Structured Electronic Design

Intrinsic CS stage
Design of static and dynamic performance

Anton J.M. Montagne

CS stage determine bias sources

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Maximum negative output voltage: 0.9V

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Maximum positive output current: 10uA

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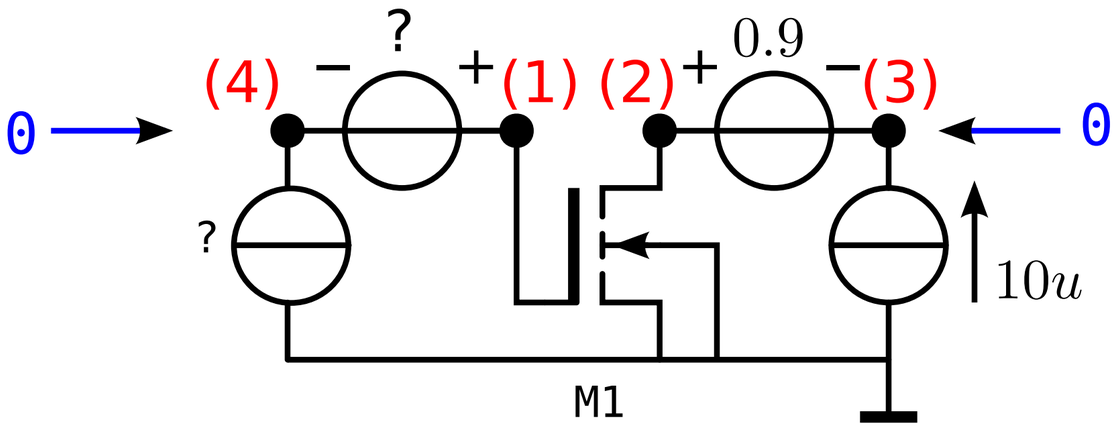

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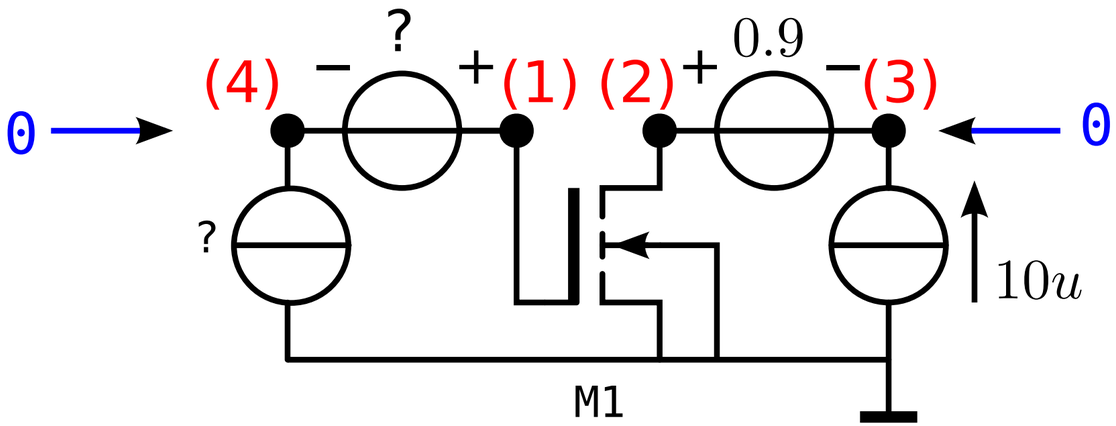
Obtain values of the input bias sources for required output drive capability:



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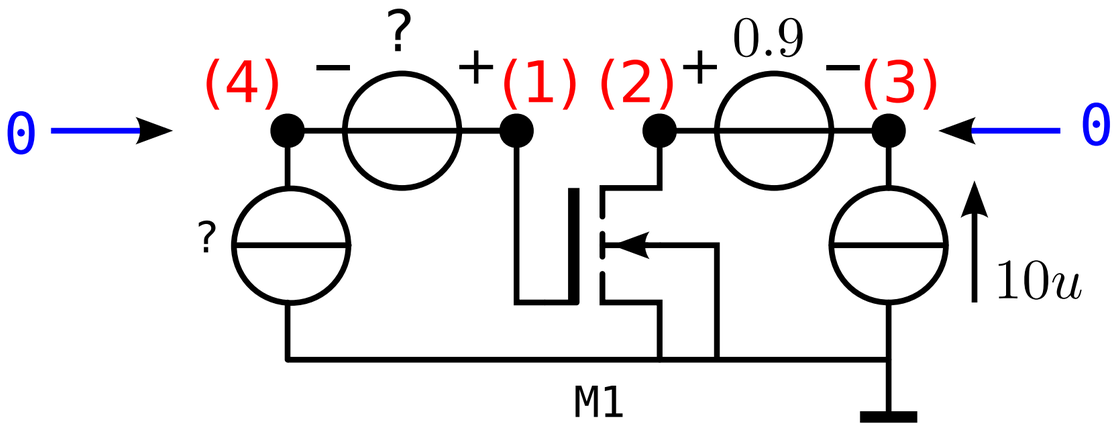

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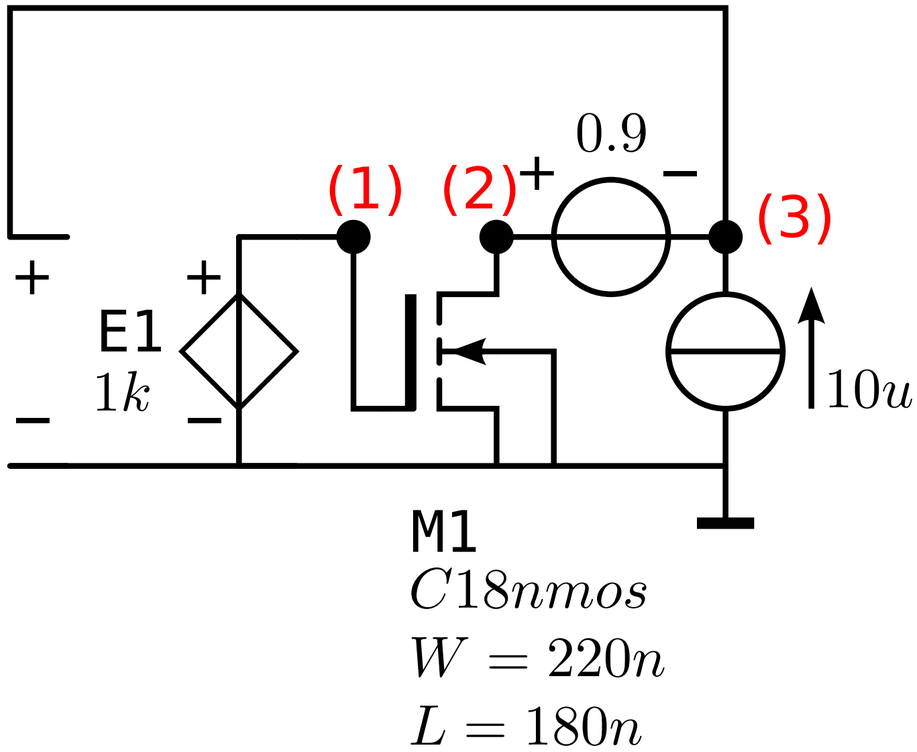

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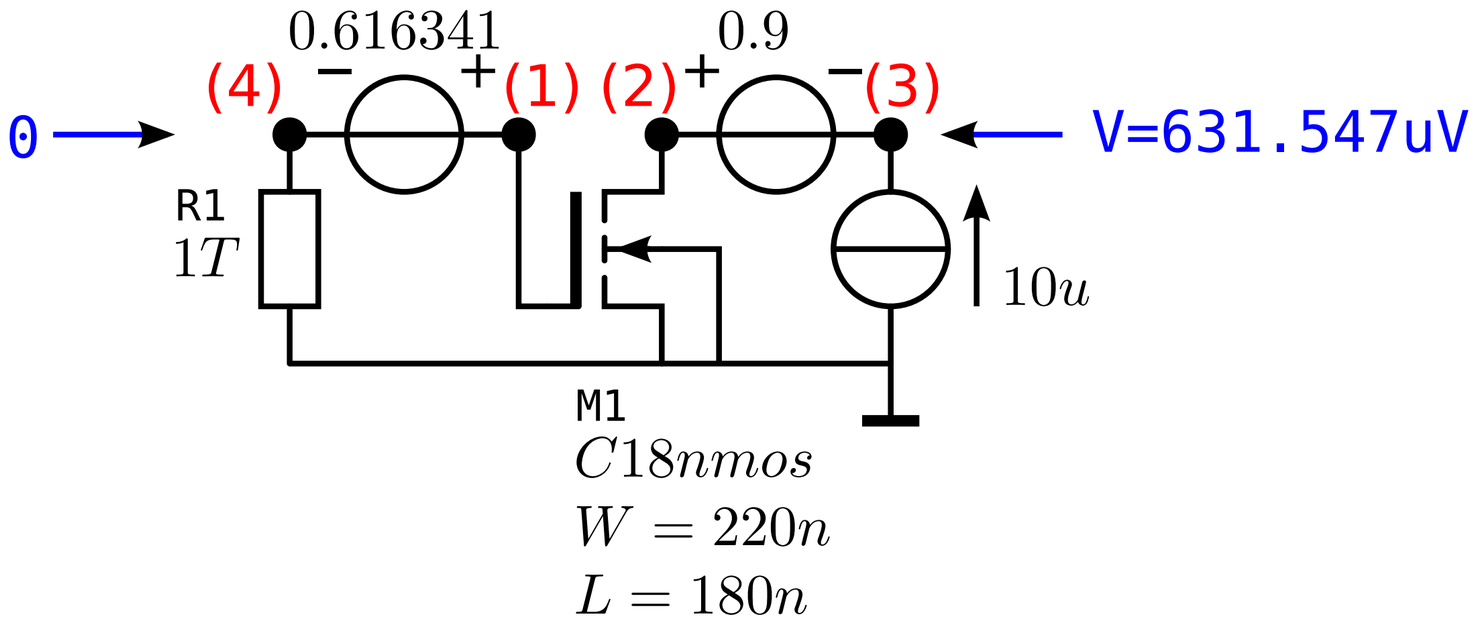

