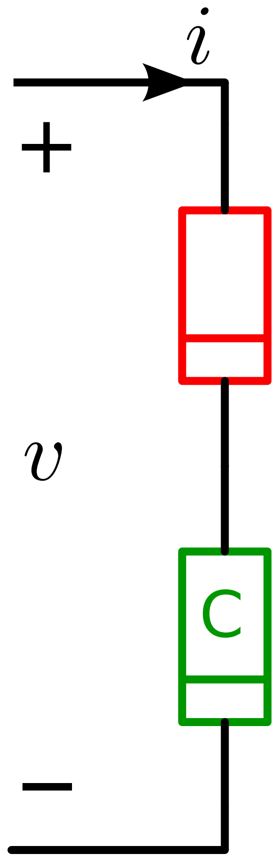

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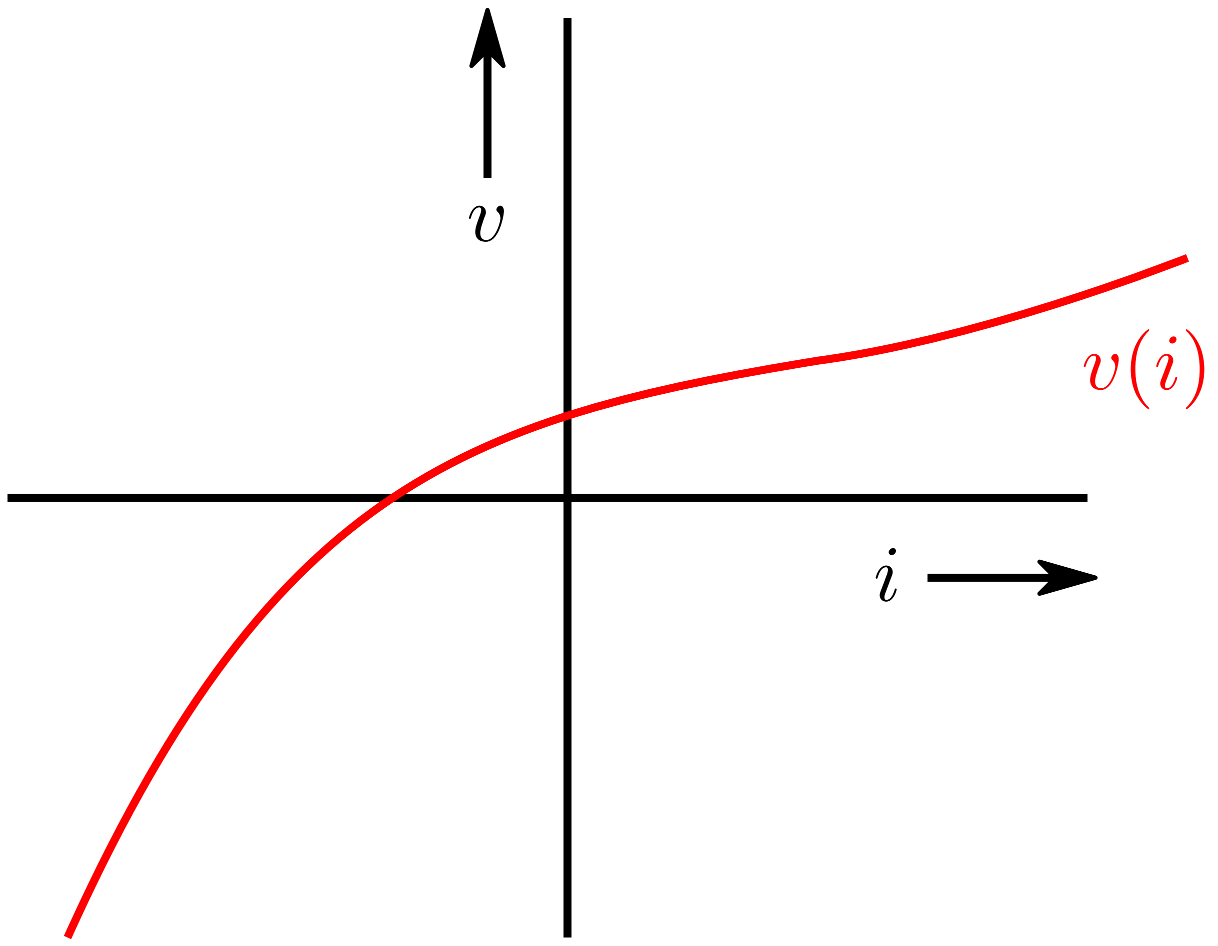

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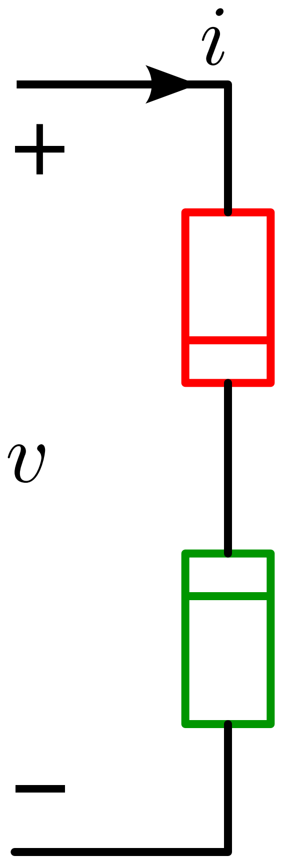

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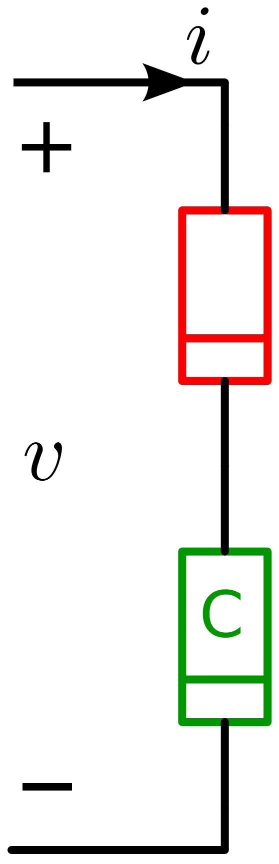
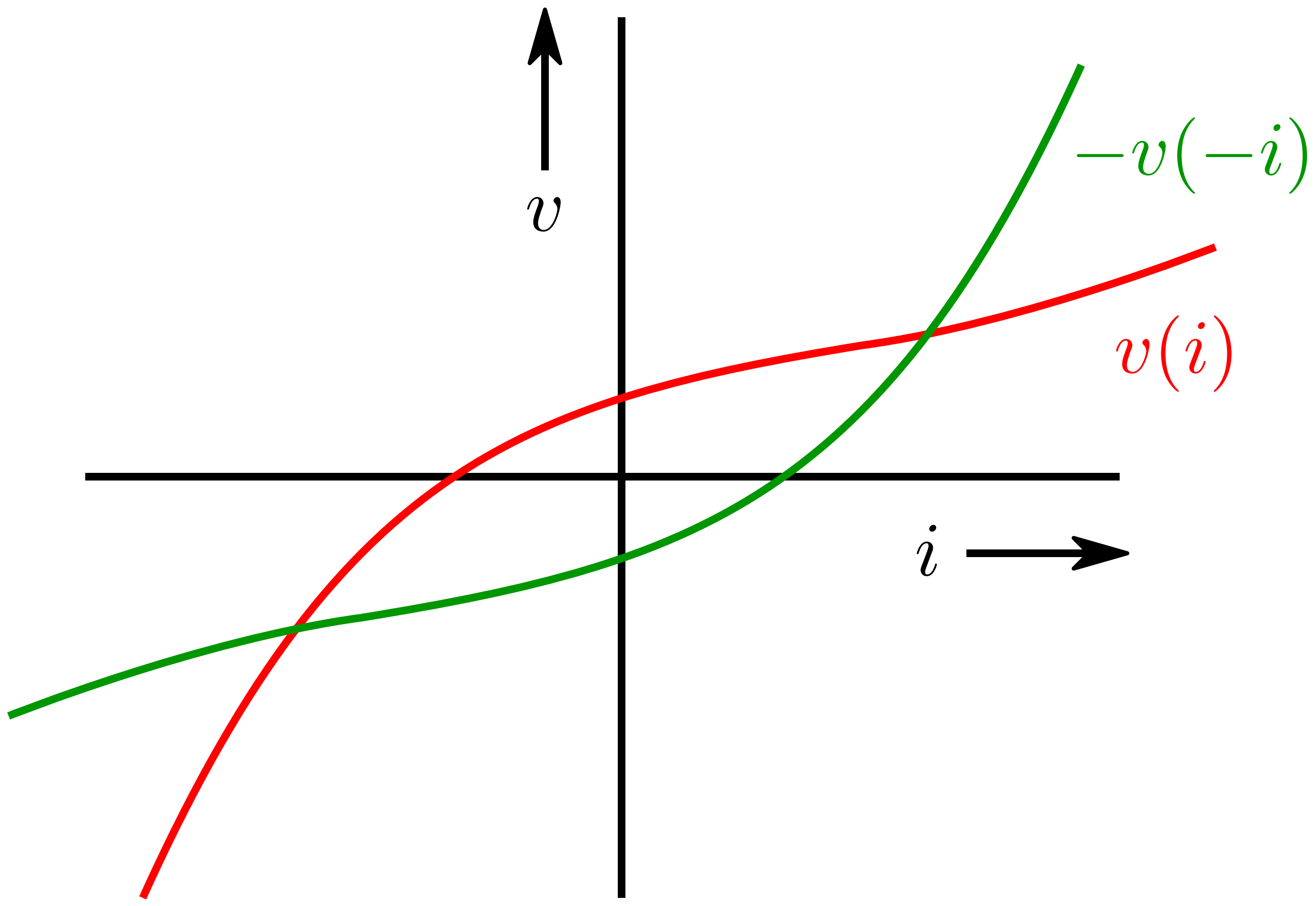


Series connection of complementary elements



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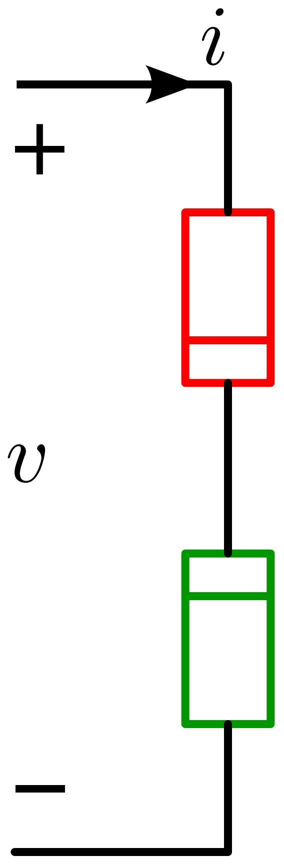

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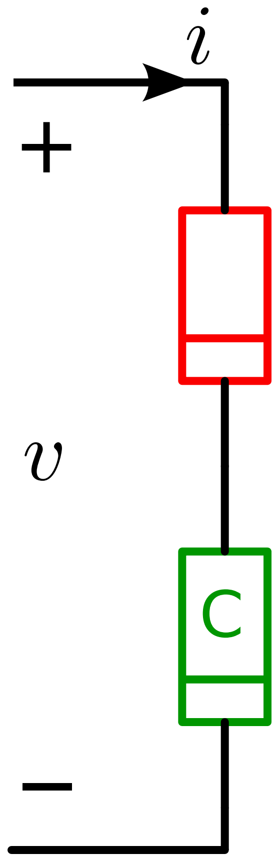

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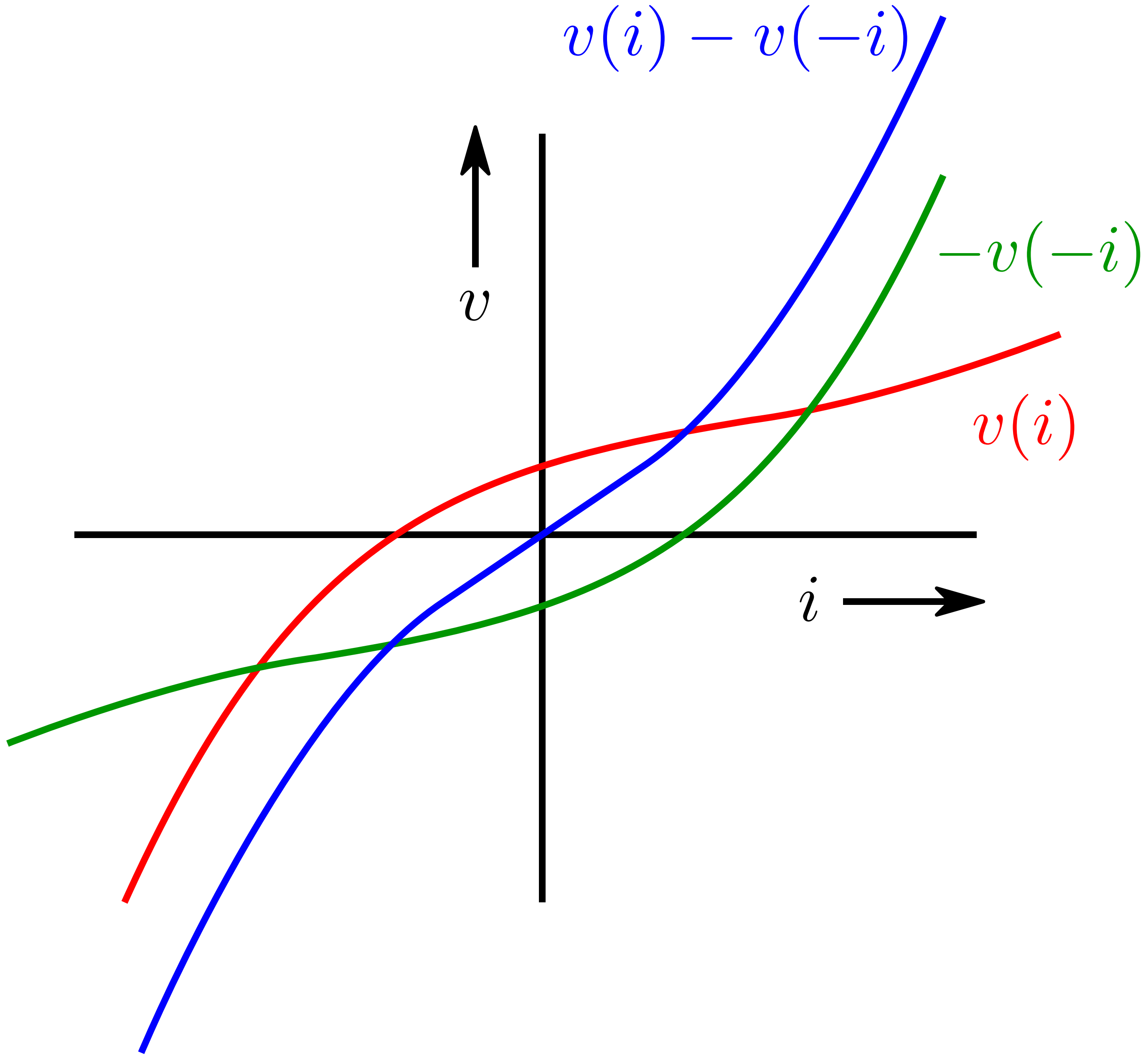

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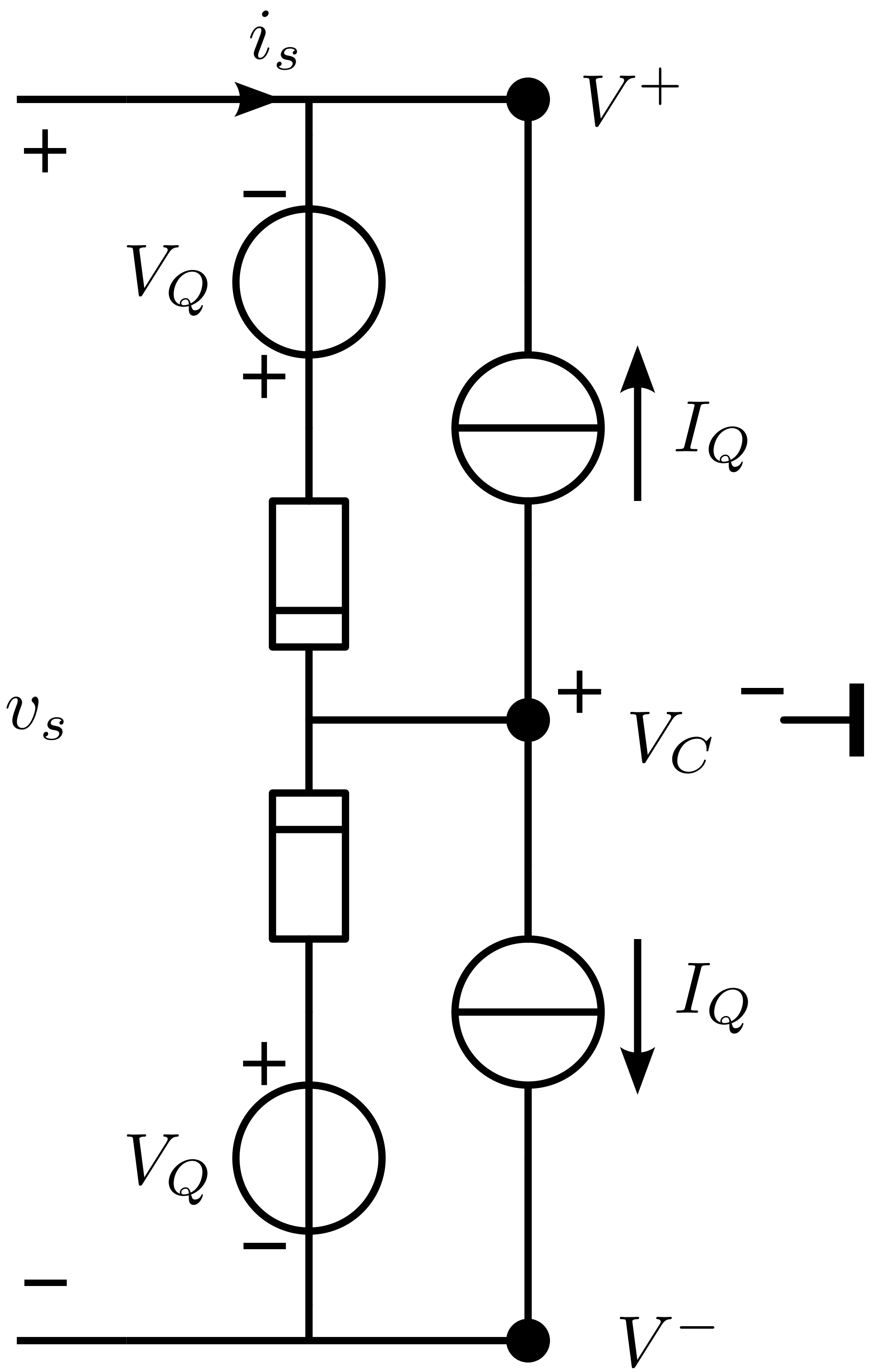

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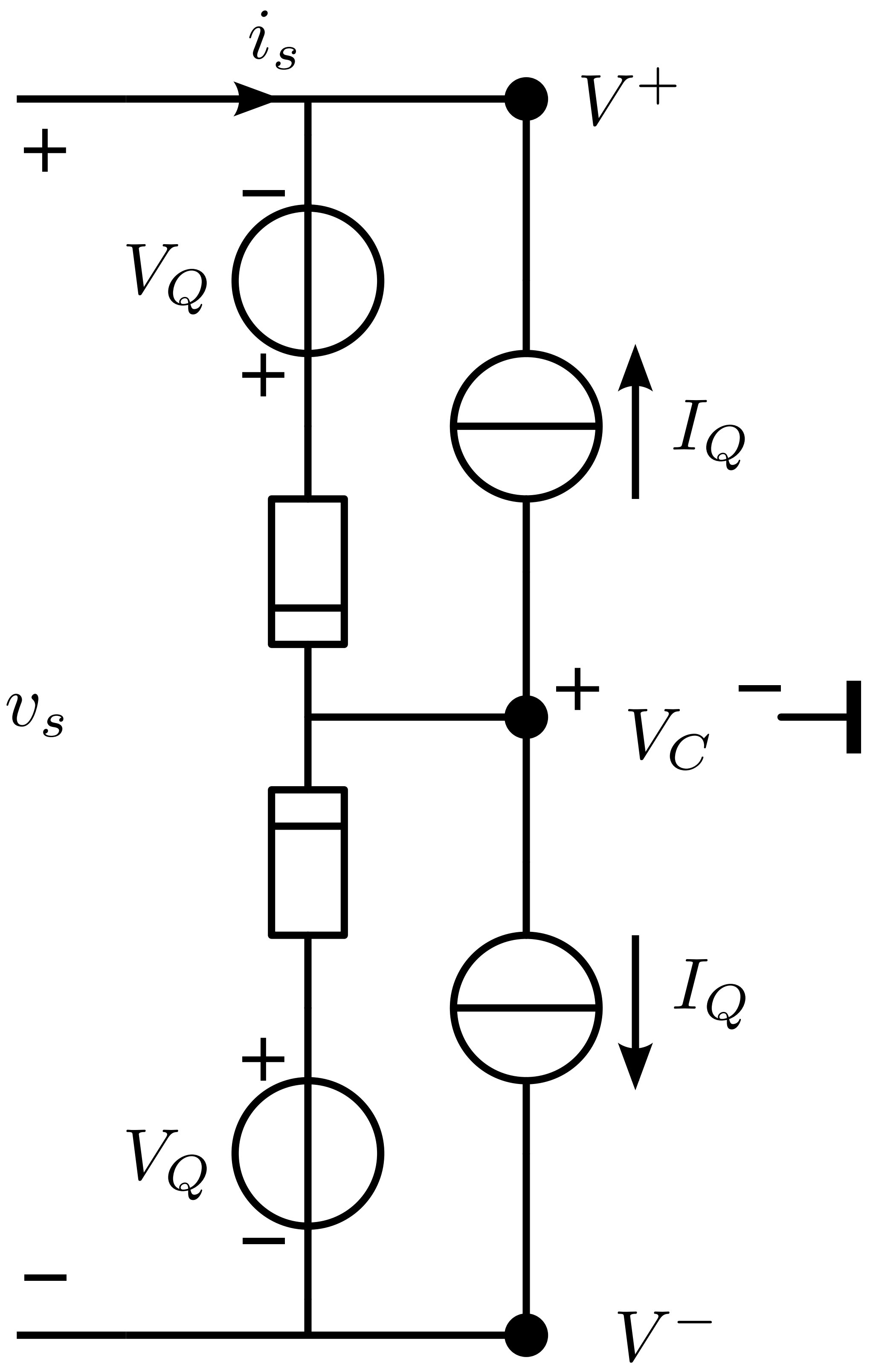

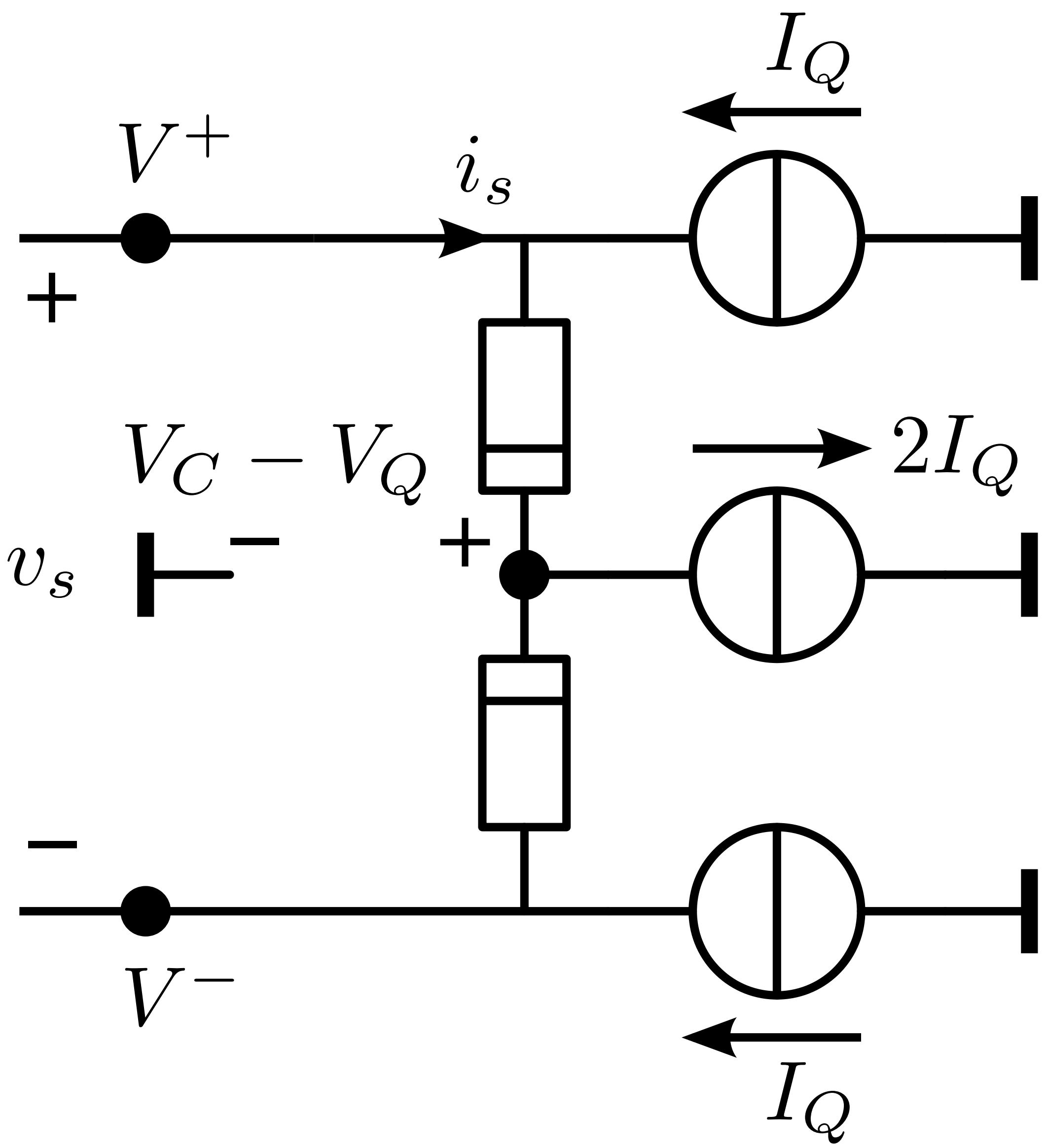

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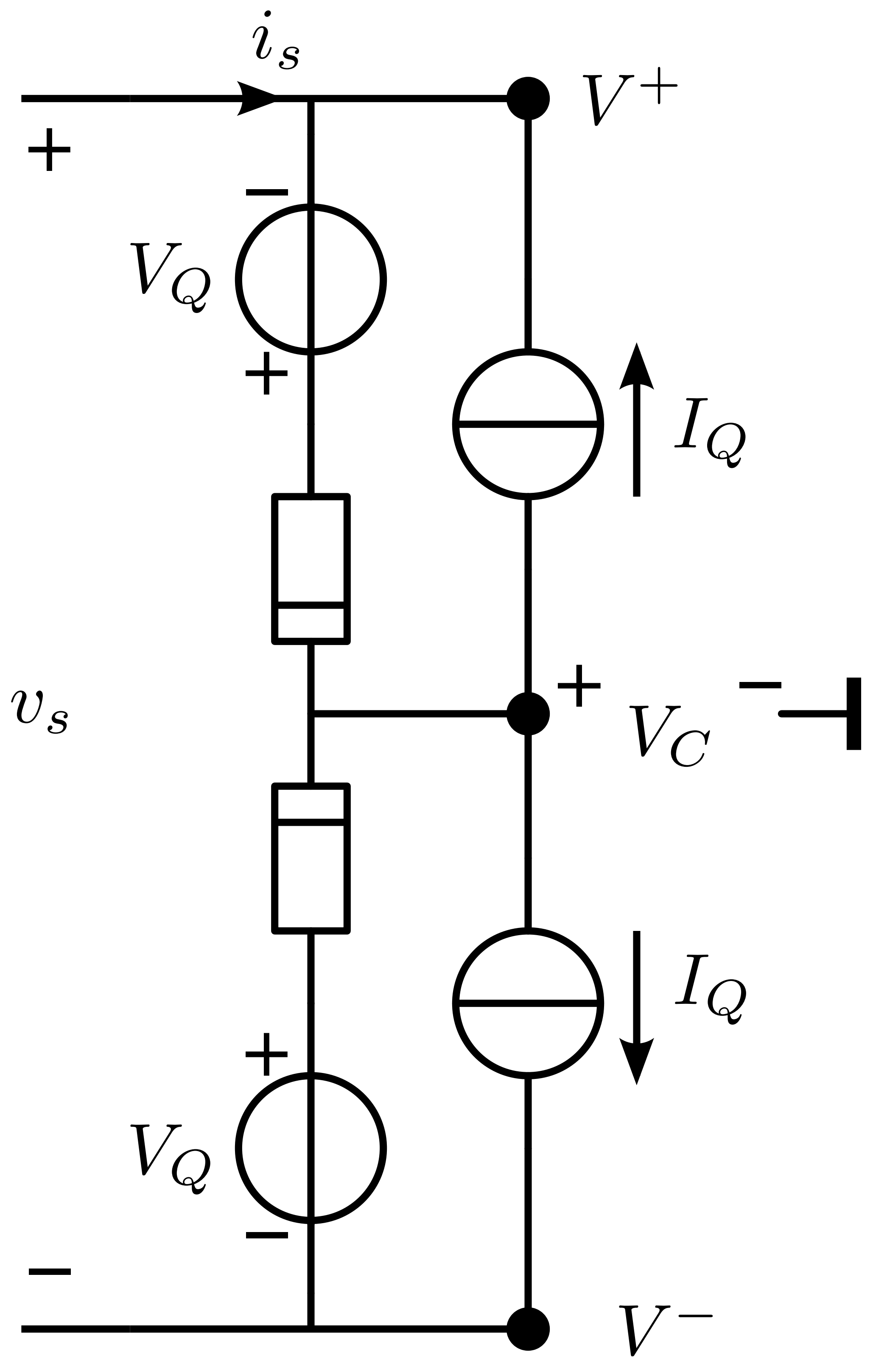
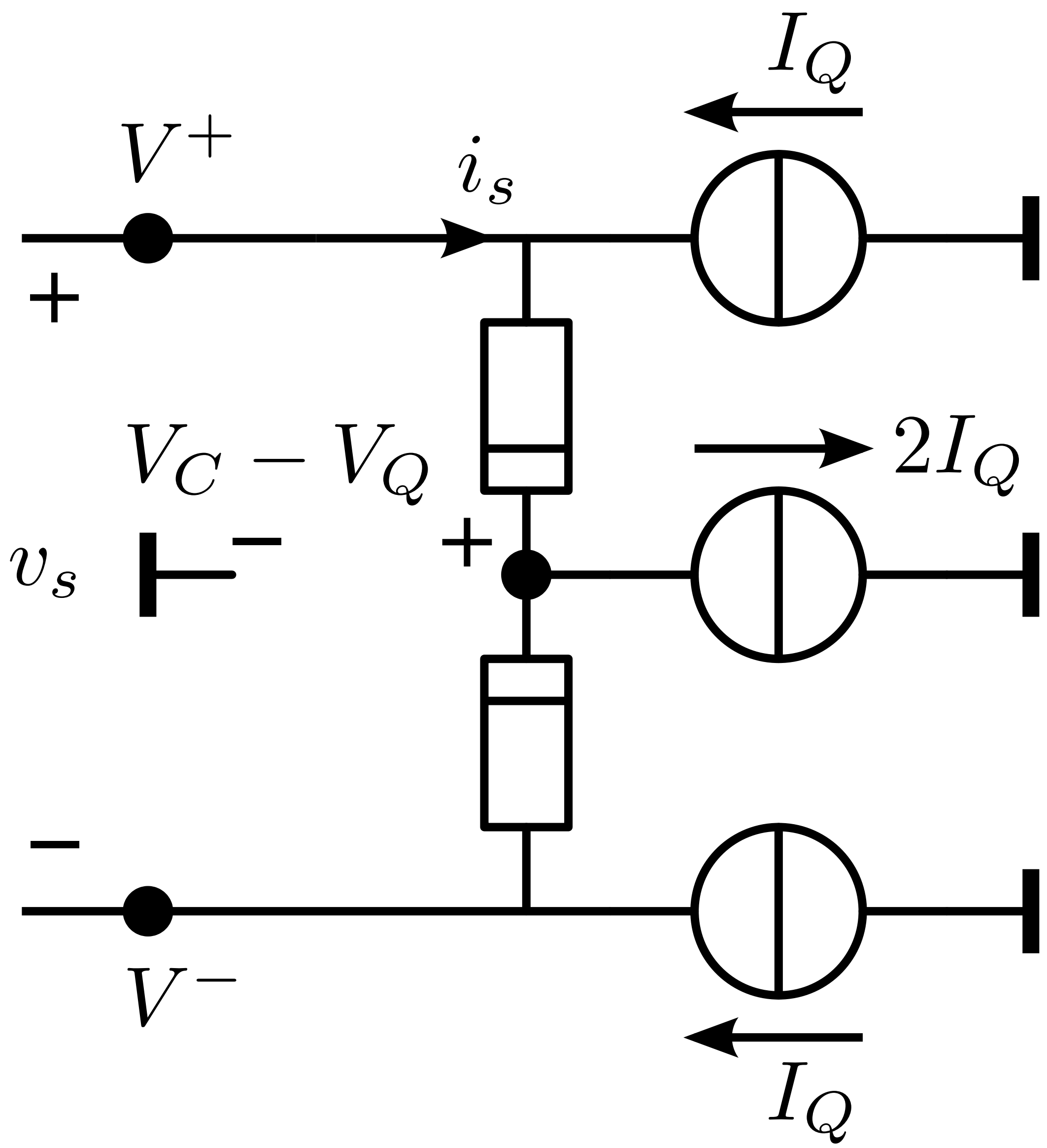
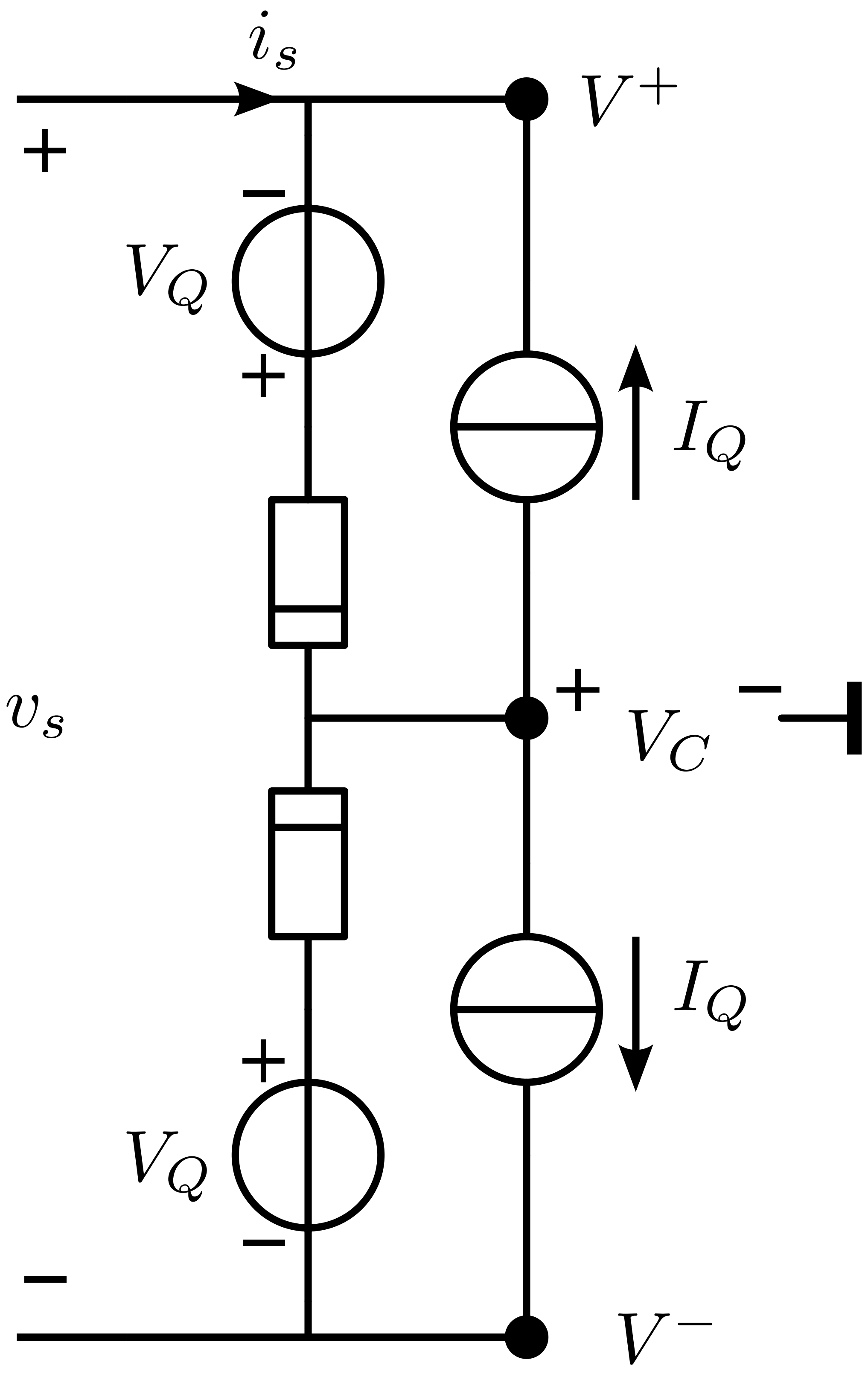
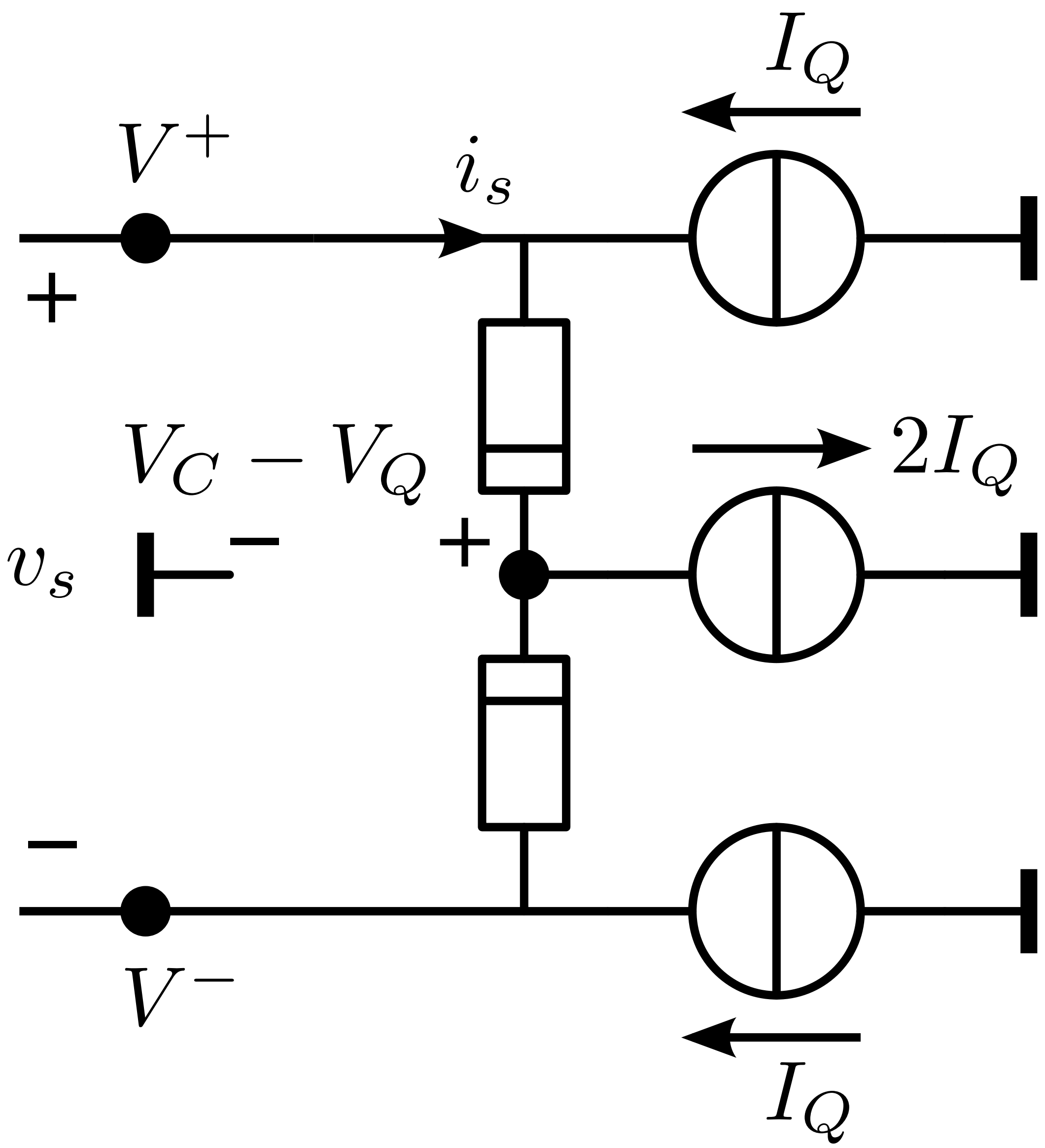