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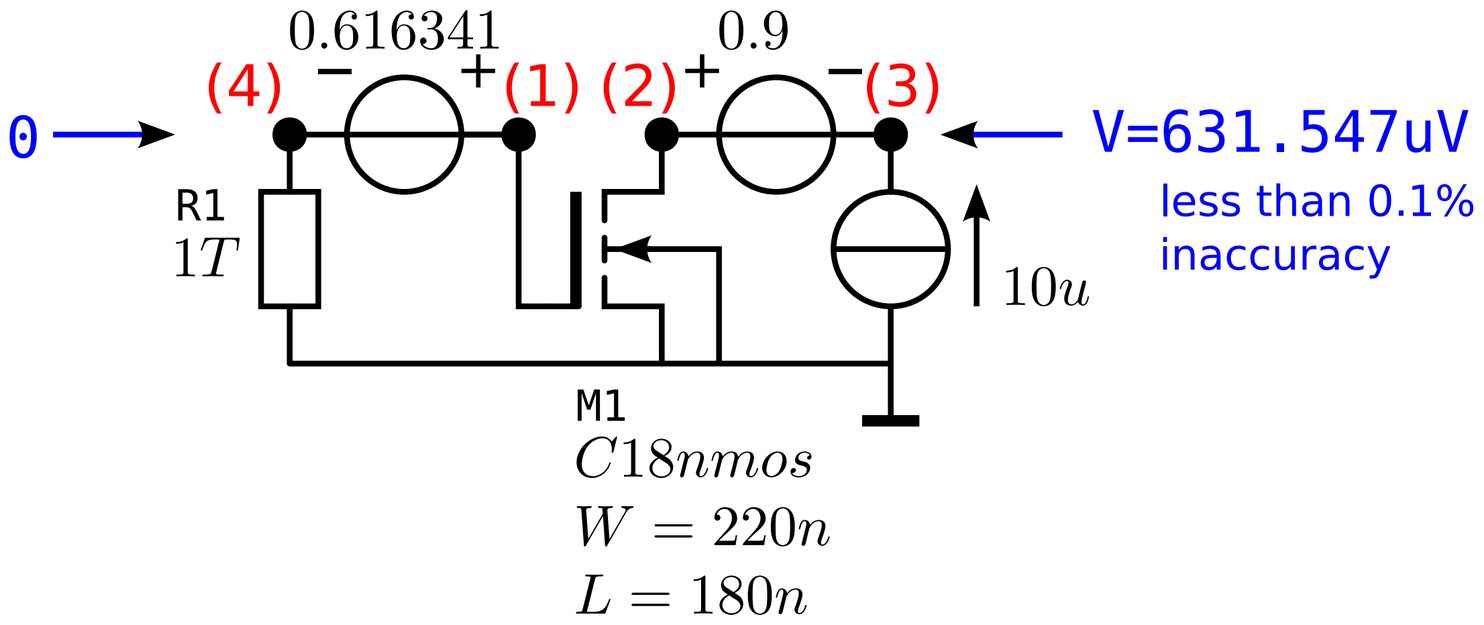

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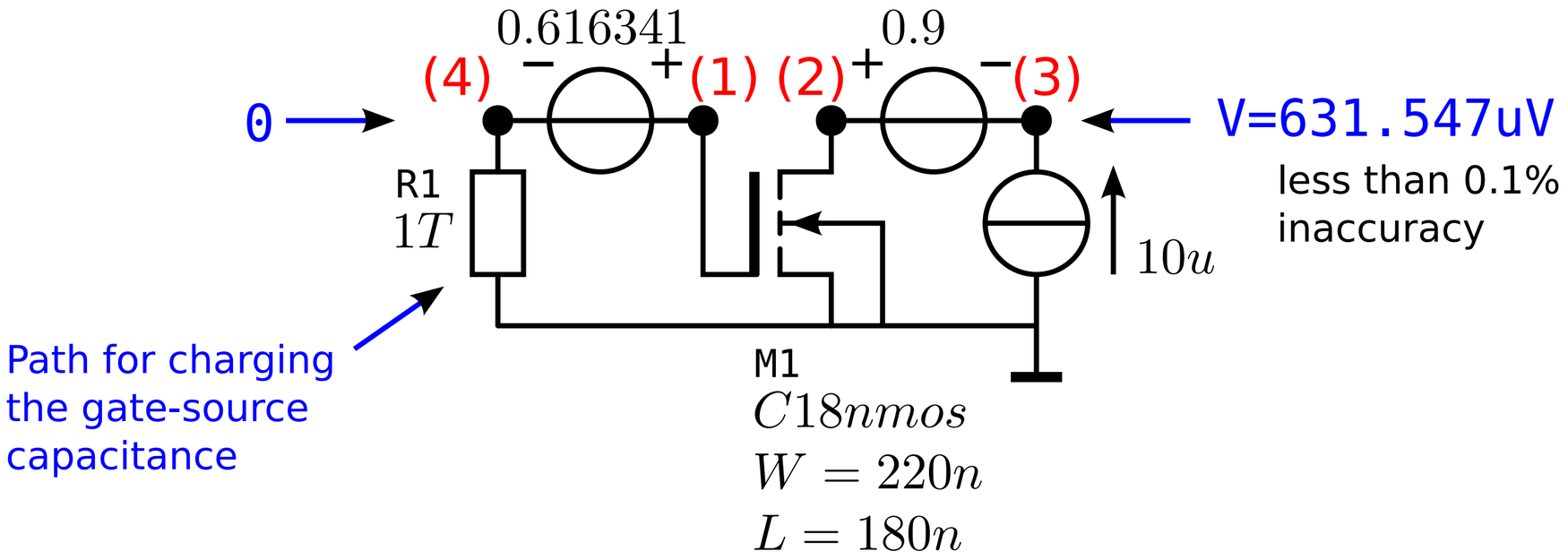

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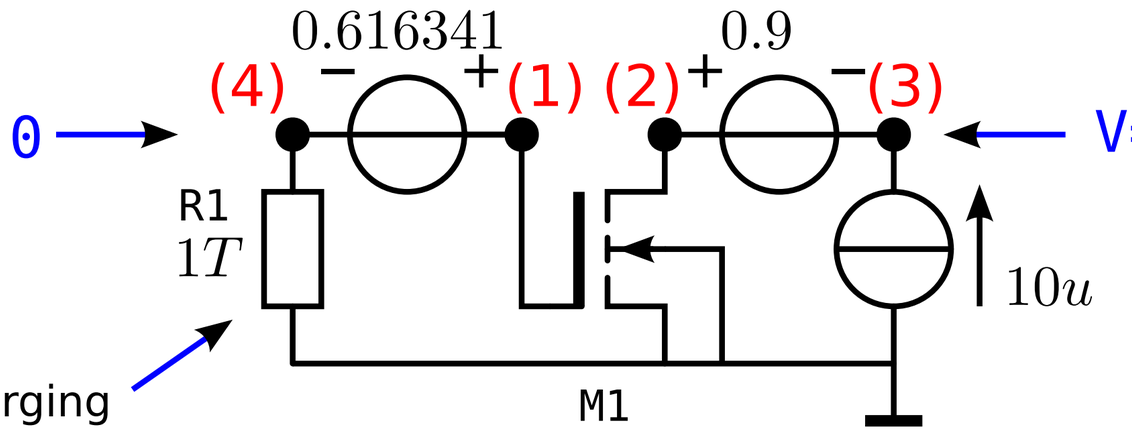
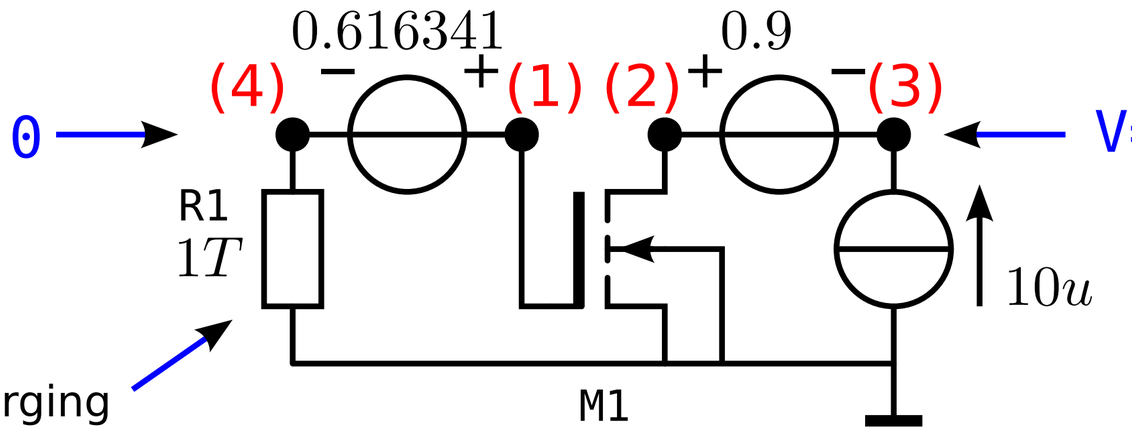


less than 0.1% inaccuracy

Path for charging the gate-source capacitance

Spice cannot handle floating node

CS apply bias sources



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All curves pass through the origin:

(v_i, i_i), (v_o, i_o), (v_i, v_o), (v_i, i_o), (i_i, v_o), (i_i, i_0)