Elements can be biased with common-mode current sources

Anti-series and complementary-series connections

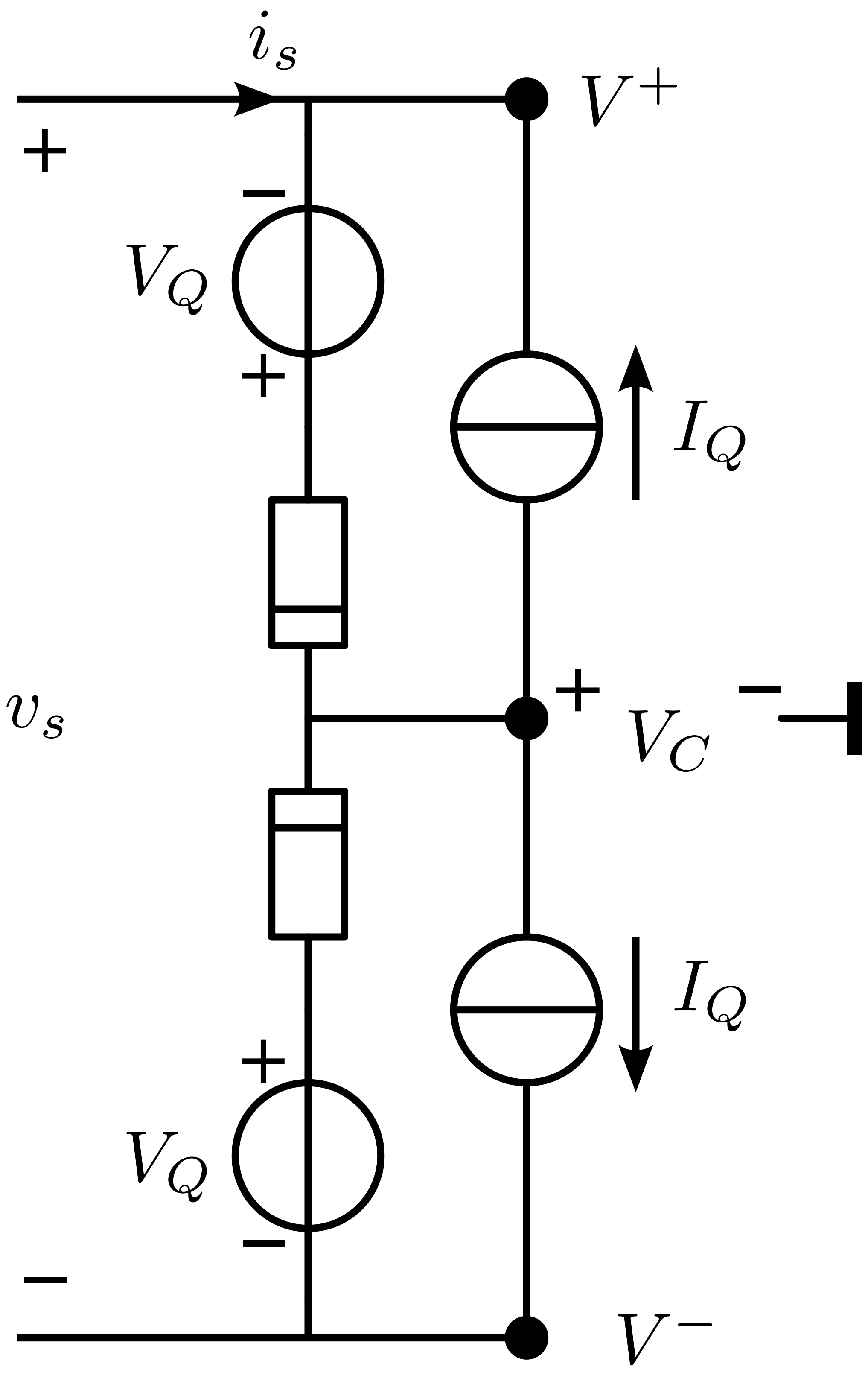


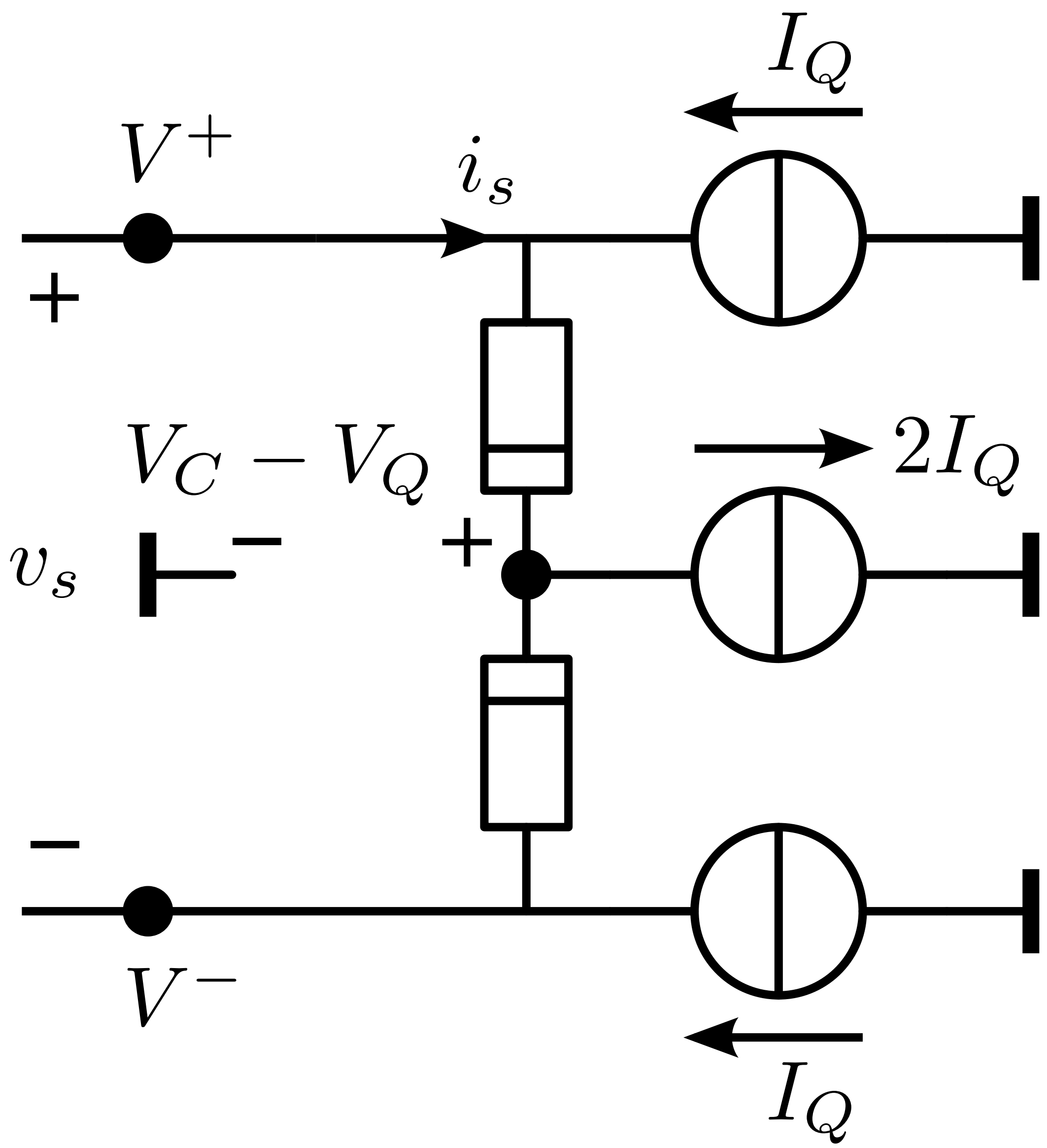


Elements can be biased with common-mode current sources

Bias voltage appears as common-mode voltage in the circuit

Anti-series and complementary-series connections





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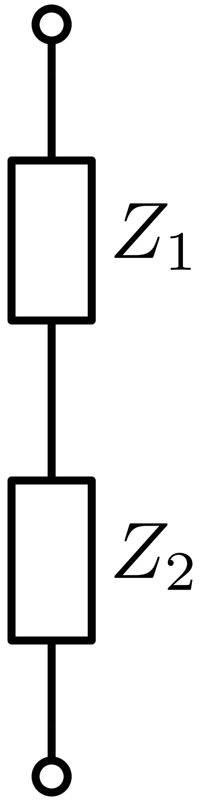
Anti-series and complementary-series connections

Small-signal model

Anti-series and complementary-series connections

Small-signal model



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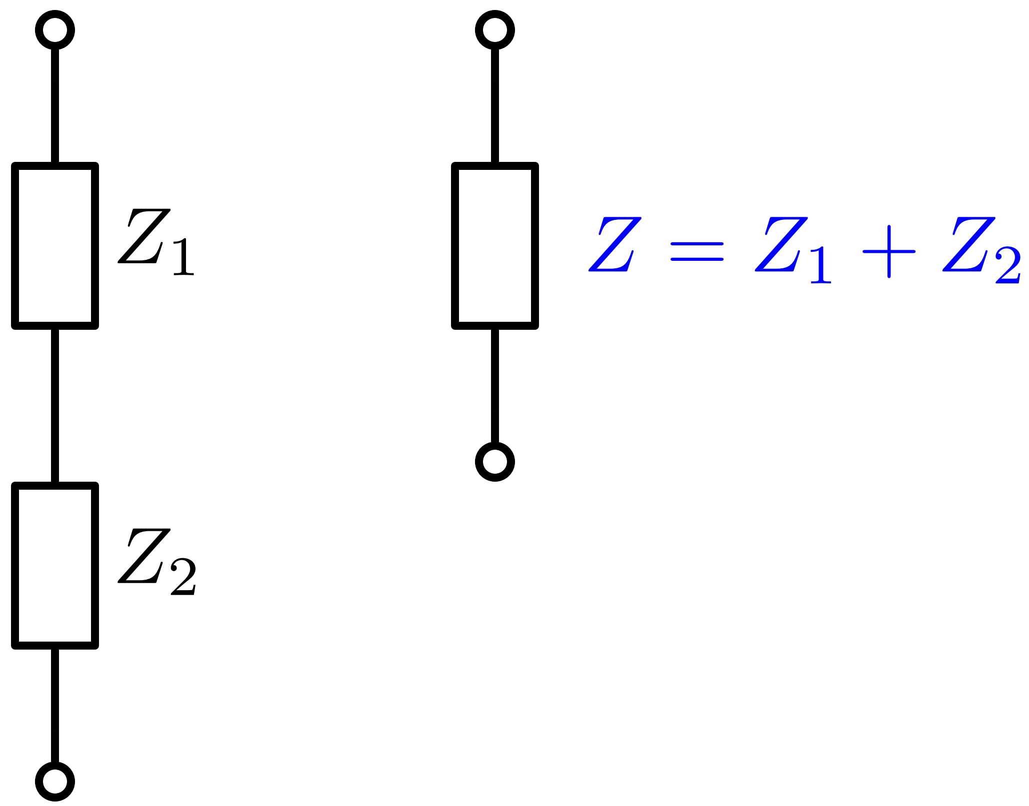
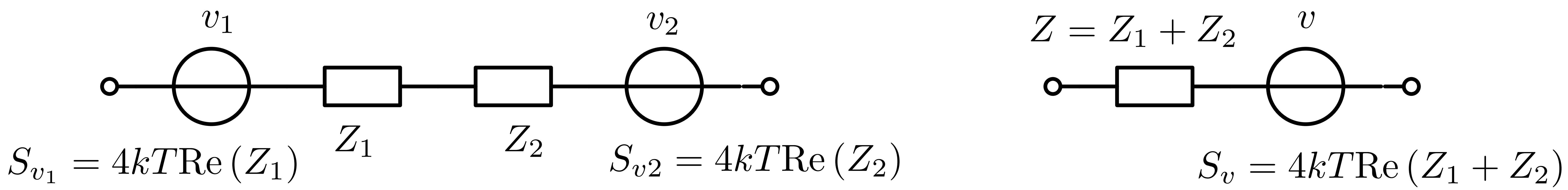