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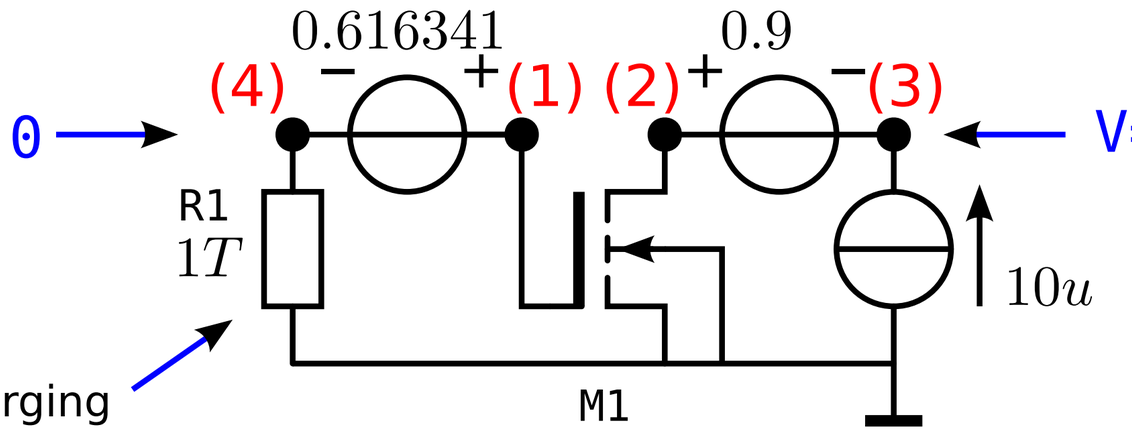

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V-I drive capability

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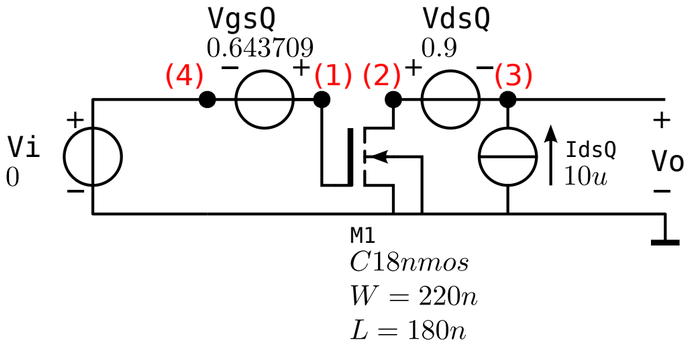
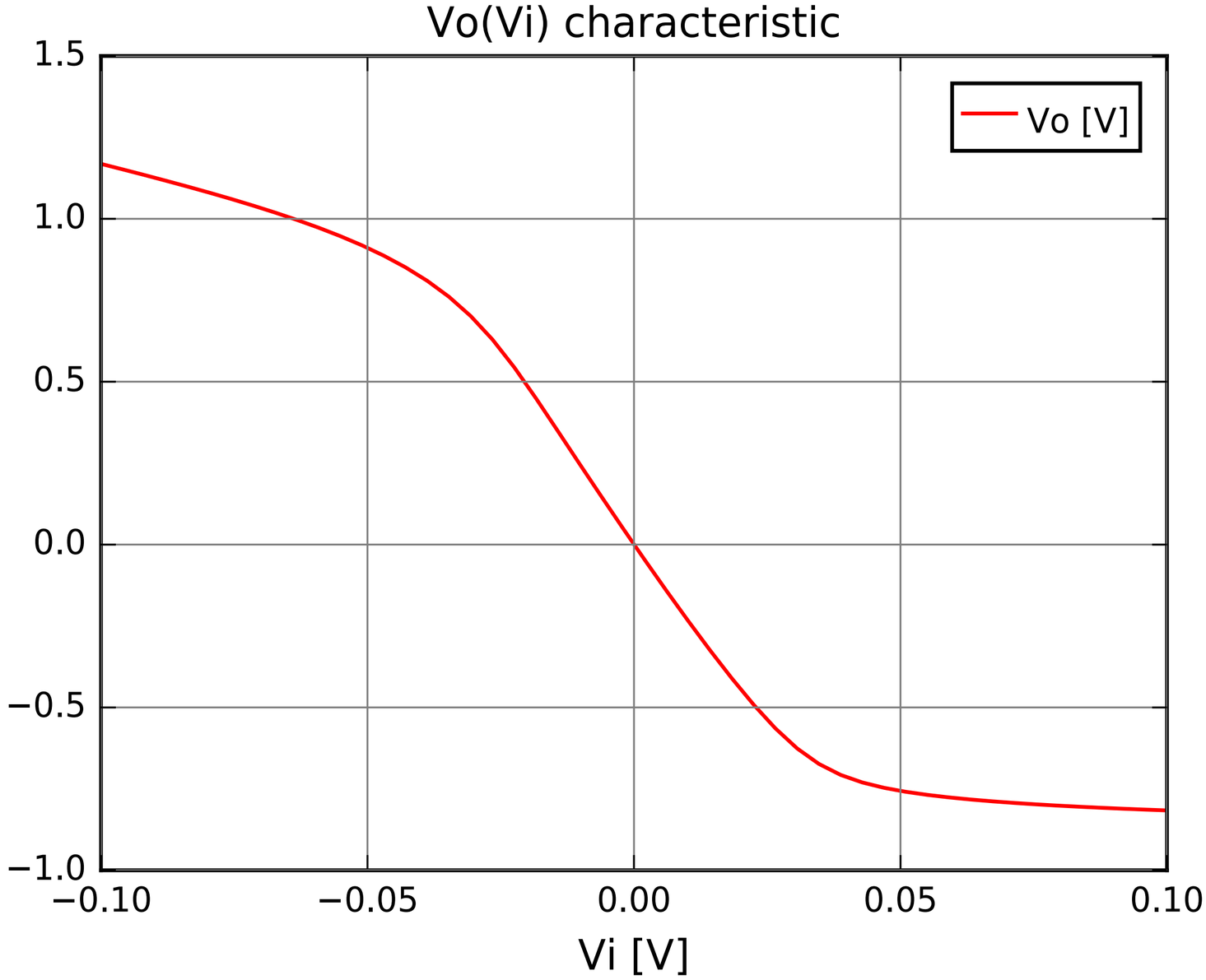
CS stage static (stationary) behavior





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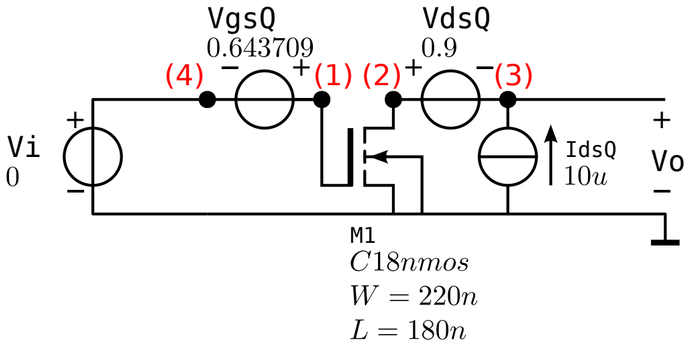

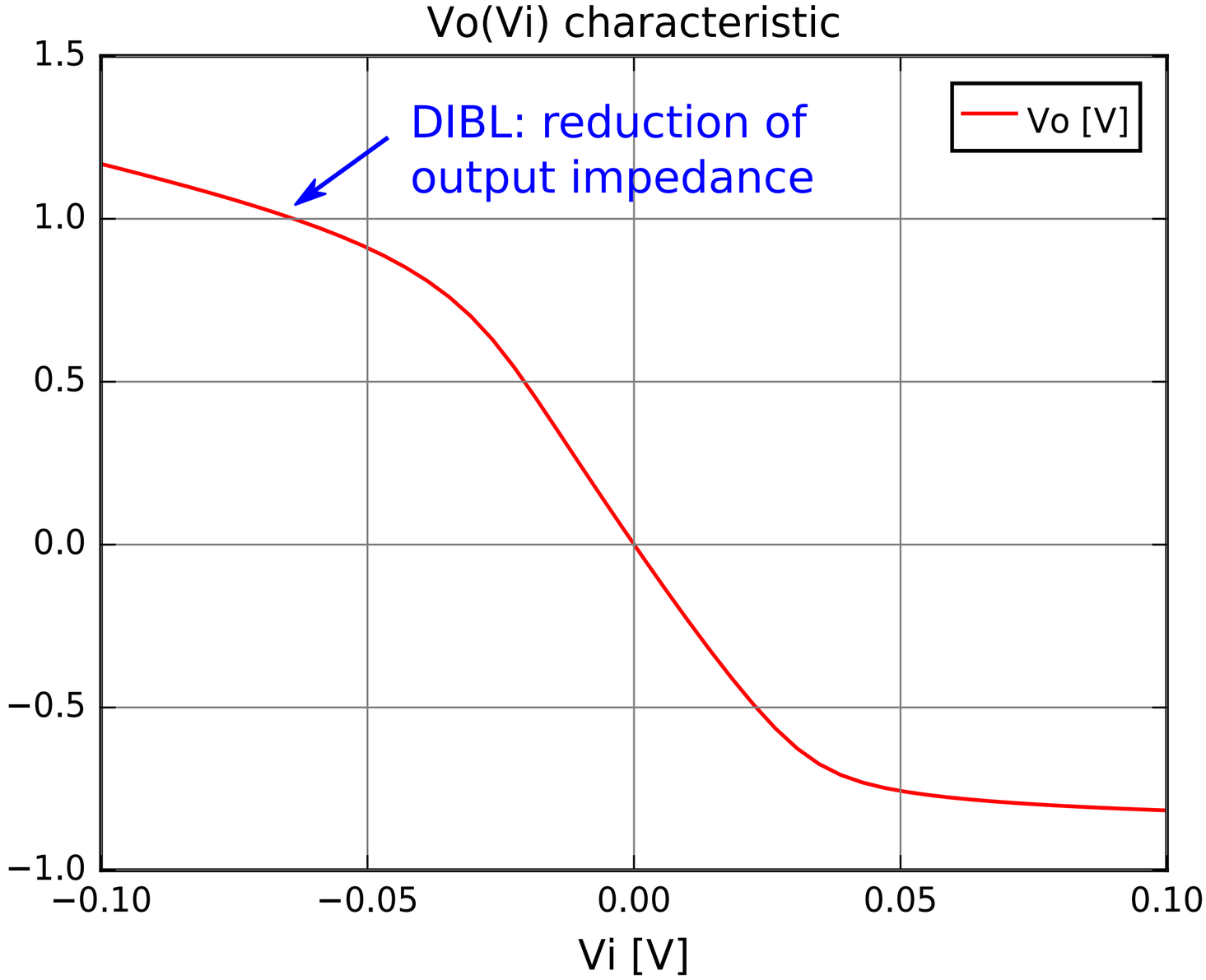

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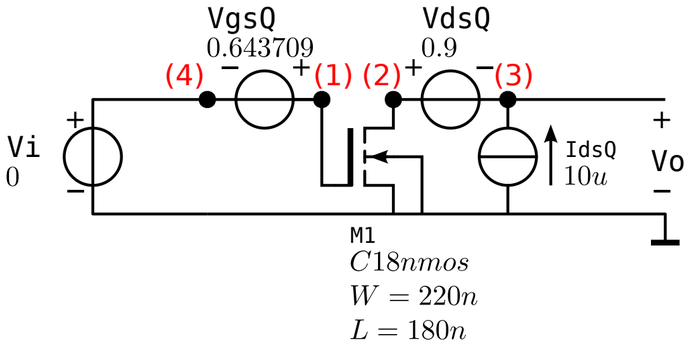

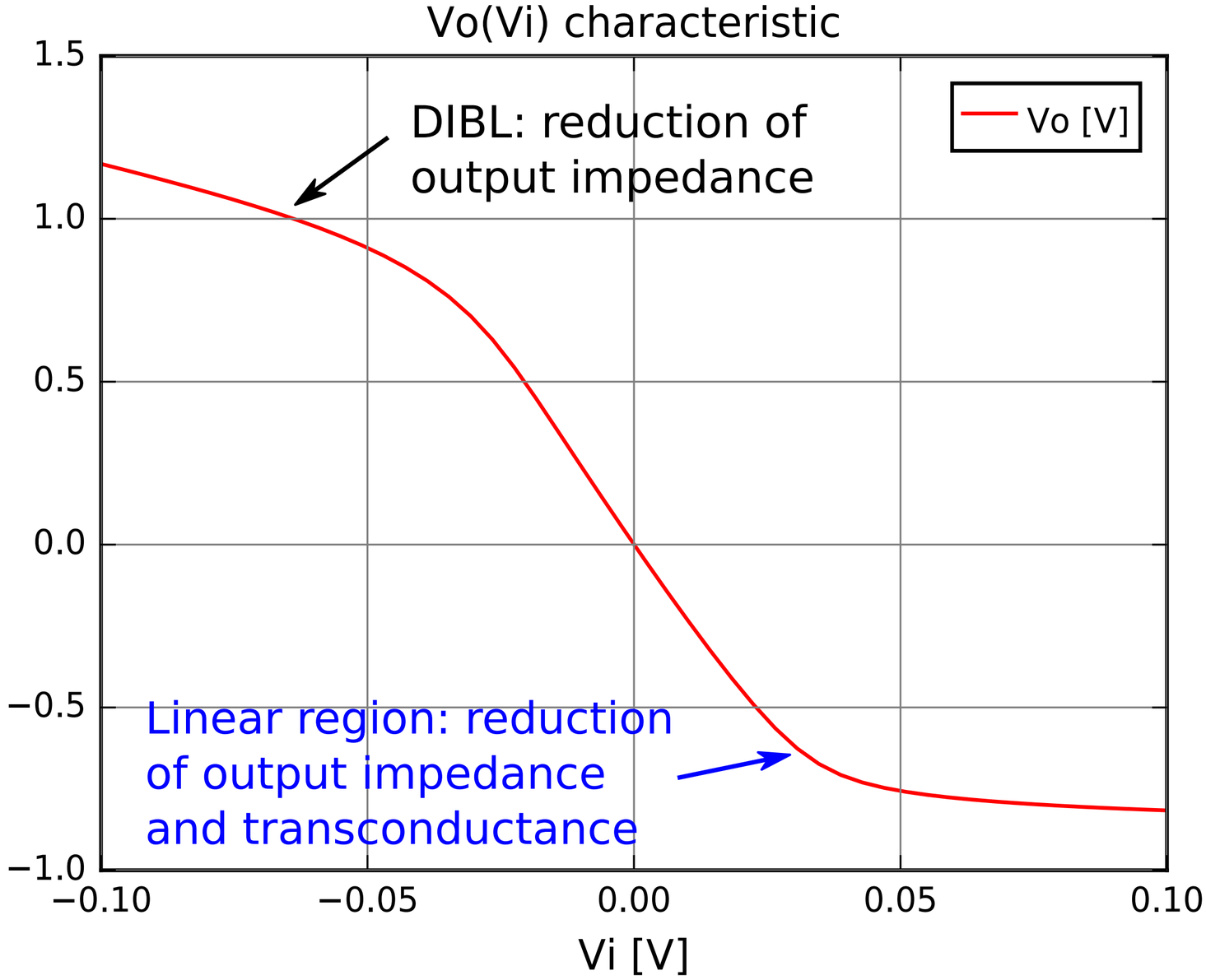

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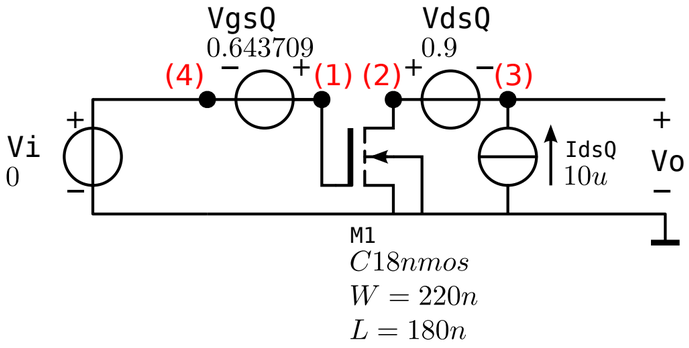
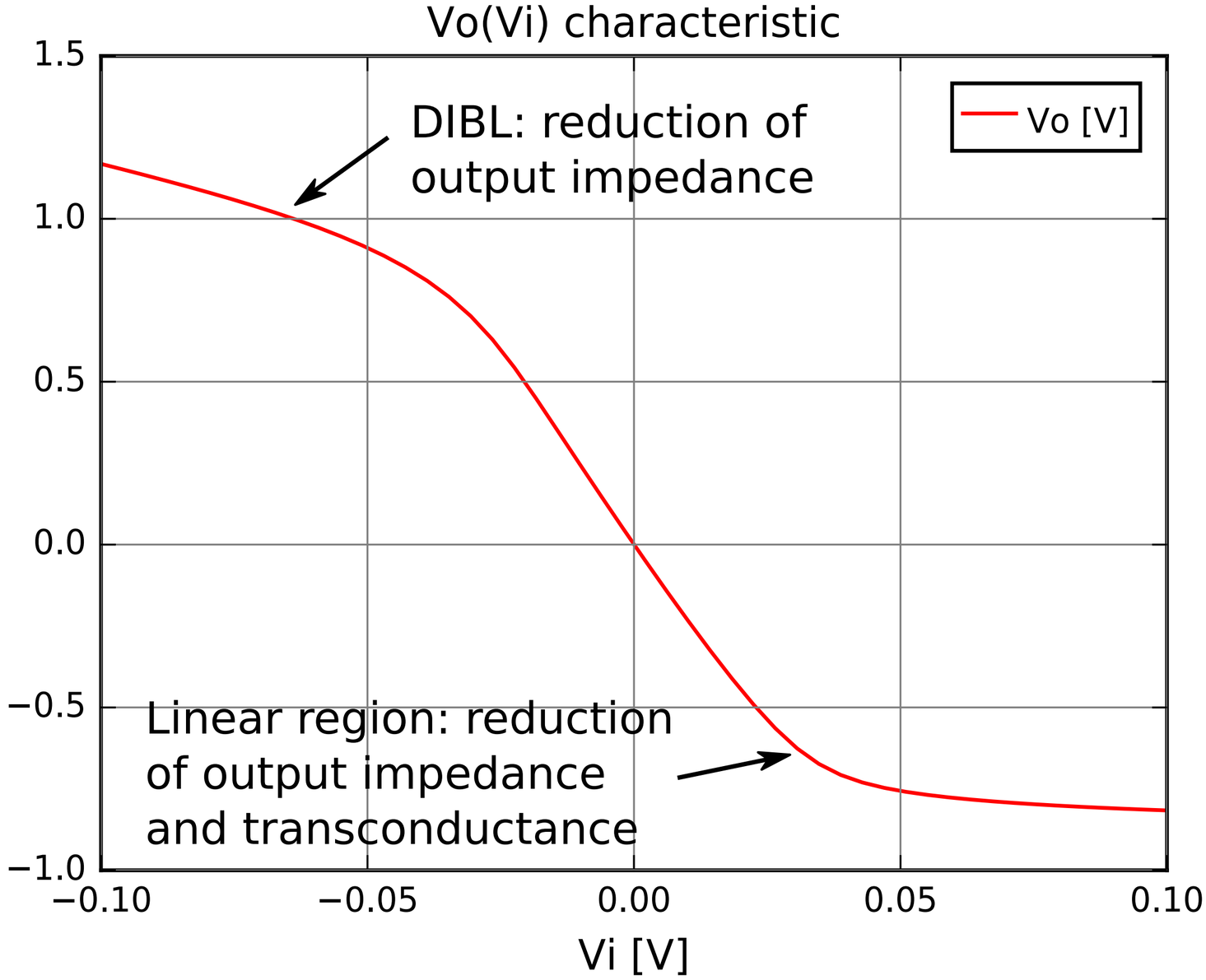


Notice:

$V_{DS} = V_o + V_{dsQ}$



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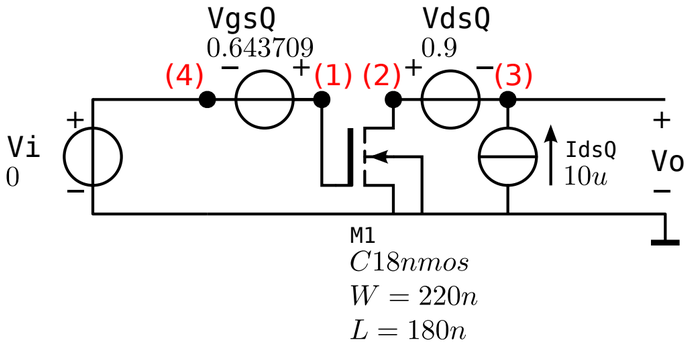