Voltage noise spectral density is the sum of the voltage noise spectral densities of the constituting elements



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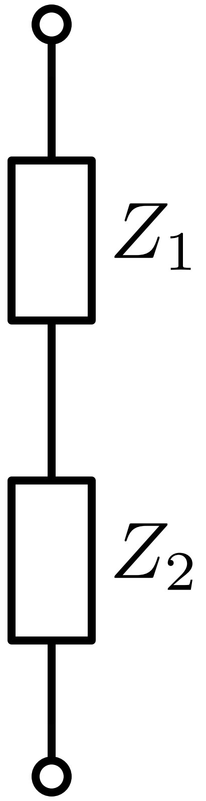
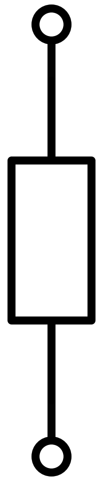


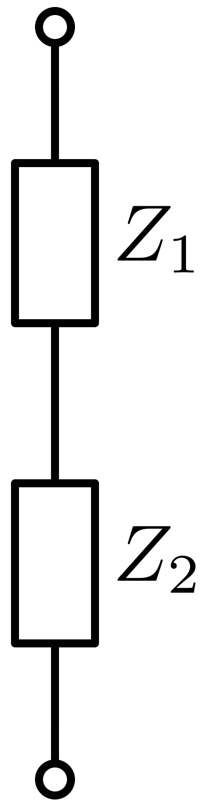


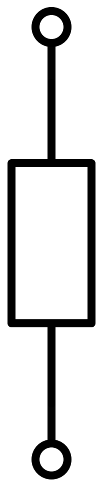
$$Z = Z_1 + Z_2$$

Small-signal impedance is sum of small-signal impedances of constituting elements

Anti-series and complementary-series connections

Small-signal model





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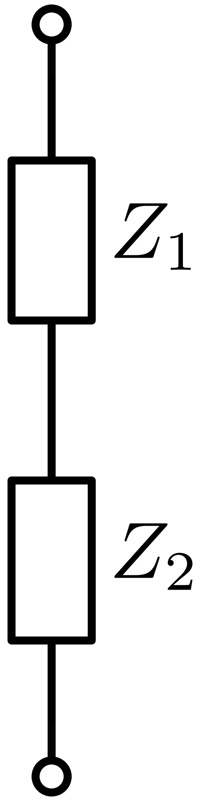
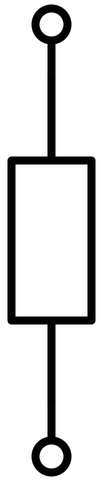
$Z = 2Z_1 = 2Z_2$

Anti-series and complementary-series connections

Small-signal model





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Twice the impedance in the quiescent operating point

Anti-series and complementary-series connections

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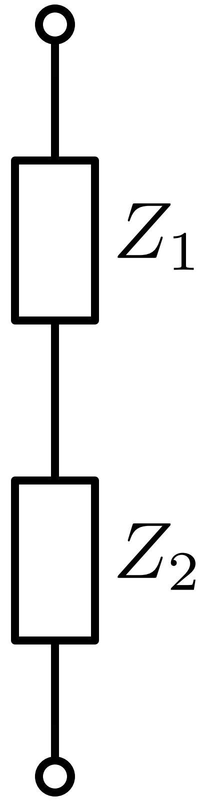

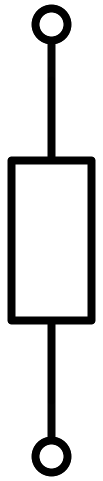

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Anti-series and complementary-series connections

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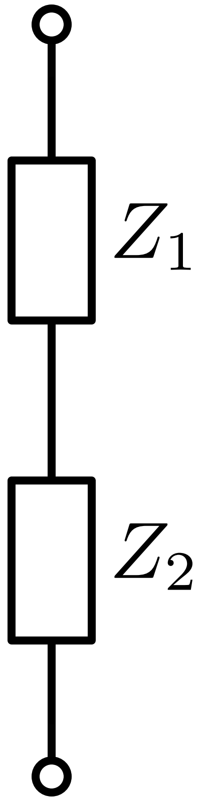

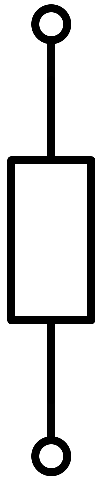

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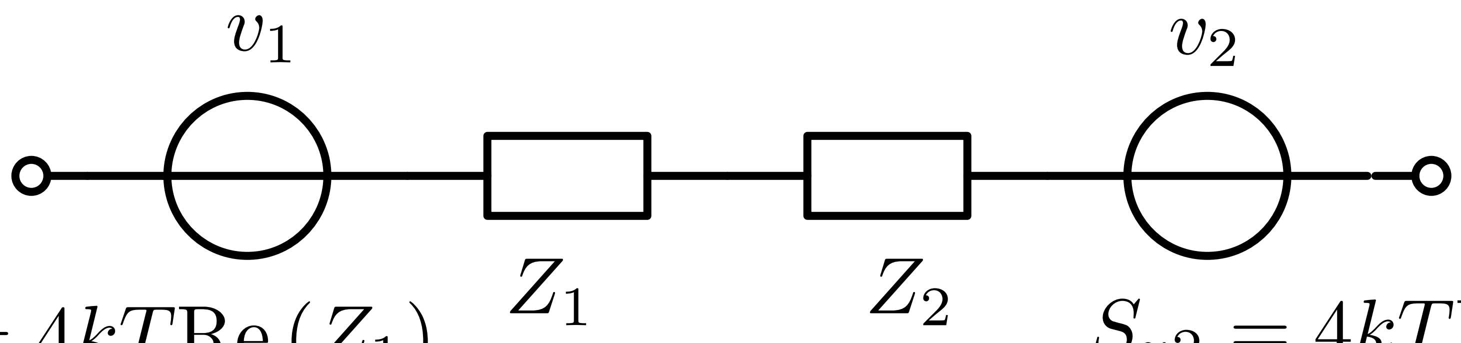

$S_{v_1} = 4kT\mathrm{Re}\left(Z_1\right)$

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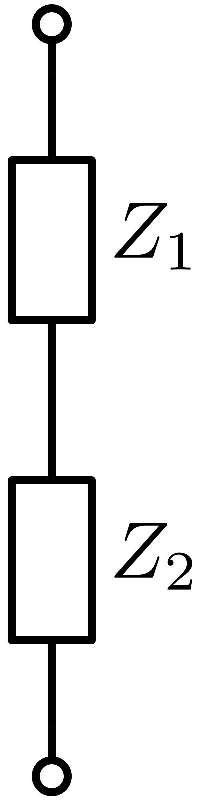
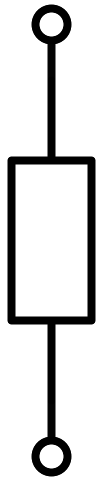
Anti-series and complementary-series connections

Small-signal model





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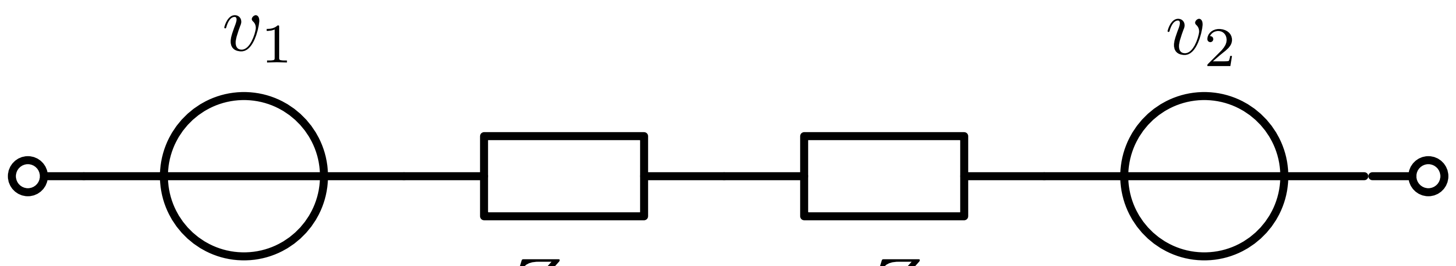

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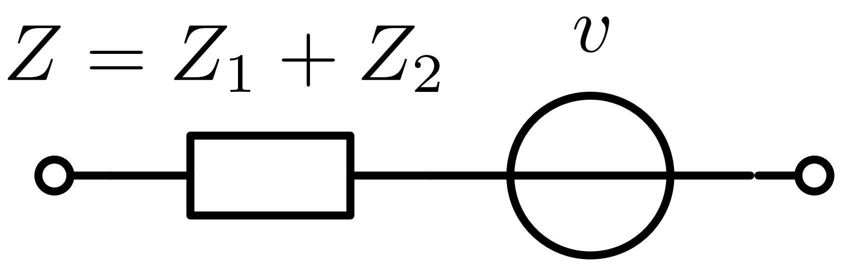

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Anti-series and complementary-series connections

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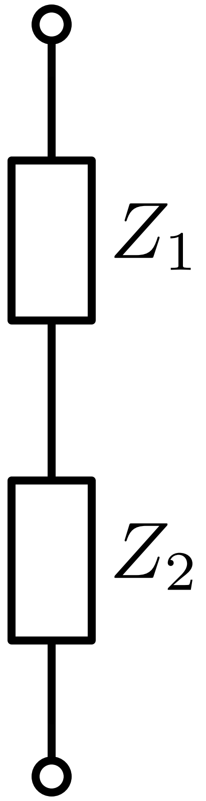

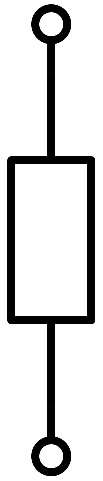

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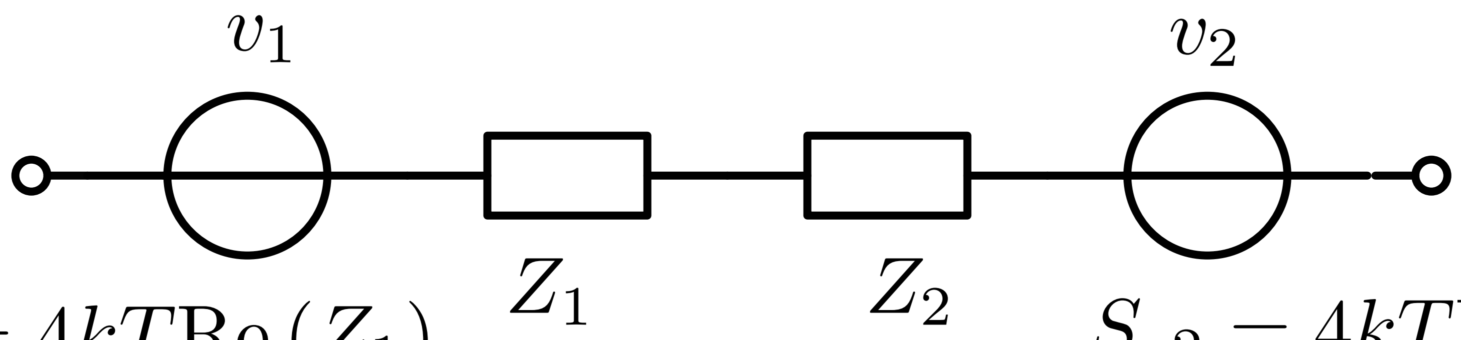

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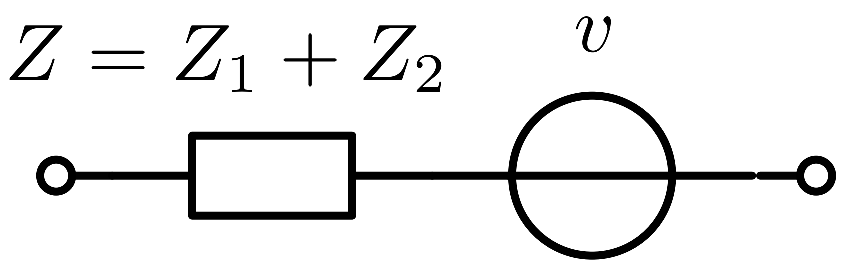

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Anti-parallel and complementary-parallel connections

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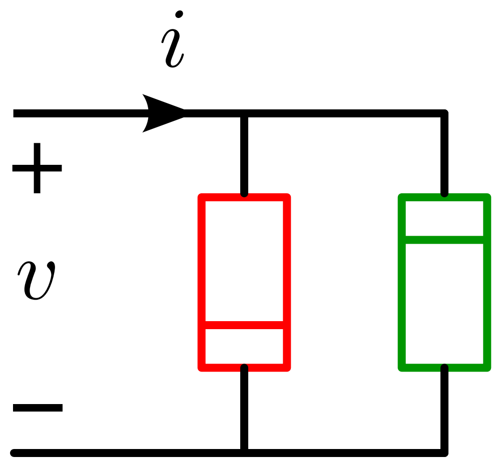

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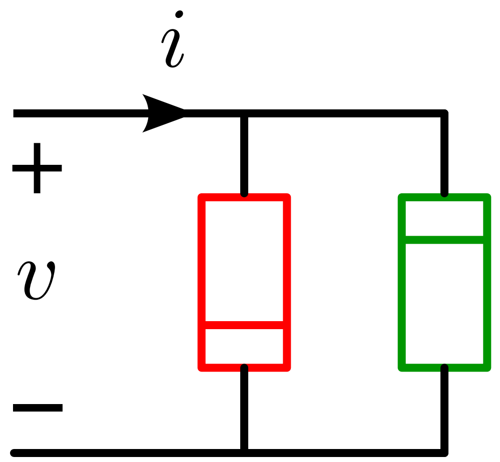
Anti-parallel and complementary-parallel connections



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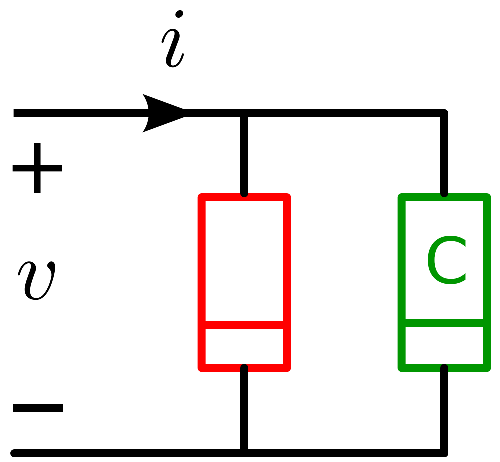
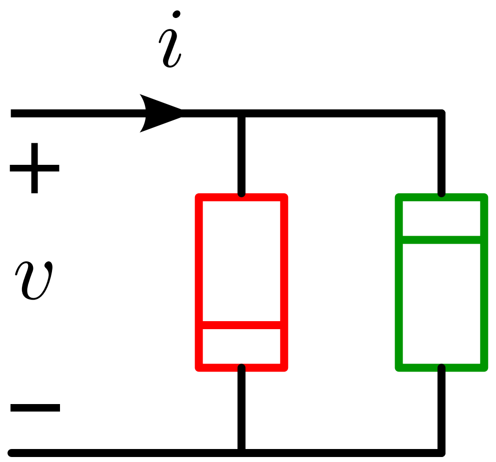
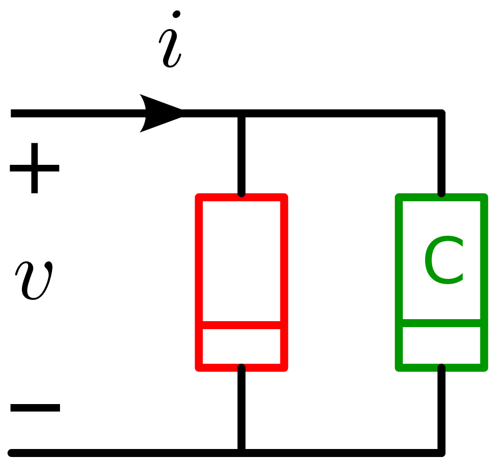
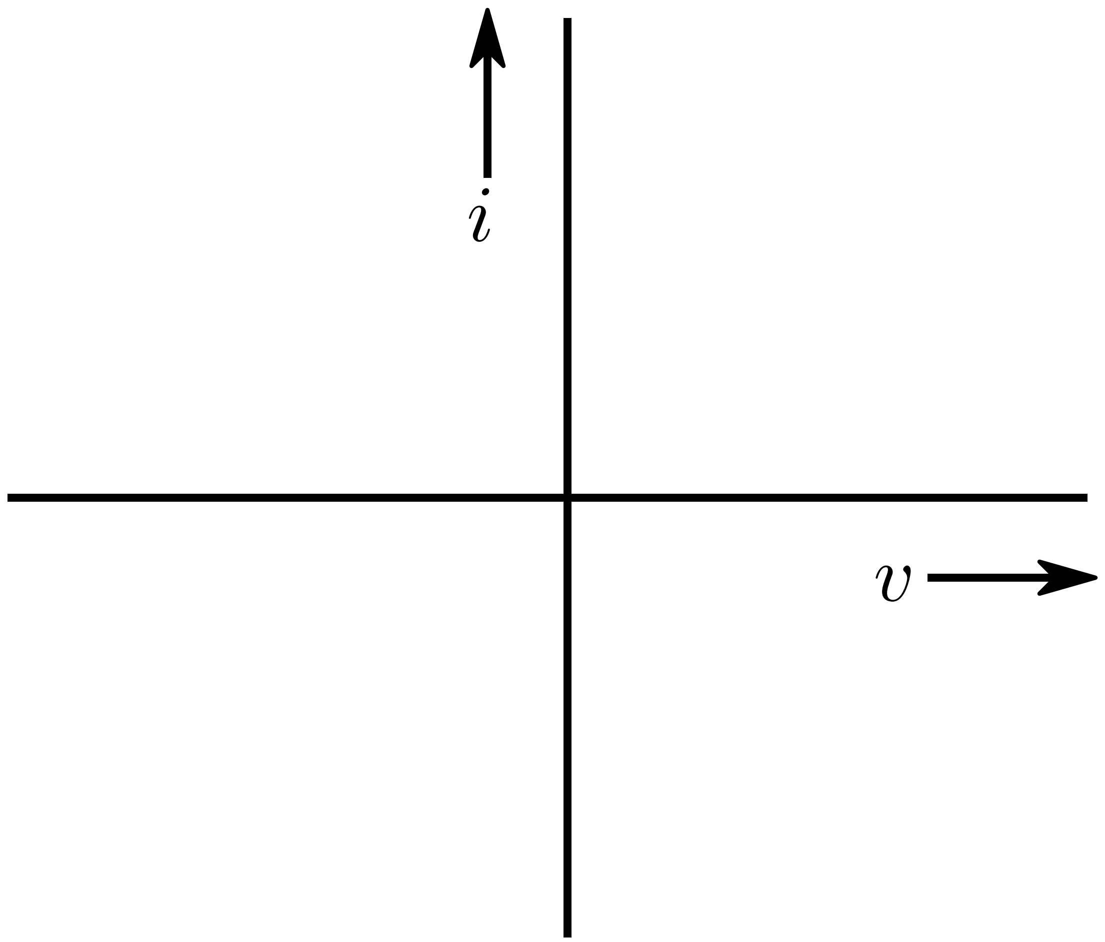


Parallel connection of complementary elements

Anti-parallel and complementary-parallel connections







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Parallel
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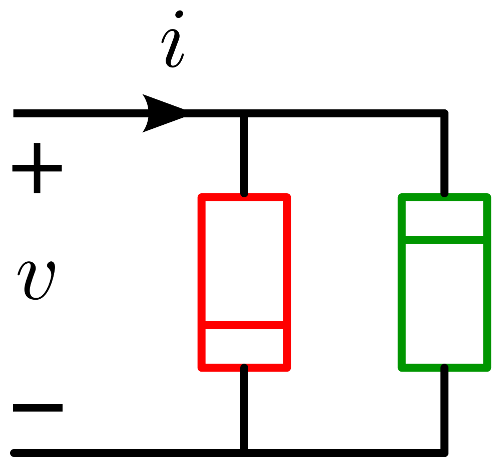
Anti-parallel and complementary-parallel connections



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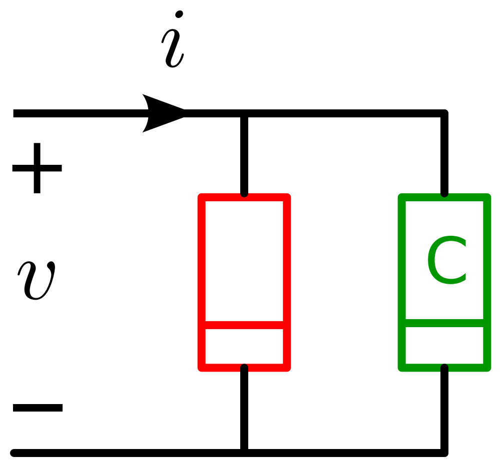

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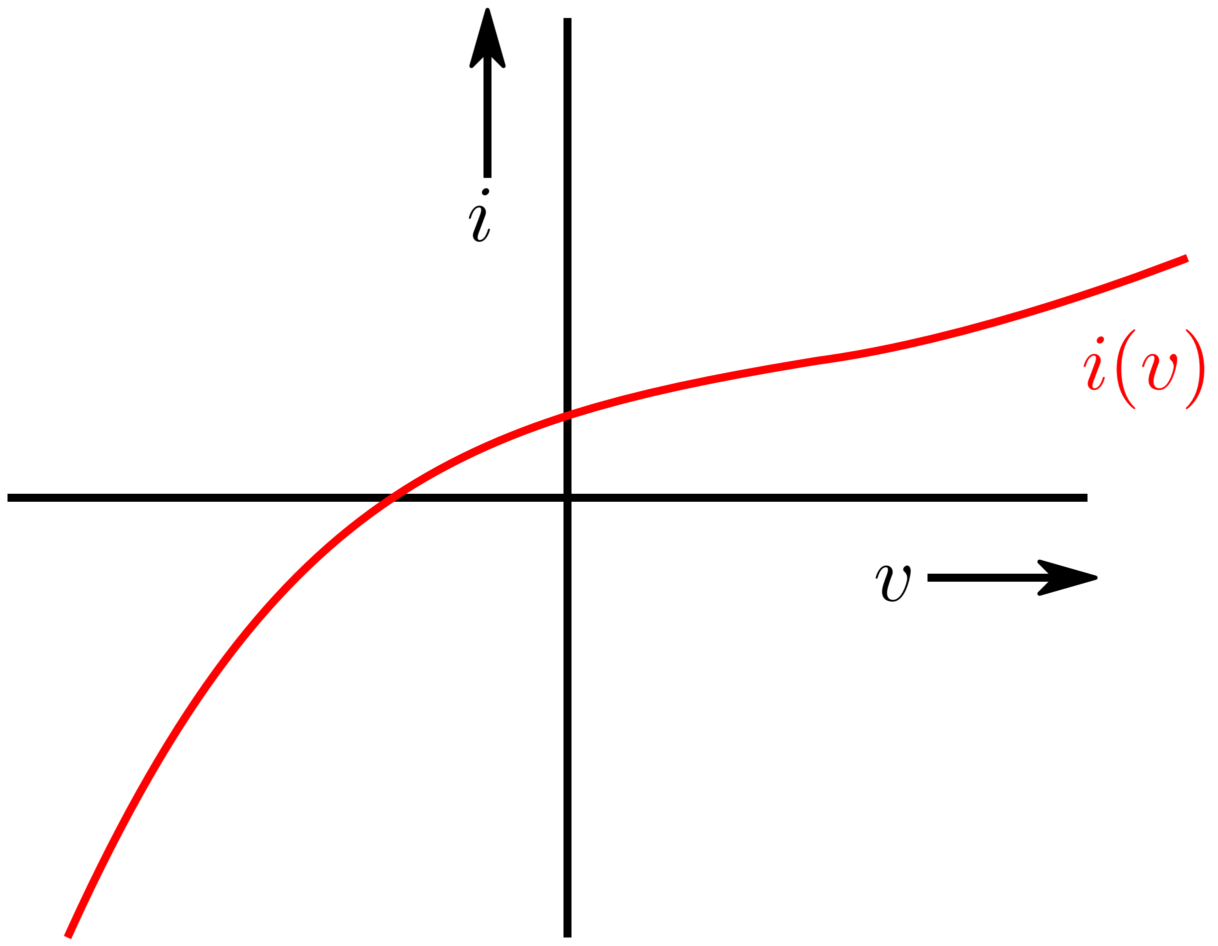

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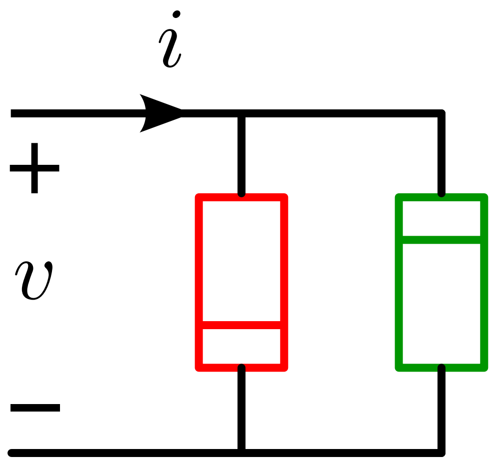
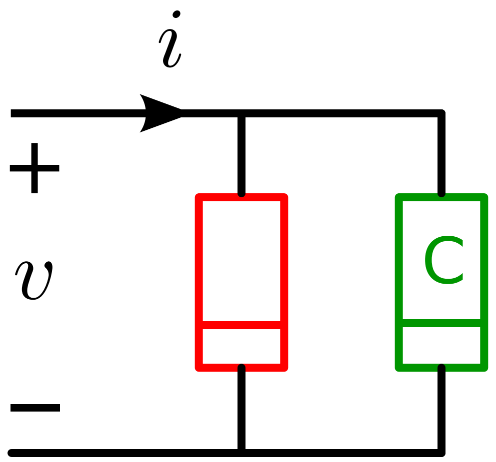
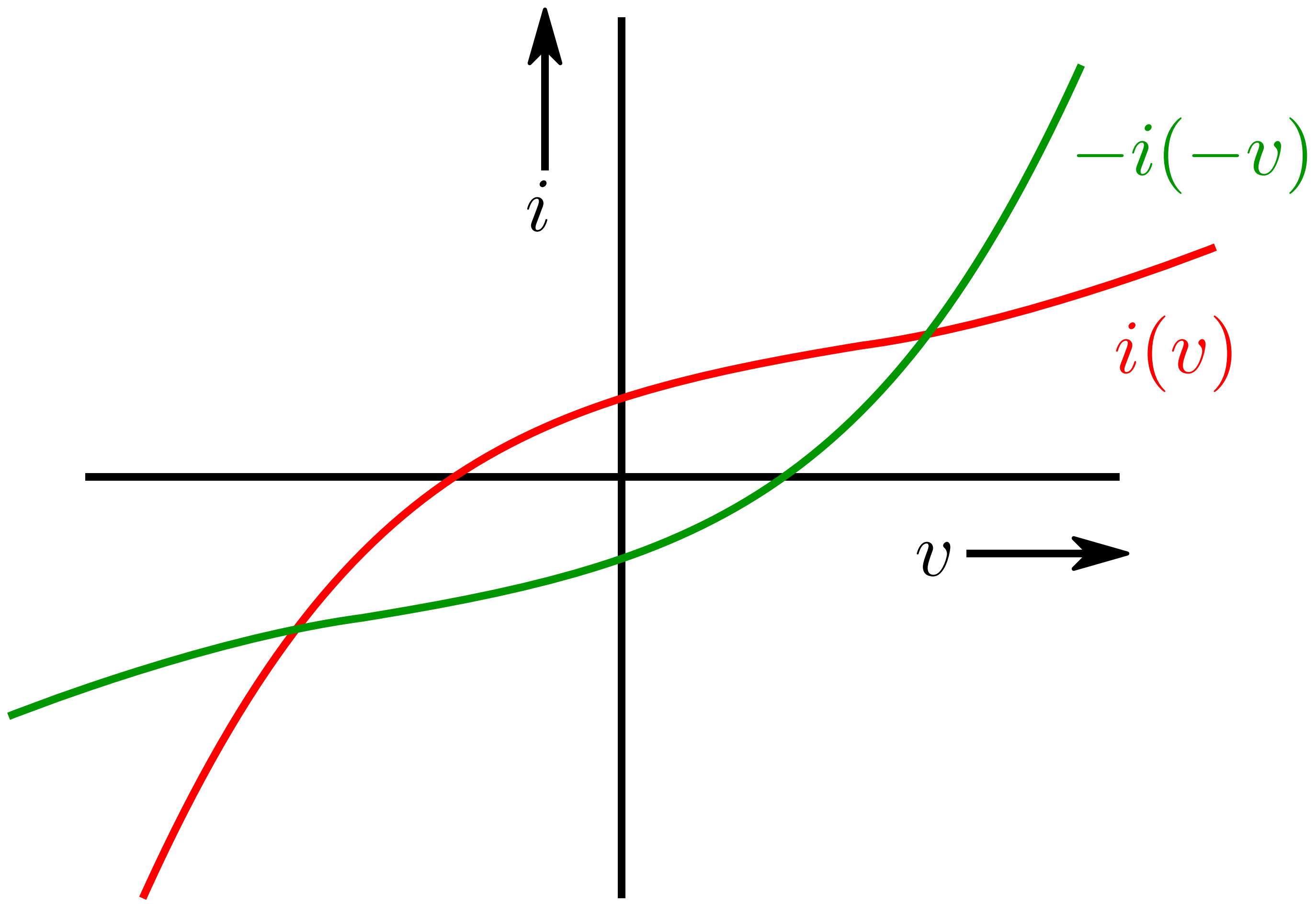


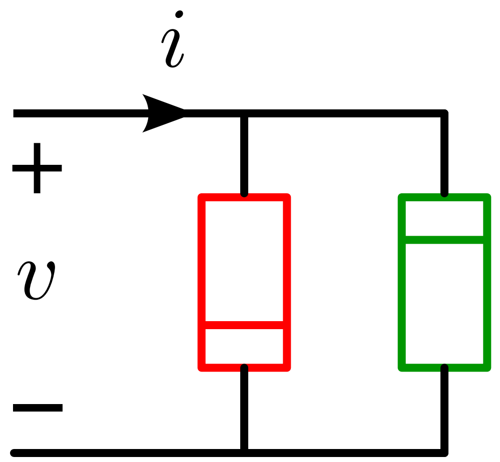
Anti-parallel connection of equal elements



Parallel connection of complementary elements



Anti-parallel and complementary-parallel connections



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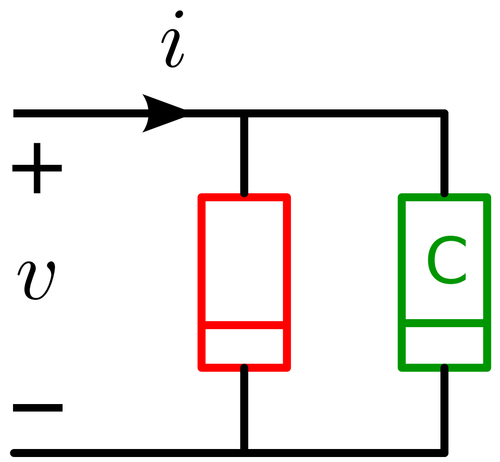

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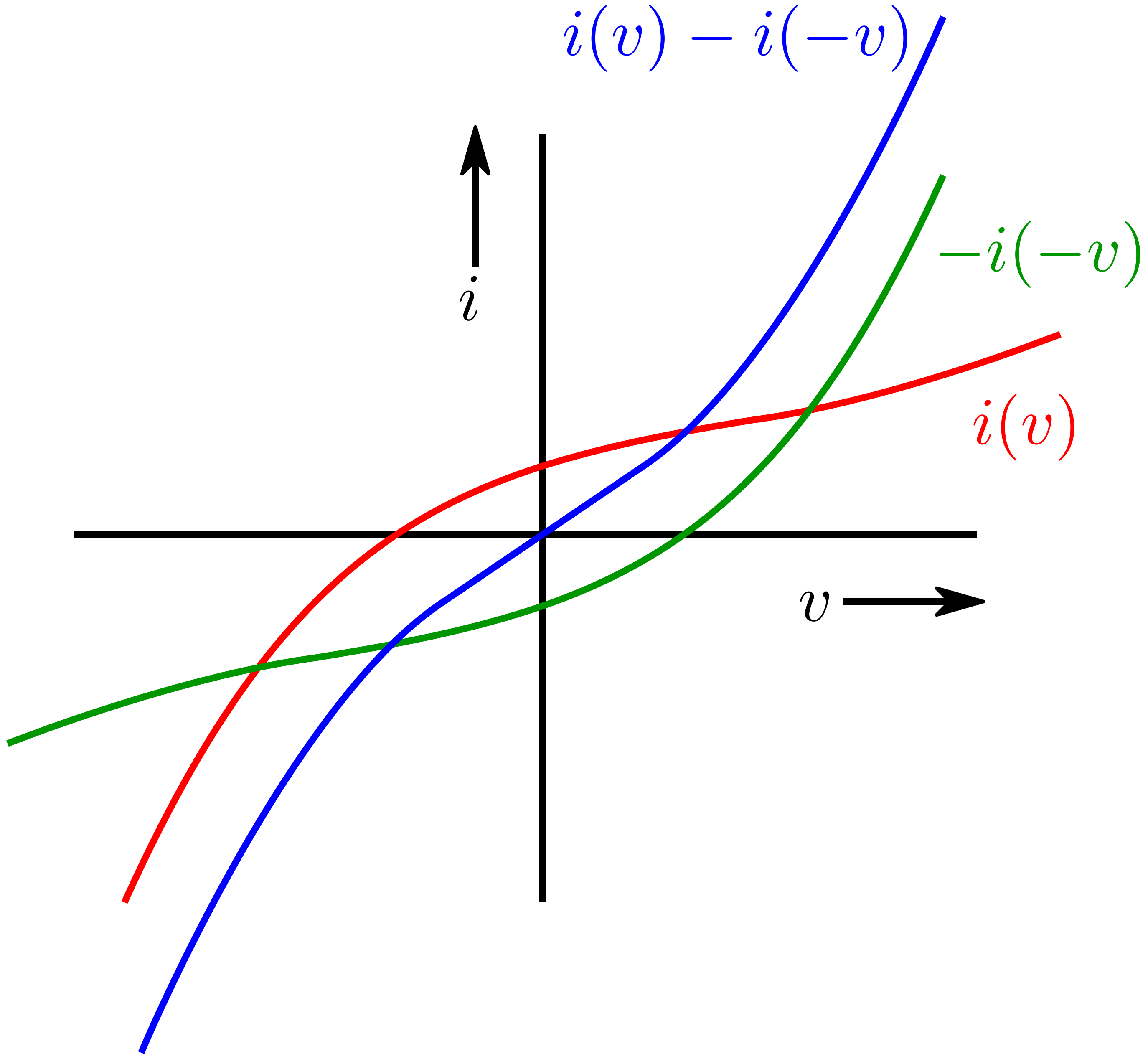