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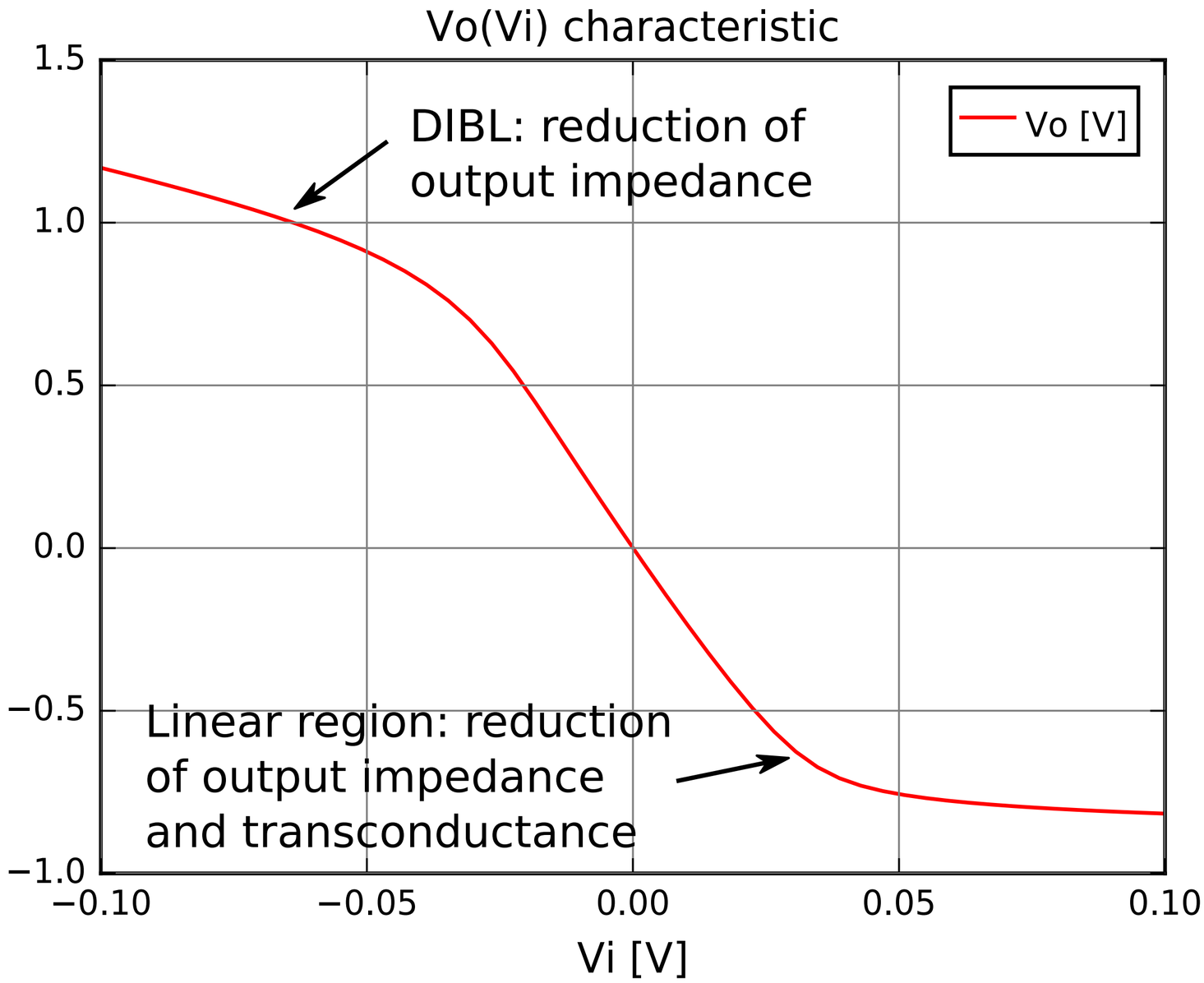

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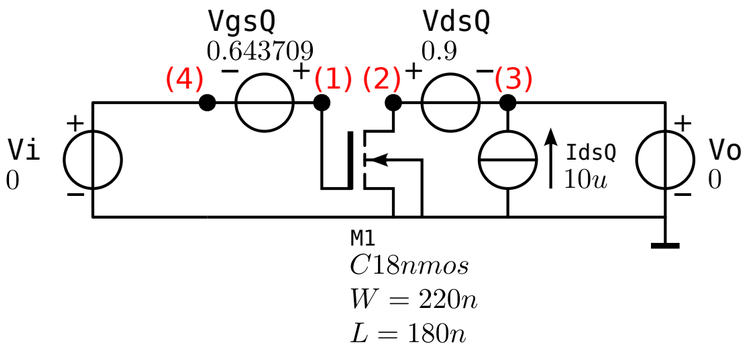

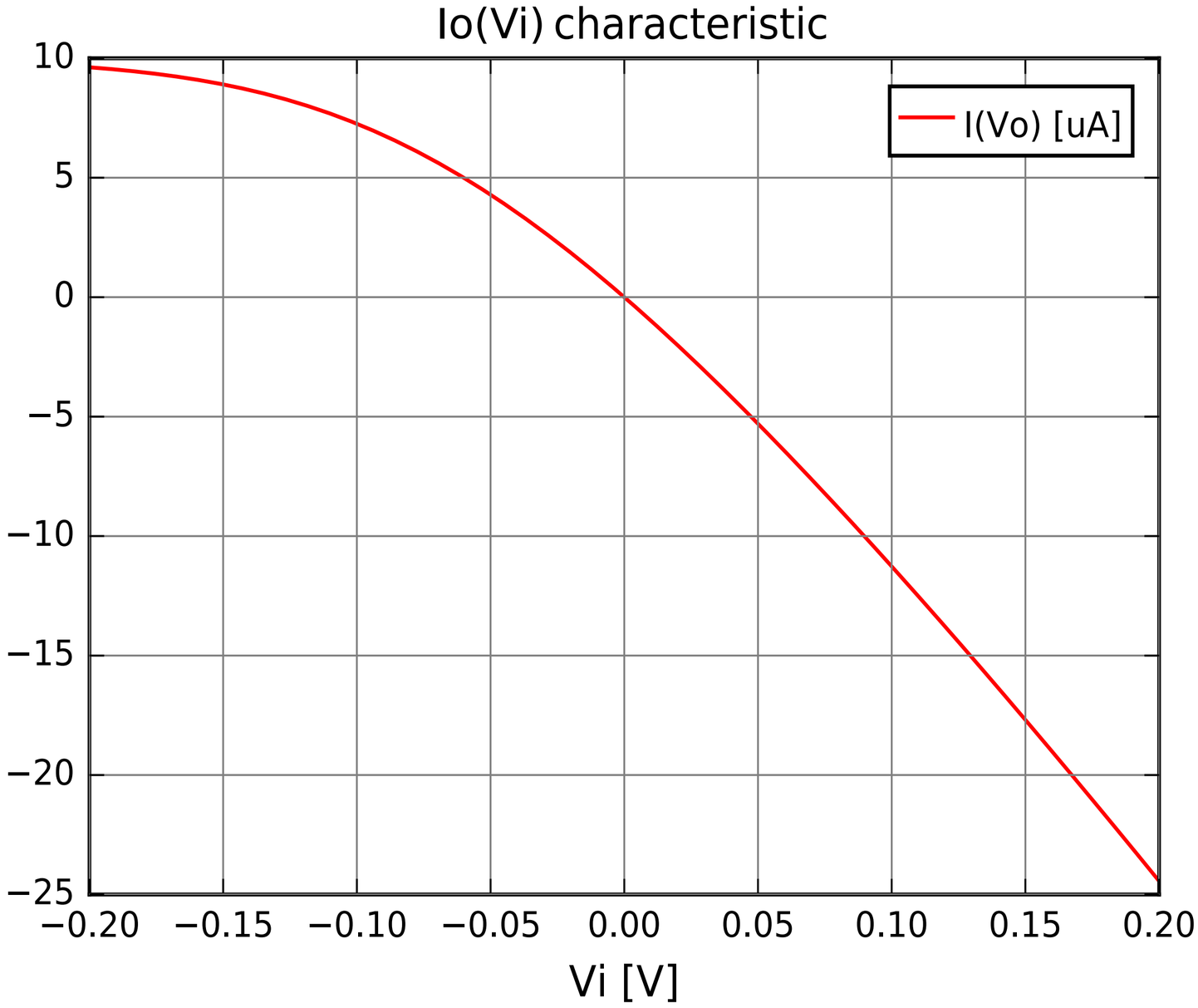

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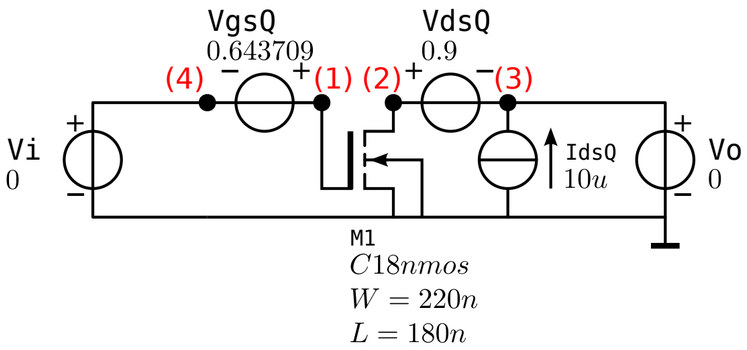