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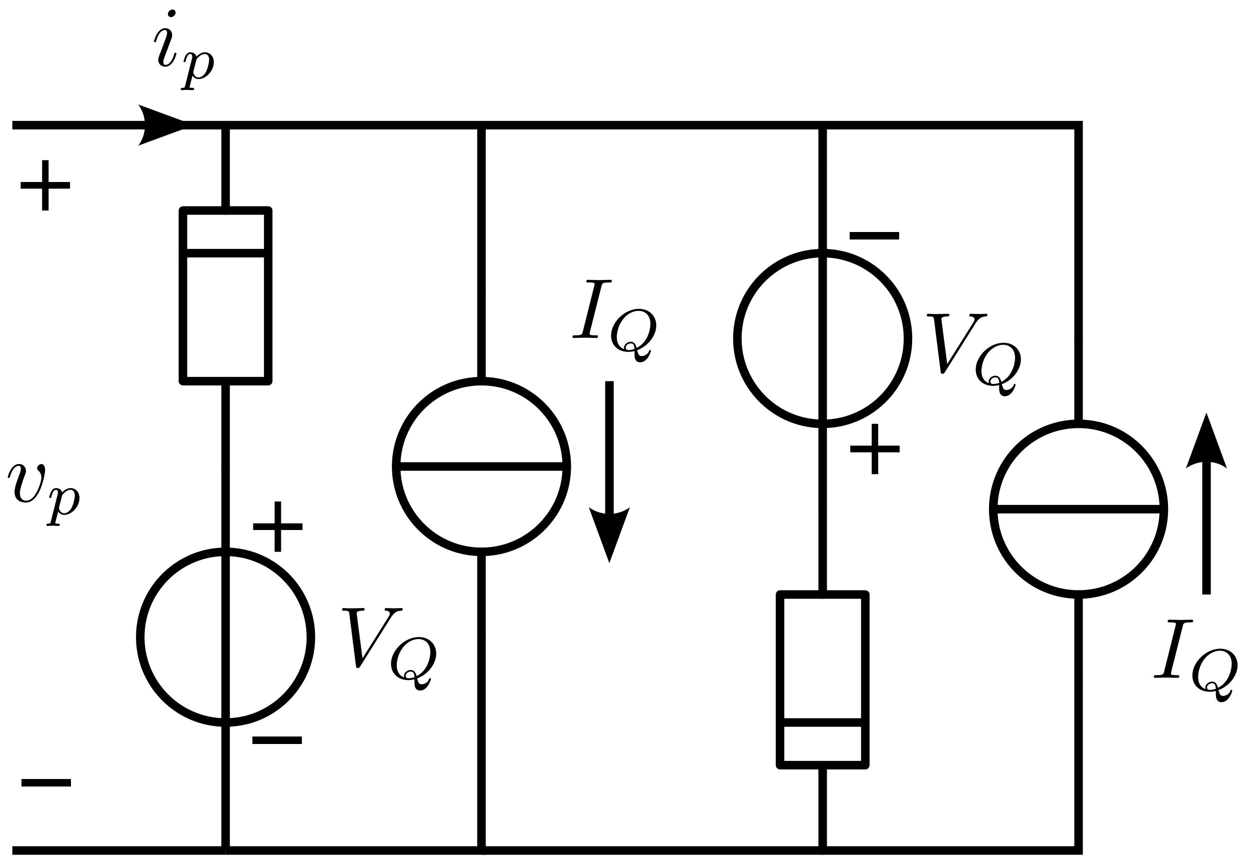

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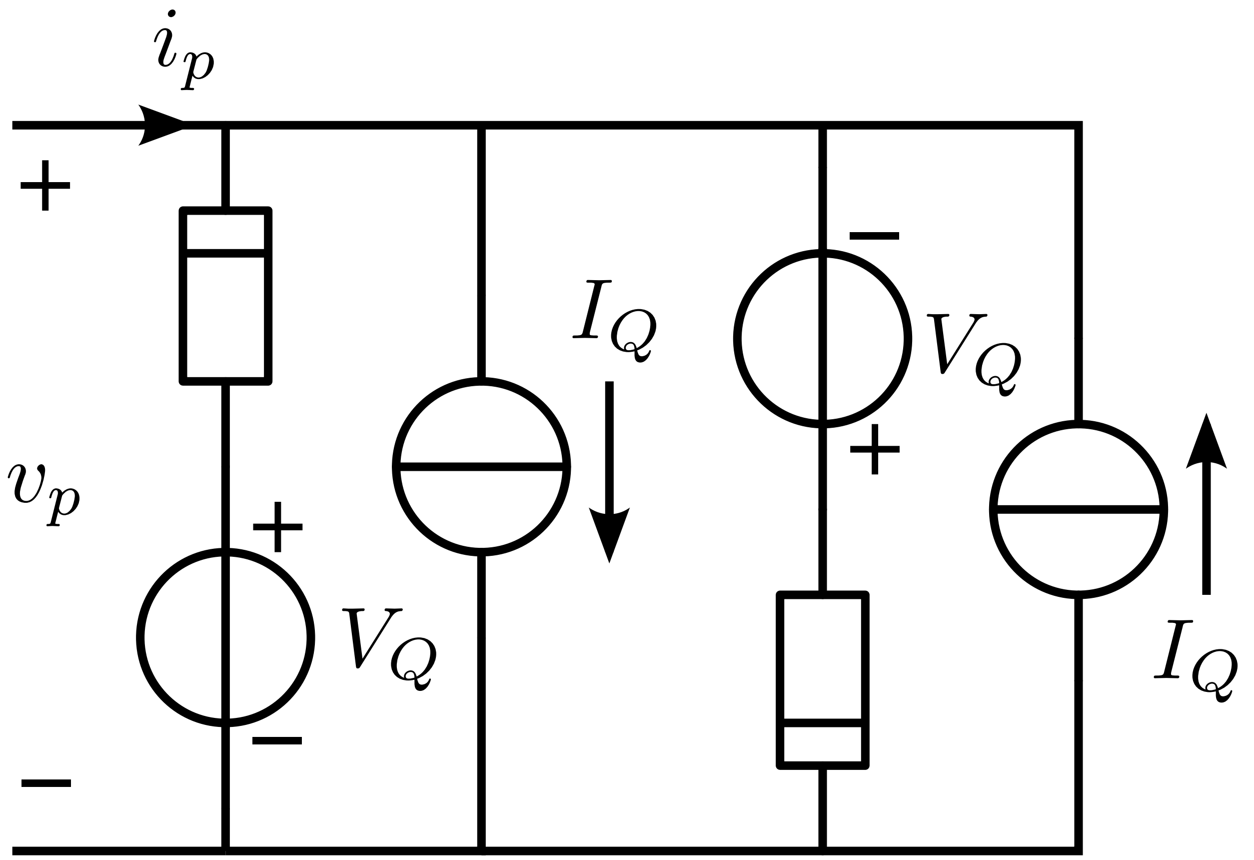
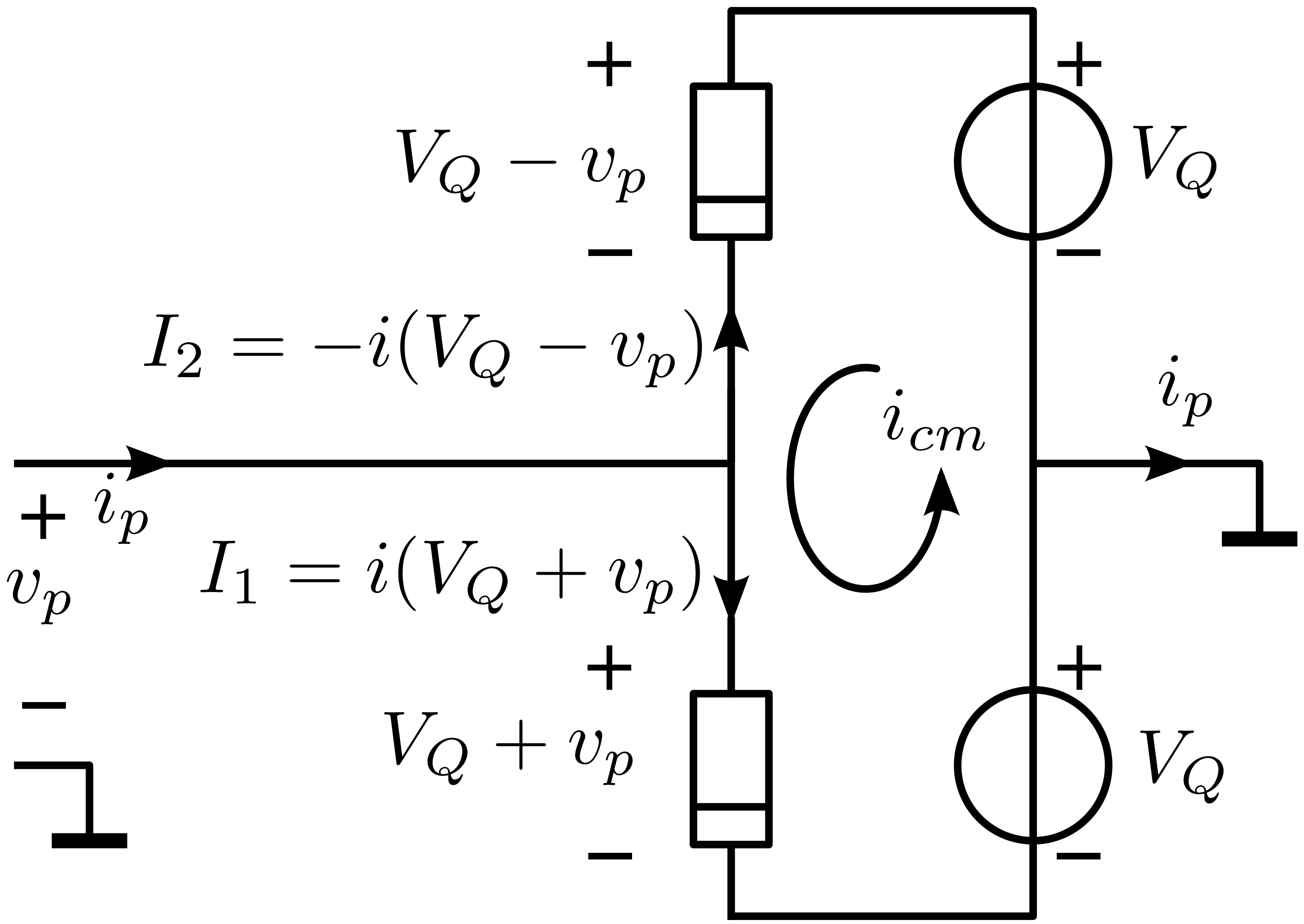
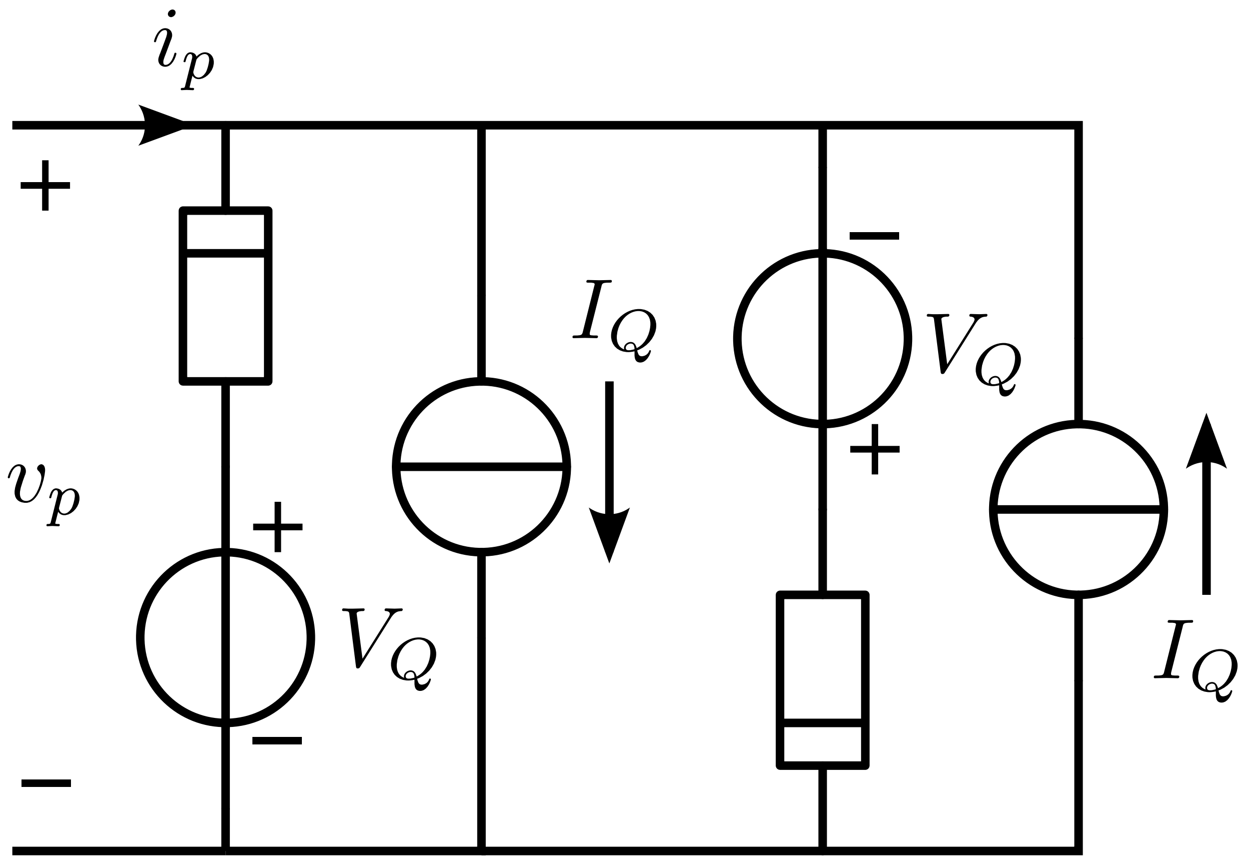
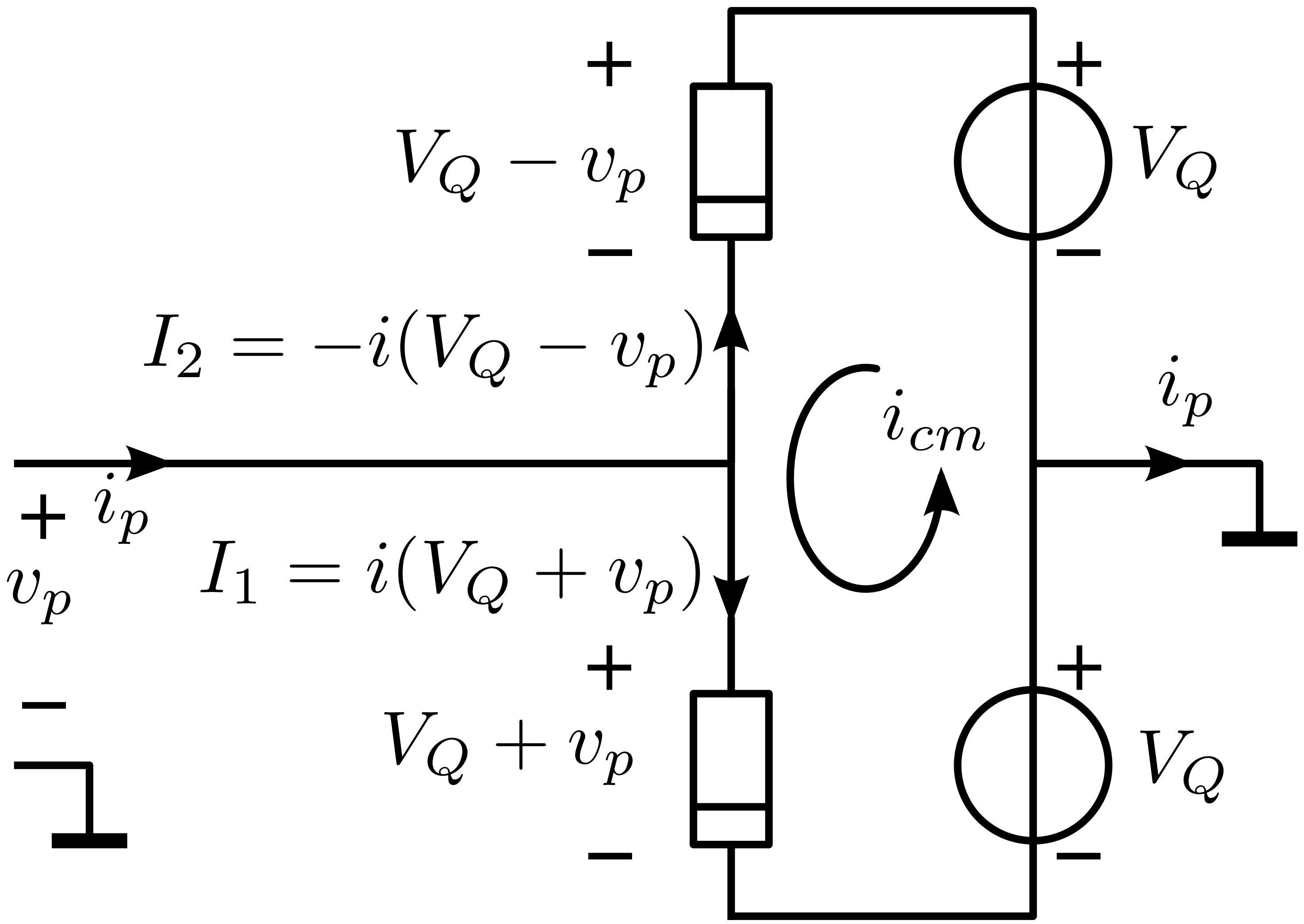




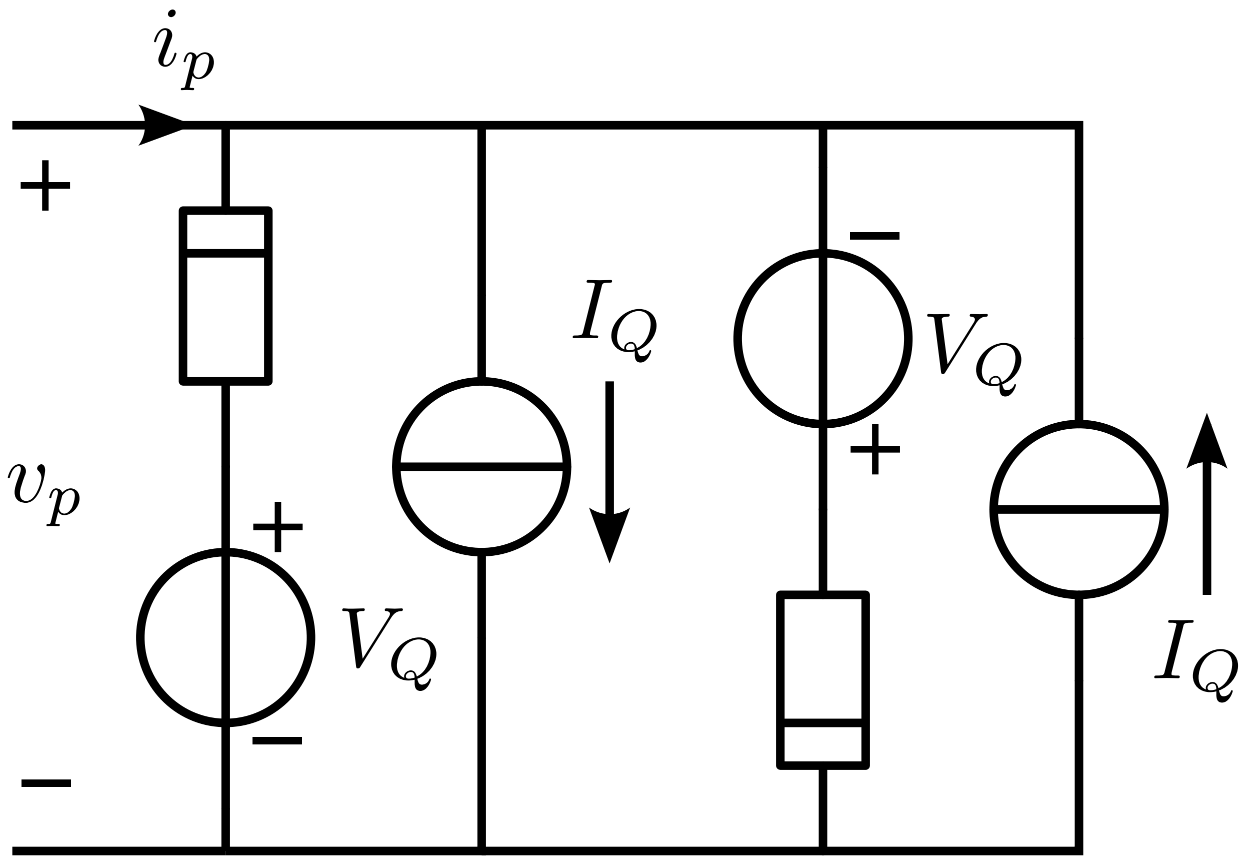
Anti-parallel and complementary-parallel connections

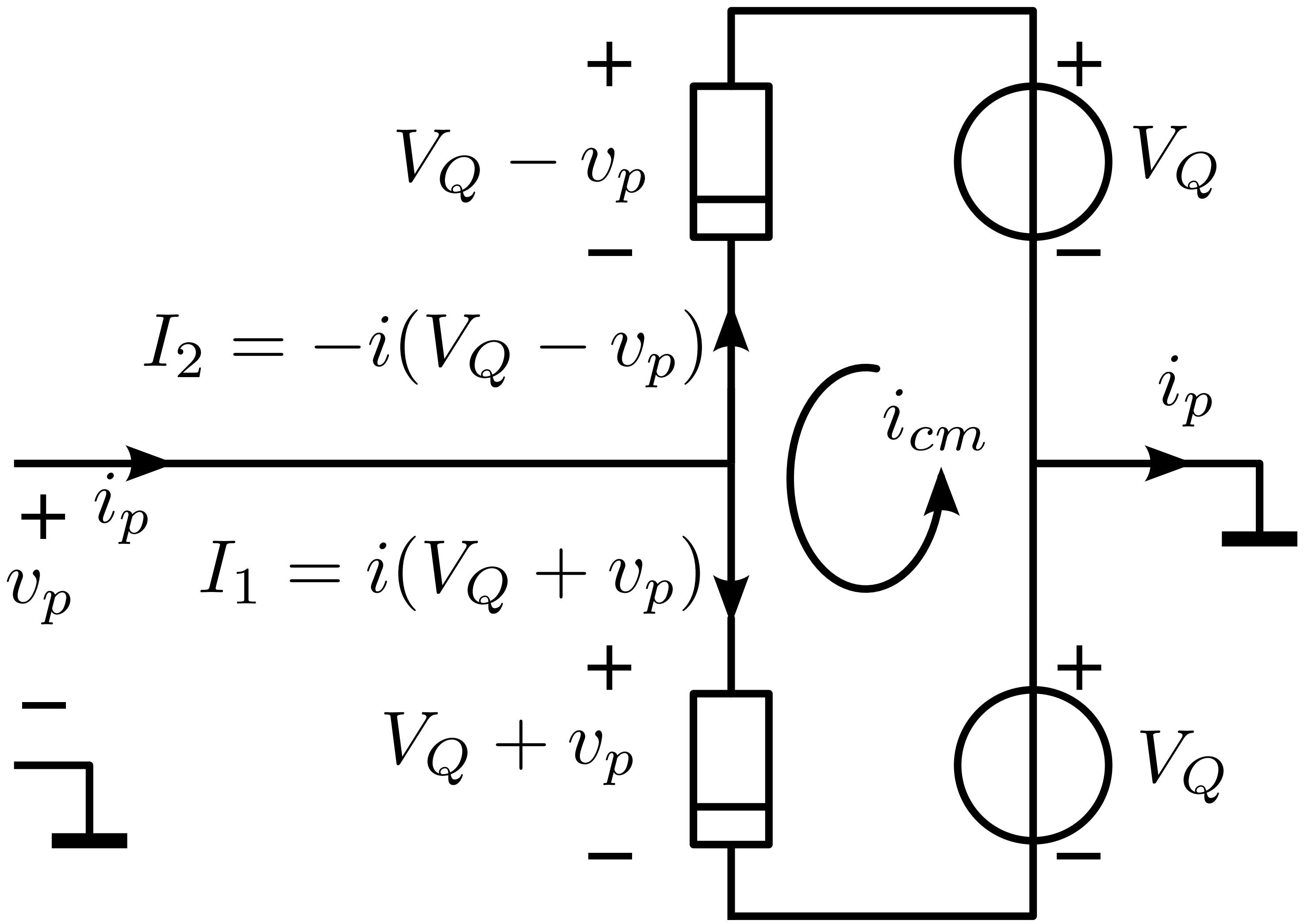




Elements can be biased with common-mode voltage sources

Anti-parallel and complementary-parallel connections

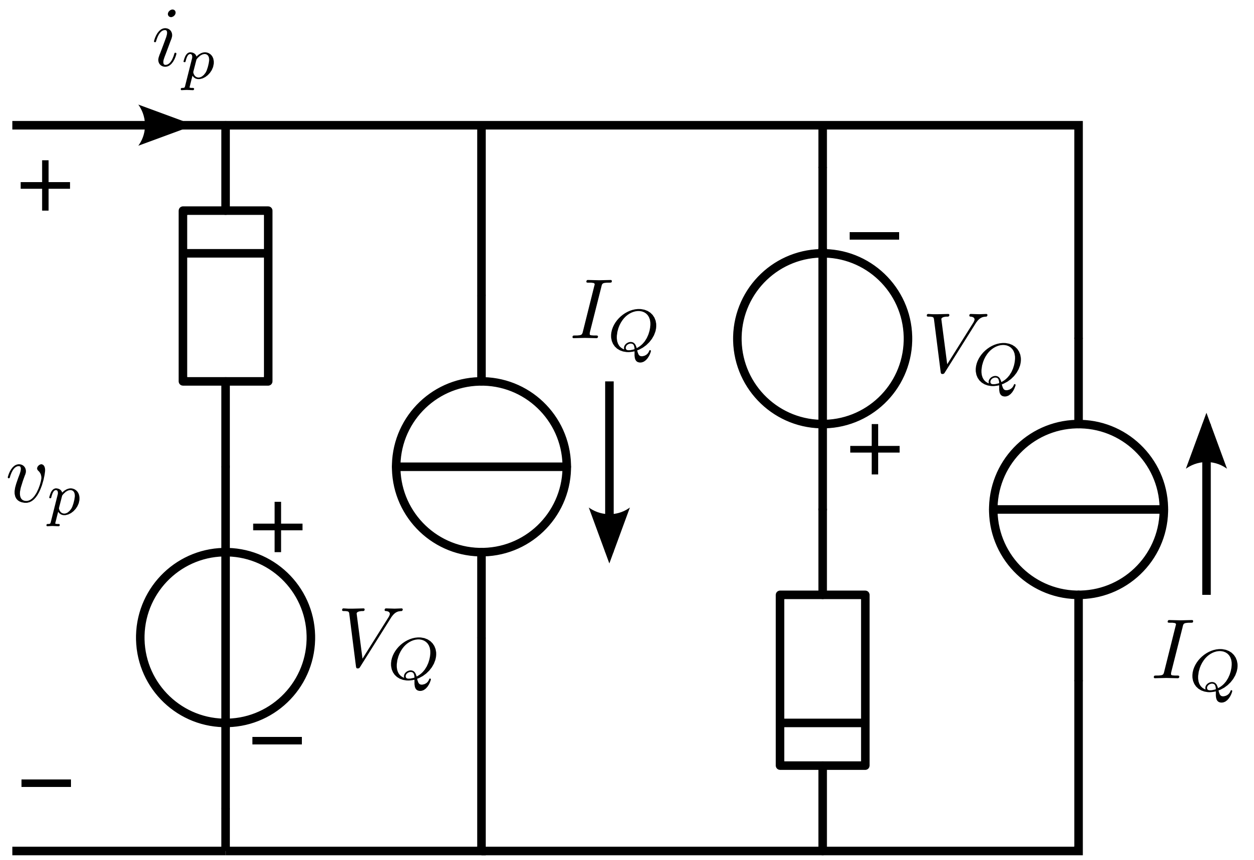


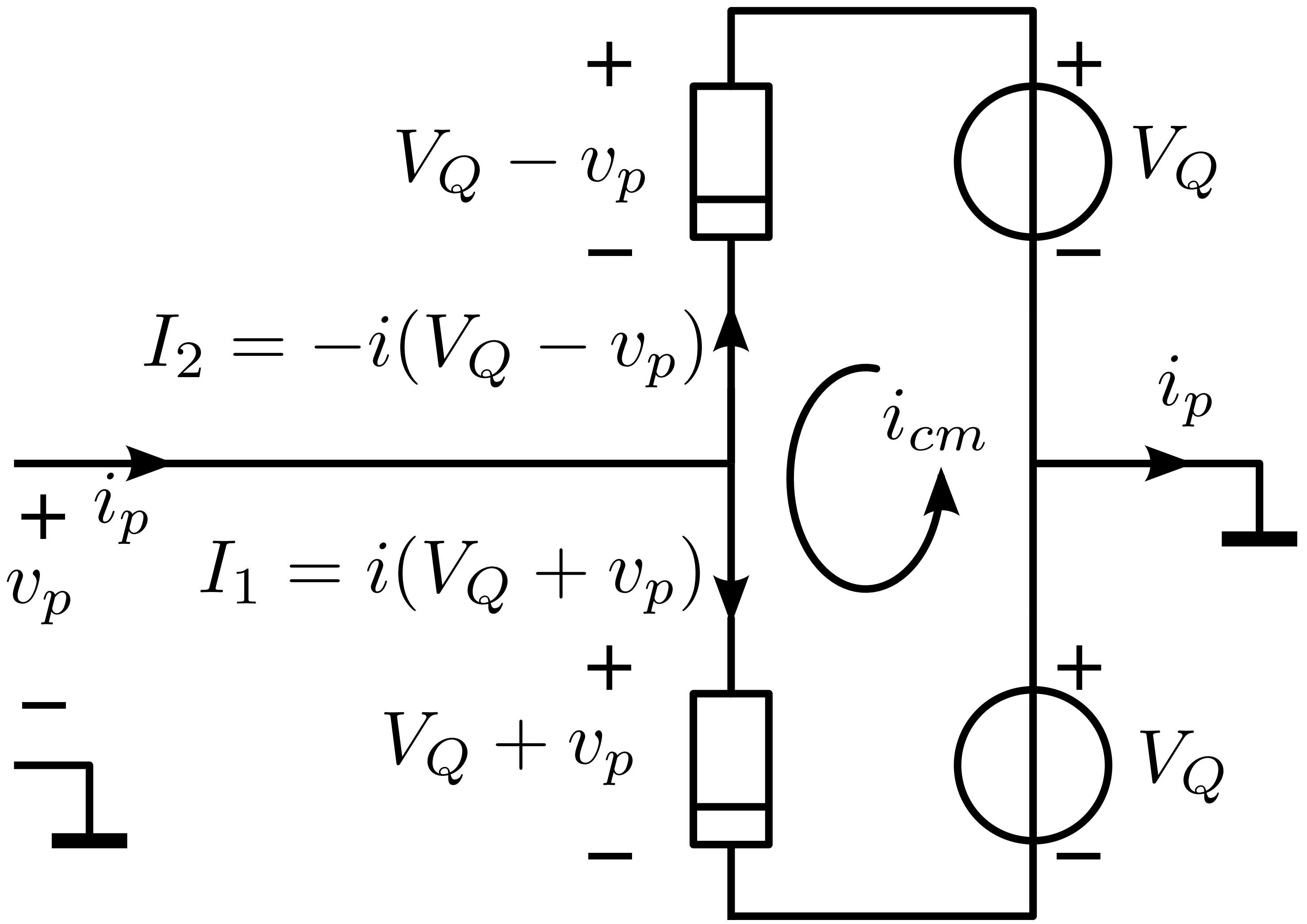


Elements can be biased with common-mode voltage sources

Bias current appears as common-mode current in the circuit

Anti-parallel and complementary-parallel connections





Elements can be biased with common-mode voltage sources

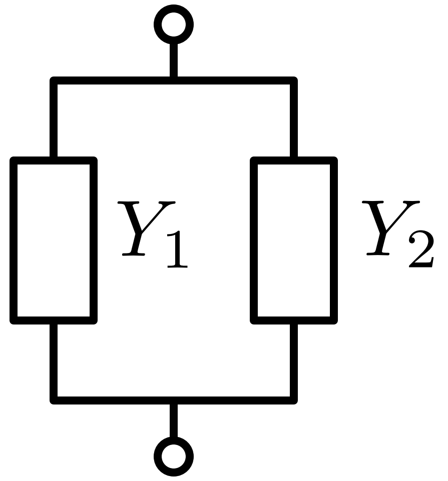
Bias current appears as common-mode current in the circuit