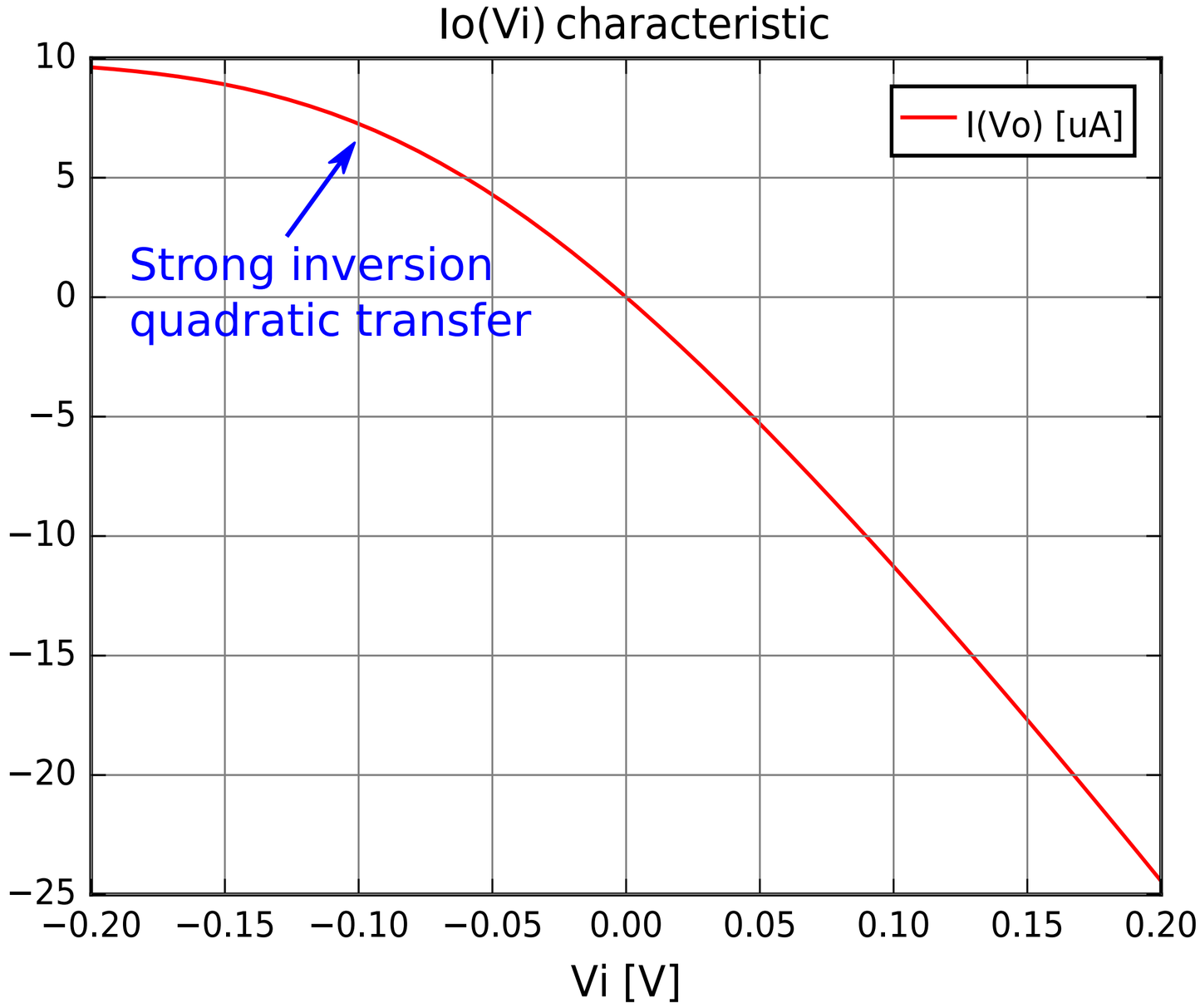

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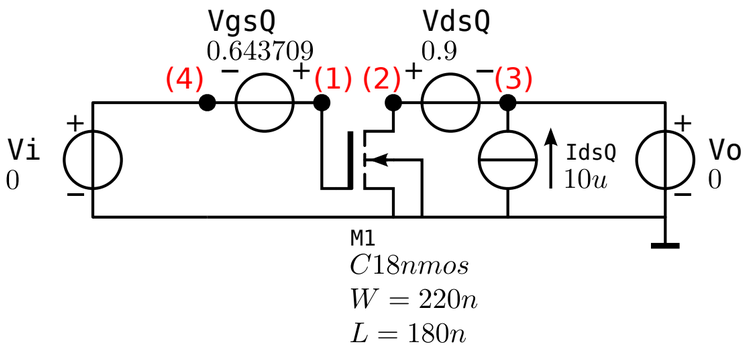