Anti-parallel and complementary parallel connections

Small-signal model

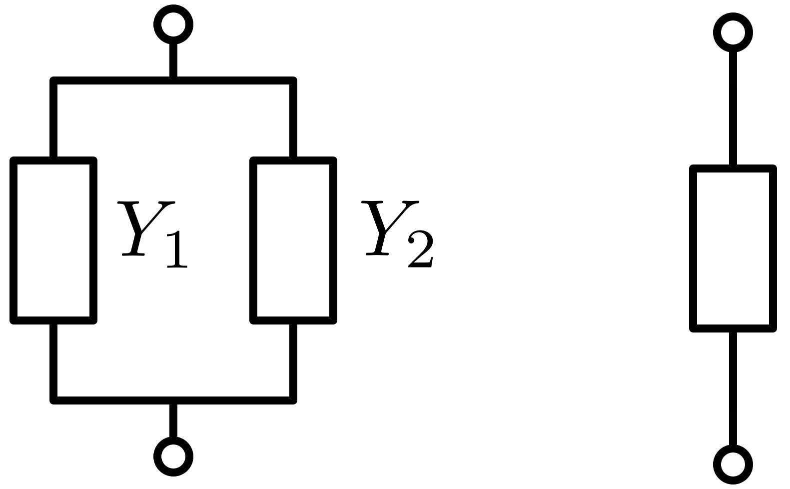
Anti-parallel and complementary parallel connections

Small-signal model



Anti-parallel and complementary parallel connections

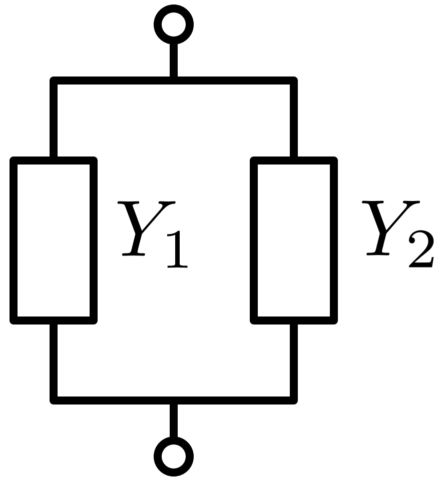
Small-signal model

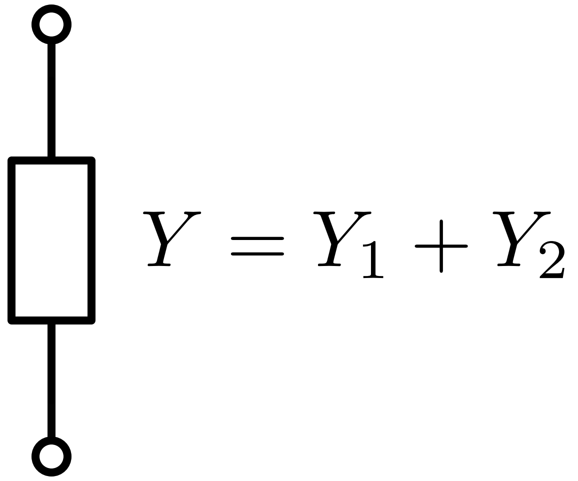


$$Y = Y_1 + Y_2$$

Anti-parallel and complementary parallel connections

Small-signal model

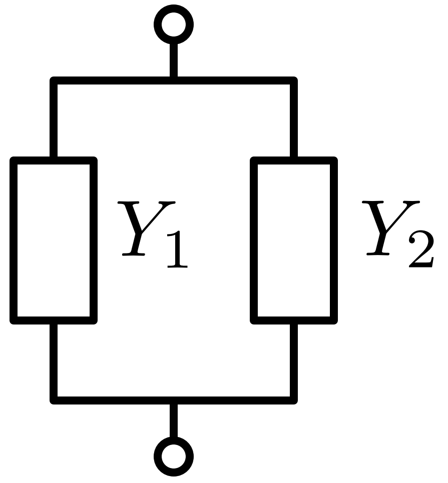


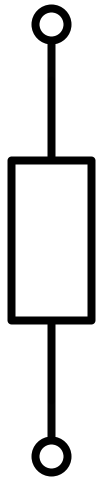


Small-signal admittance is sum of small-signal admittances of the constituting elements

Anti-parallel and complementary parallel connections

Small-signal model





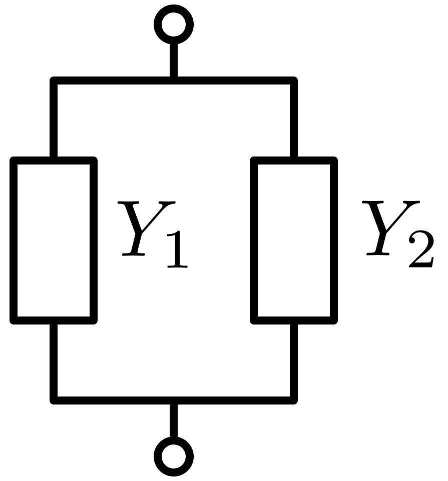
$$Y = Y_1 + Y_2$$

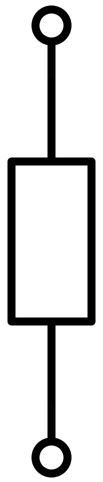
Small-signal admittance is sum of small-signal admittances of the constituting elements

$$Y = 2Y_1 = 2Y_2$$

Anti-parallel and complementary parallel connections

Small-signal model





$$Y = Y_1 + Y_2$$

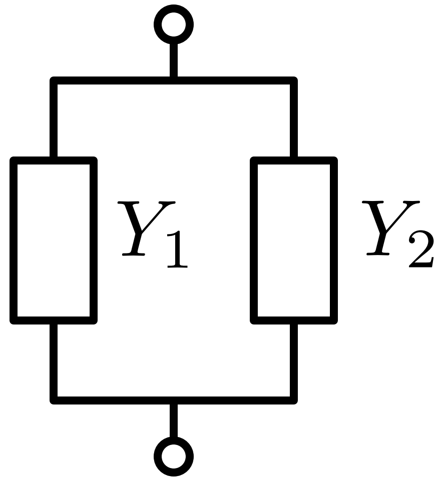
Small-signal admittance is sum of small-signal admittances of the constituting elements

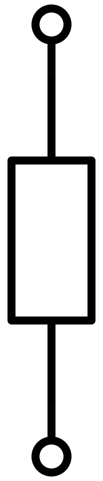
$$Y = 2Y_1 = 2Y_2$$

Twice the admittance in the quiescent operating point

Anti-parallel and complementary parallel connections

Small-signal model





$$Y = Y_1 + Y_2$$

Small-signal admittance is sum of small-signal admittances of the constituting elements

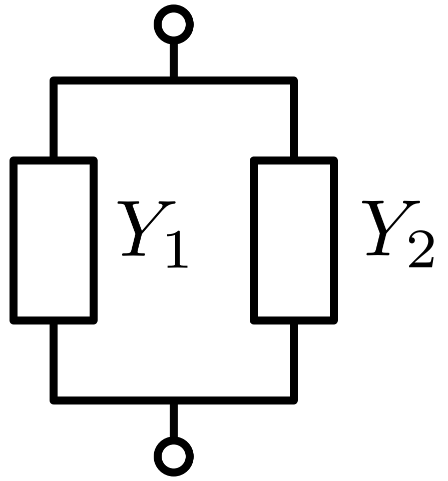
$$Y = 2Y_1 = 2Y_2$$

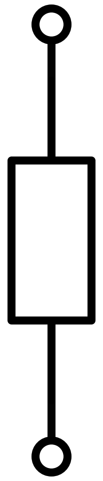
Twice the admittance in the quiescent operating point

Current noise spectral density is the sum of the current noise spectral densities of the constituting elements

Anti-parallel and complementary parallel connections

Small-signal model





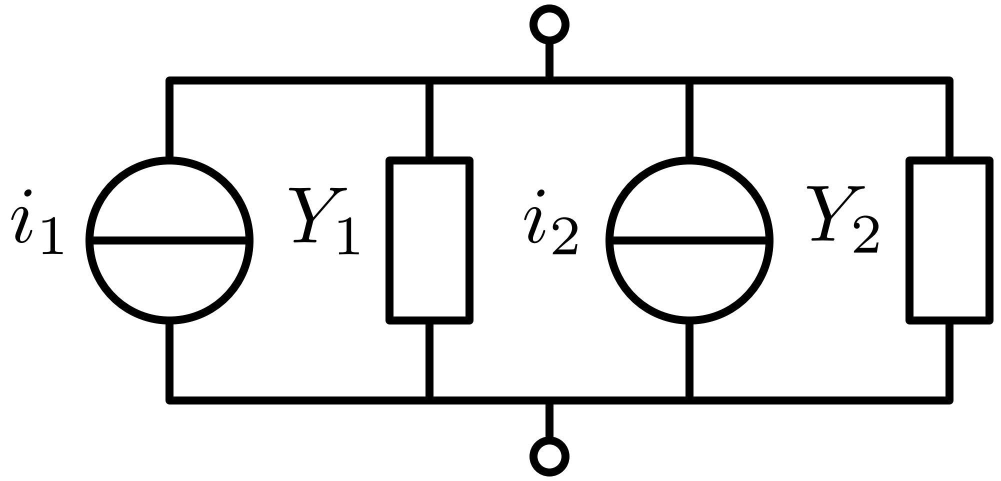
$$Y = Y_1 + Y_2$$

Small-signal admittance is sum of small-signal admittances of the constituting elements

$$Y = 2Y_1 = 2Y_2$$

Twice the admittance in the quiescent operating point

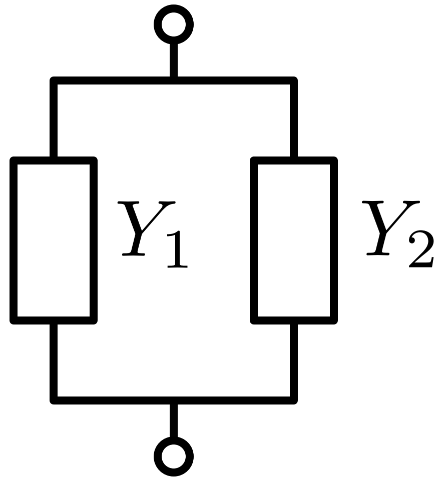
Current noise spectral density is the sum of the current noise spectral densities of the constituting elements

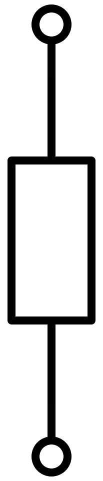


$$S_{i_1} = 4kT\mathrm{Re}\left(Y_1\right) \qquad S_{i2} = 4kT\mathrm{Re}\left(Y_2\right)$$

Anti-parallel and complementary parallel connections

Small-signal model





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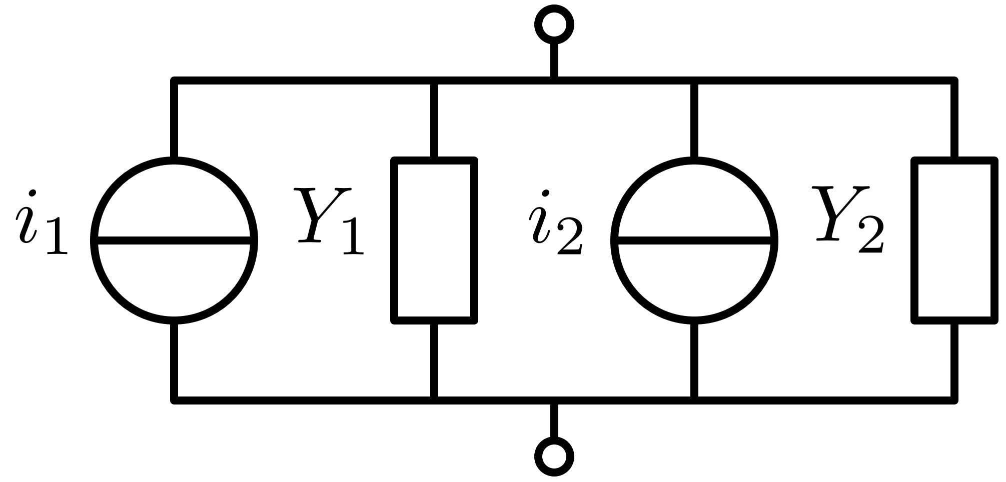
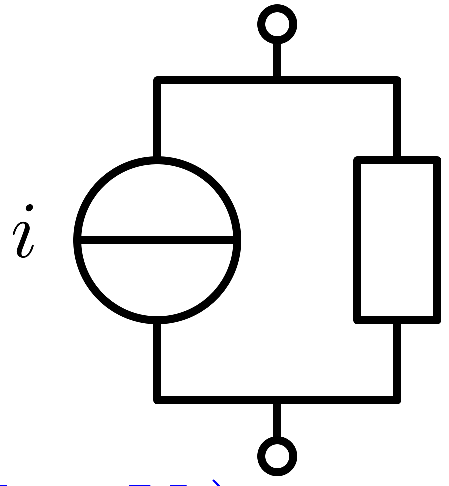
Small-signal admittance is sum of small-signal admittances of the constituting elements

$$Y = 2Y_1 = 2Y_2$$

Twice the admittance in the quiescent operating point

Current noise spectral density is the sum of the current noise spectral densities of the constituting elements





$$Y = Y_1 + Y_2$$

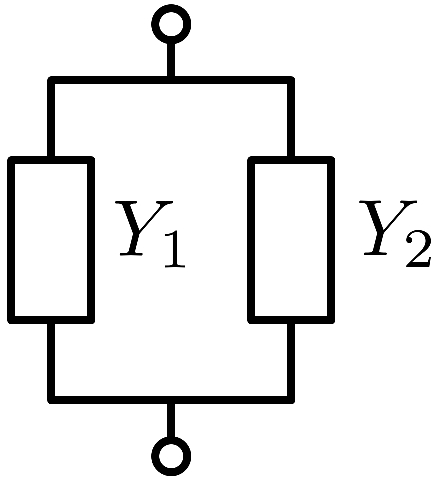
$$S_{i_1} = 4kT\mathrm{Re}\left(Y_1\right)$$

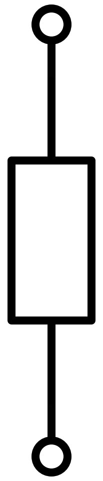
$$S_{i2} = 4kT\mathrm{Re}\left(Y_2\right)$$

$$S_i = 4kT\mathrm{Re}\left(Y_1 + Y_2\right)$$

Anti-parallel and complementary parallel connections

Small-signal model





$$Y = Y_1 + Y_2$$

Small-signal admittance is sum of small-signal admittances of the constituting elements

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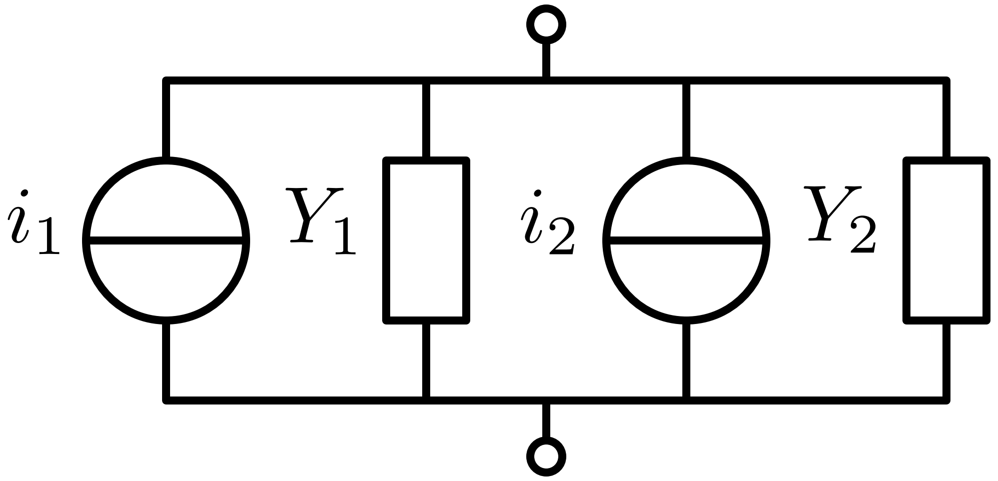
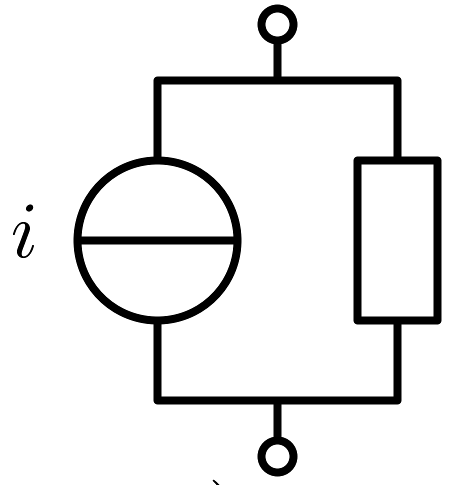
Twice the admittance in the quiescent operating point

Current noise spectral density is the sum of the current noise spectral densities of the constituting elements





$$Y = Y_1 + Y_2$$

$$S_{i_1} = 4kT\mathrm{Re}\left(Y_1\right) \qquad S_{i2} = 4kT\mathrm{Re}\left(Y_2\right) \qquad S_i = 4kT\mathrm{Re}\left(Y_1 + Y_2\right)$$