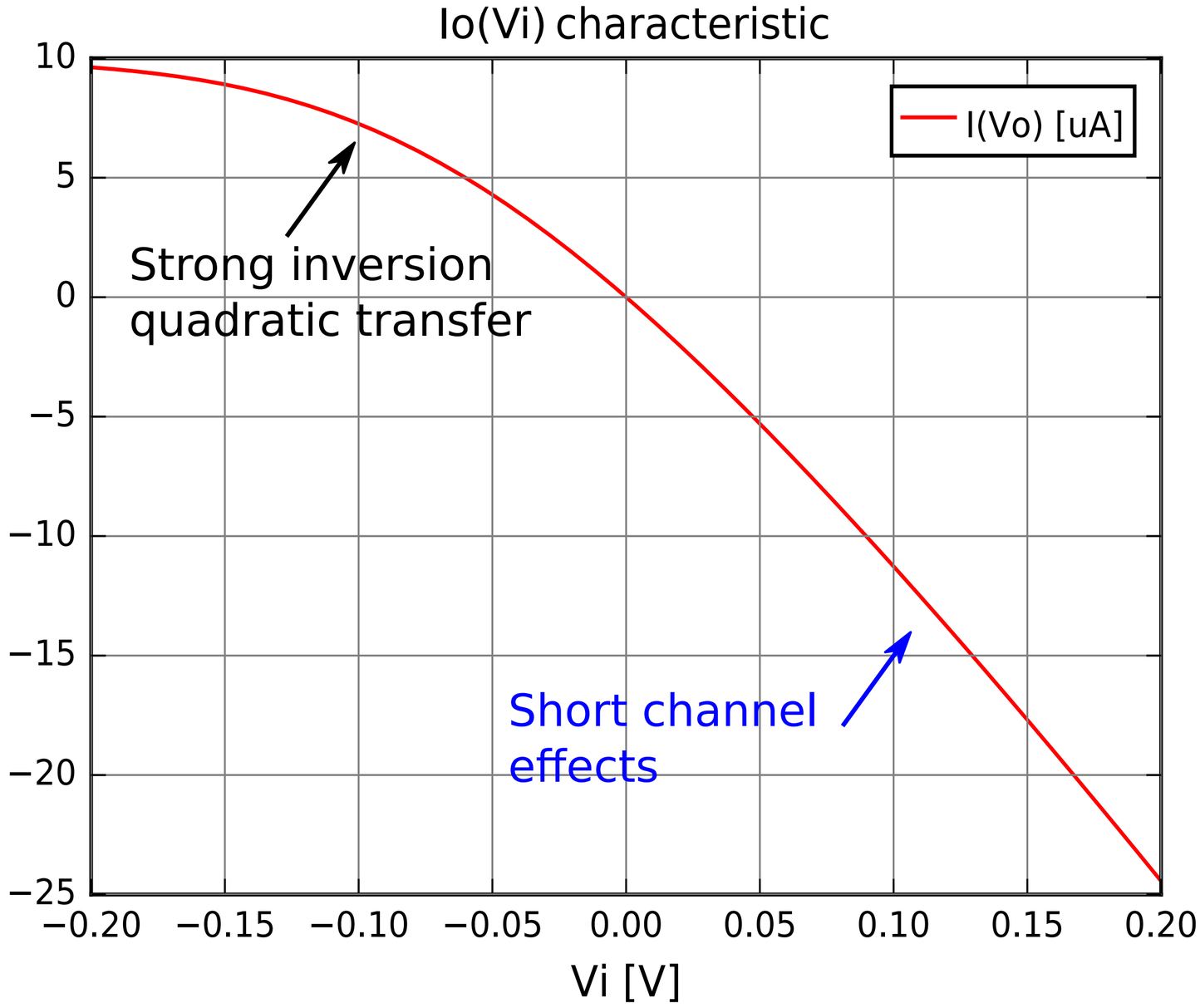

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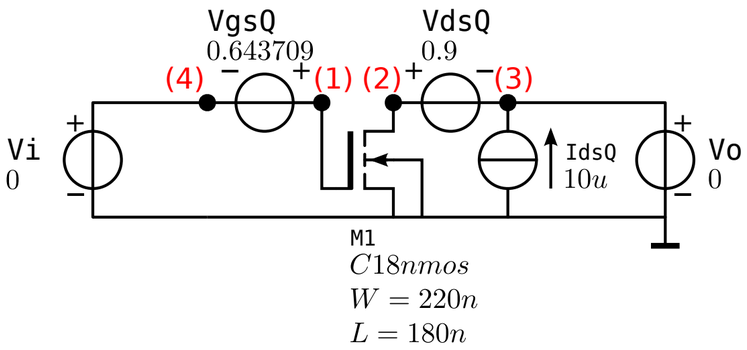
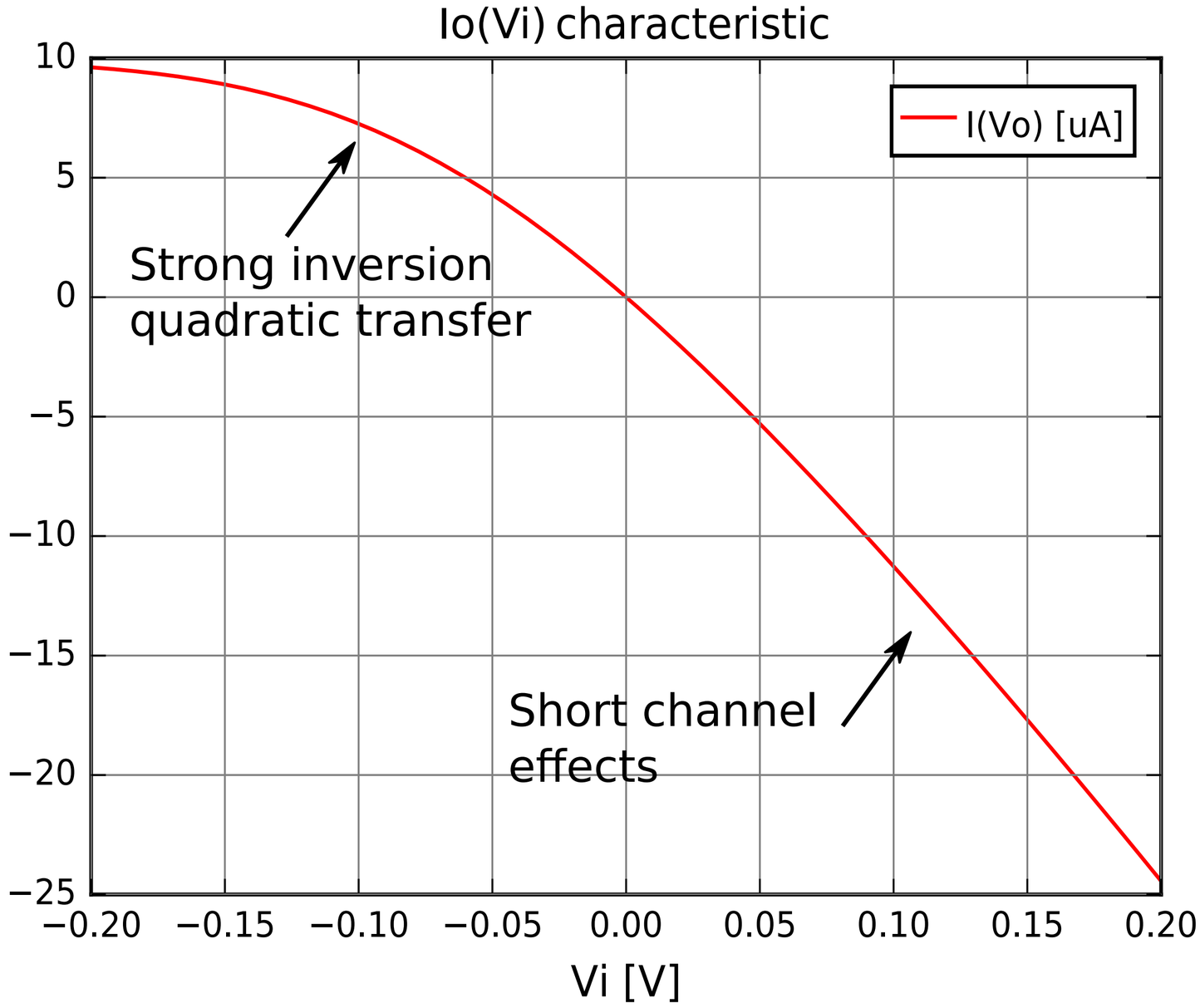
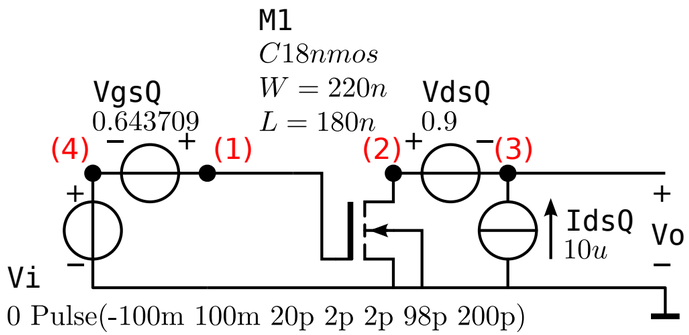
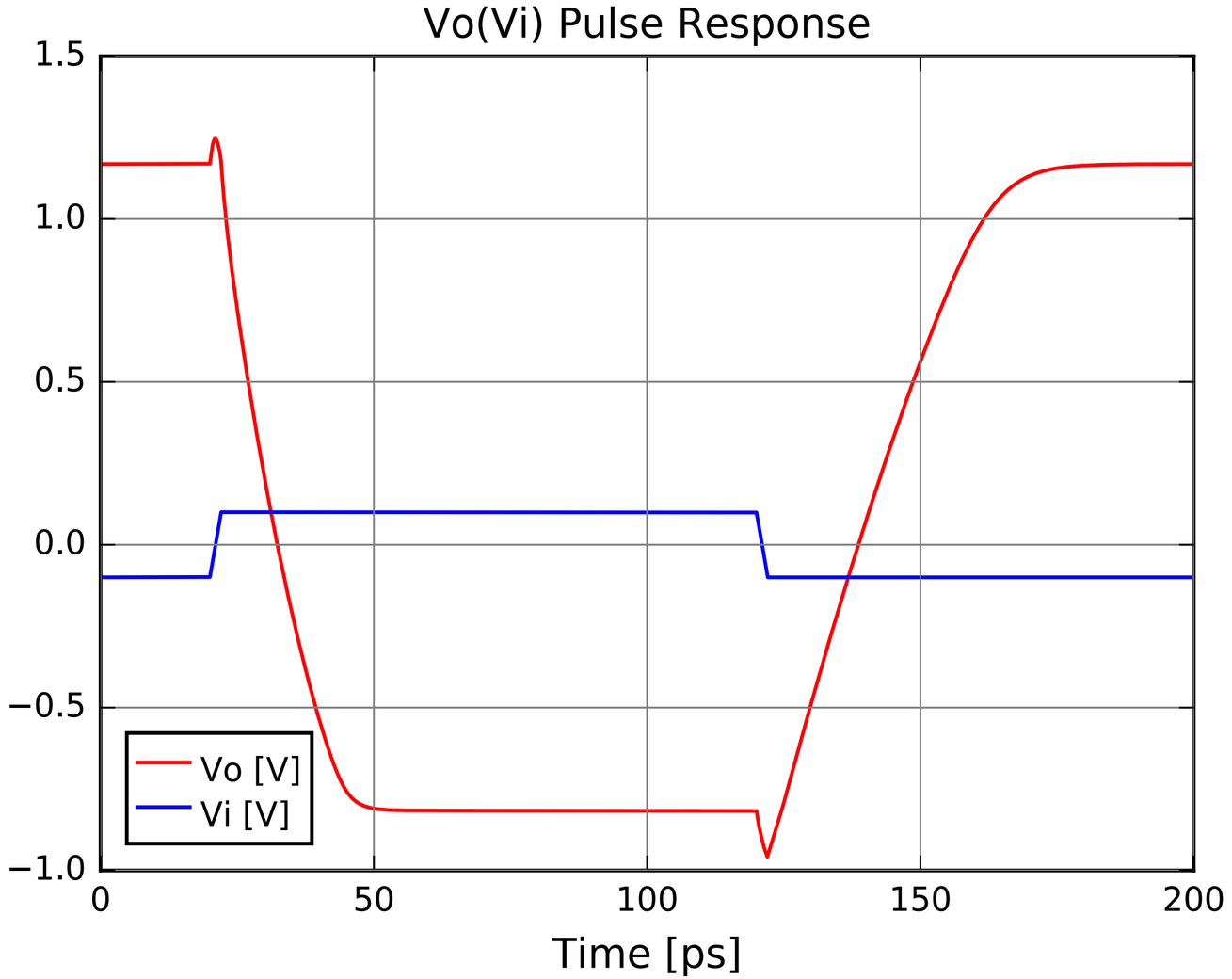




CS stage large-signal dynamic behavior





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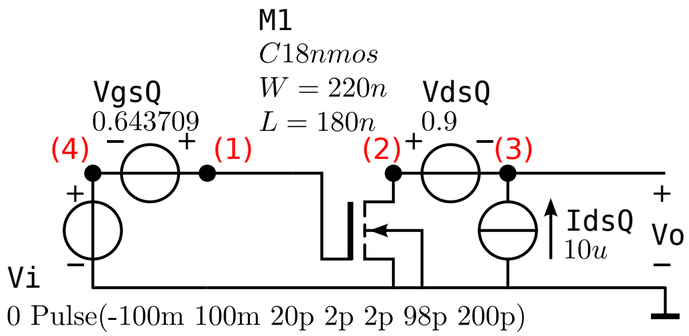

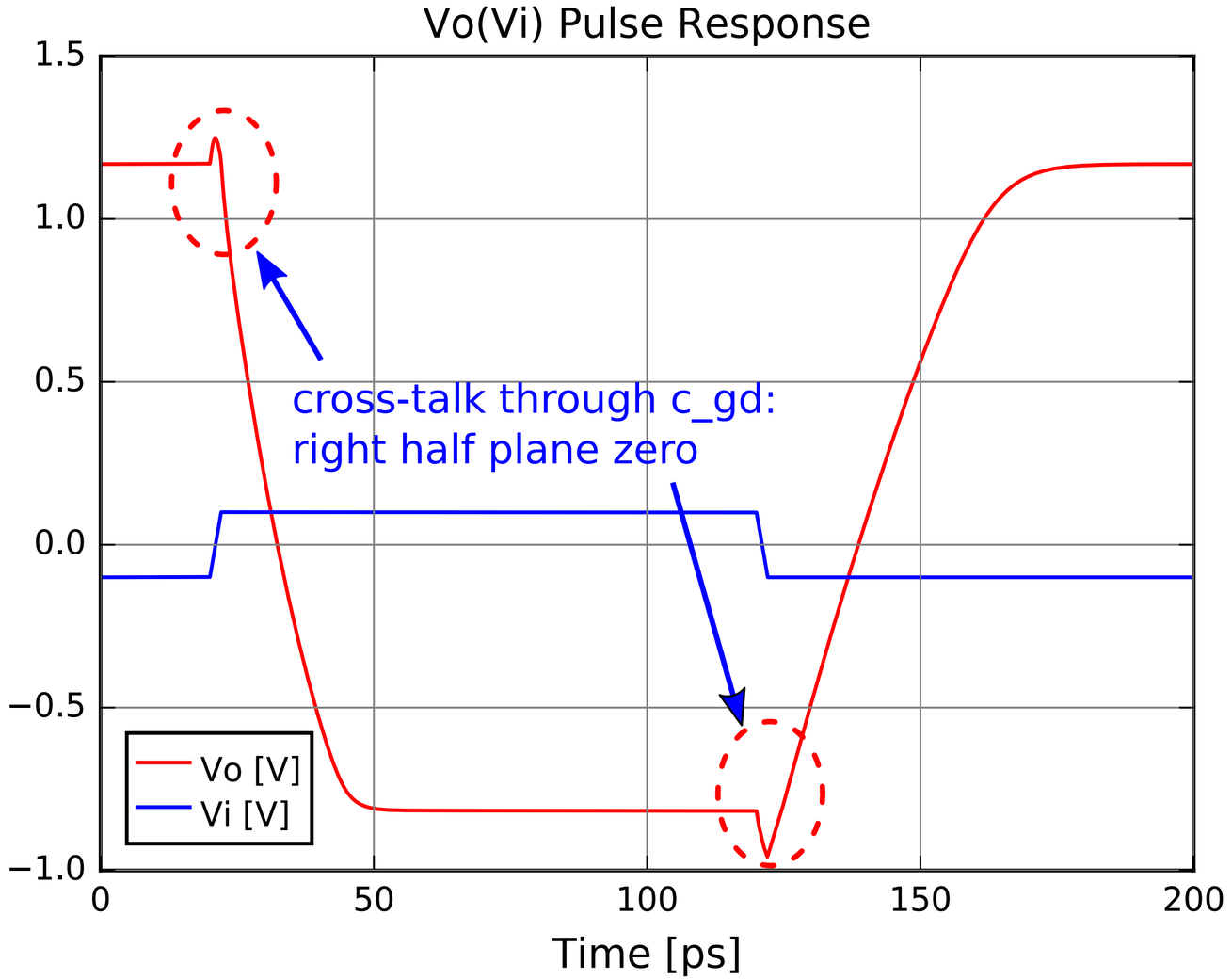

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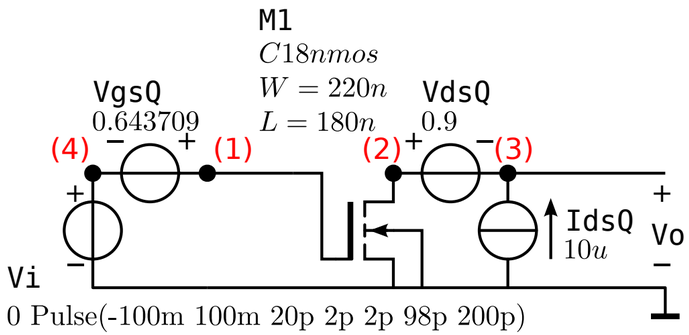
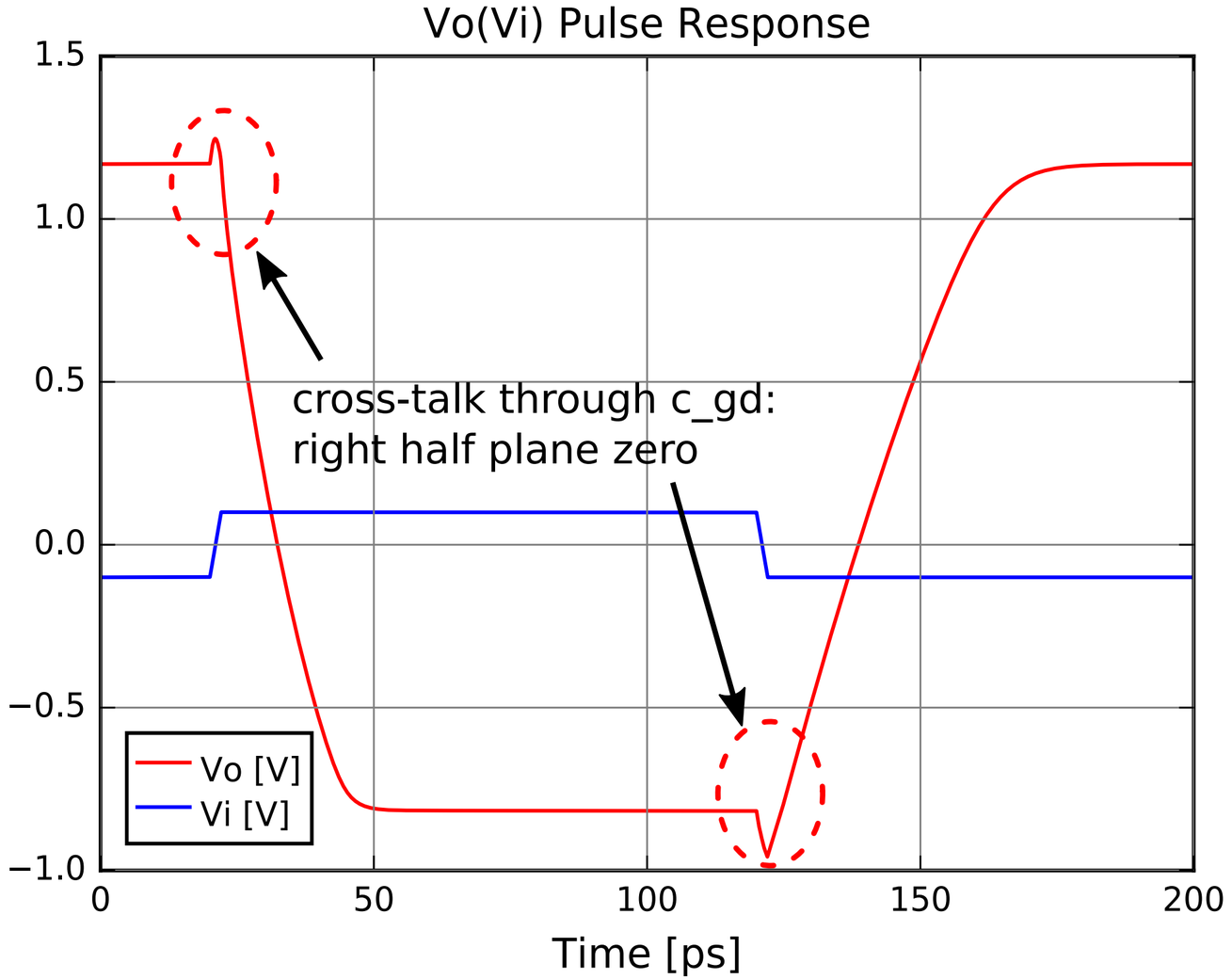


+/- 100mV:



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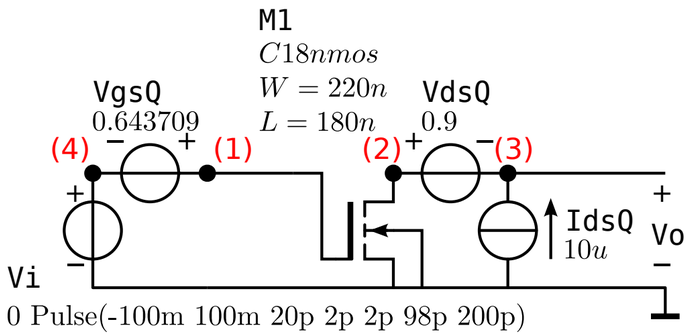
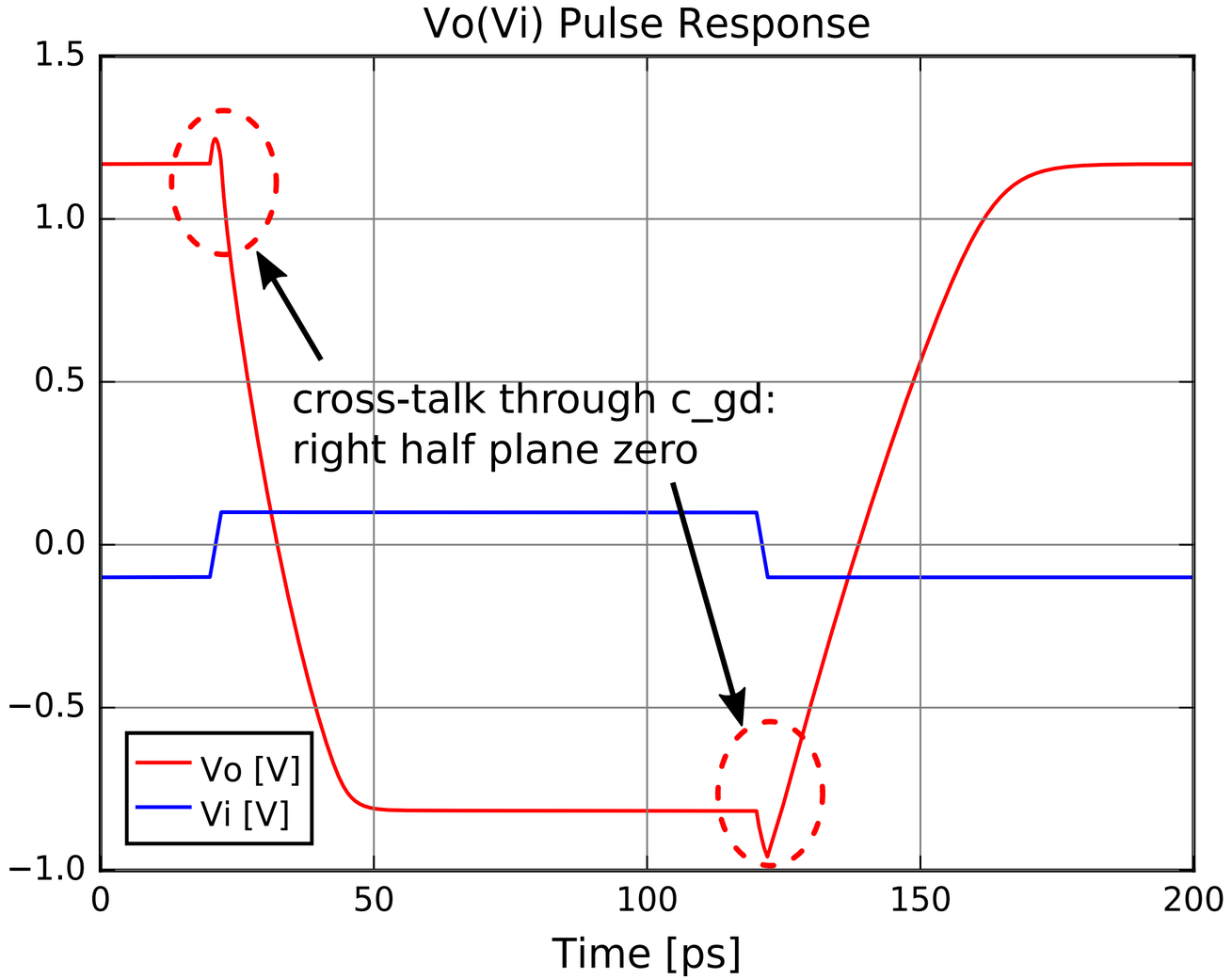


+/- 100mV:

7uA source



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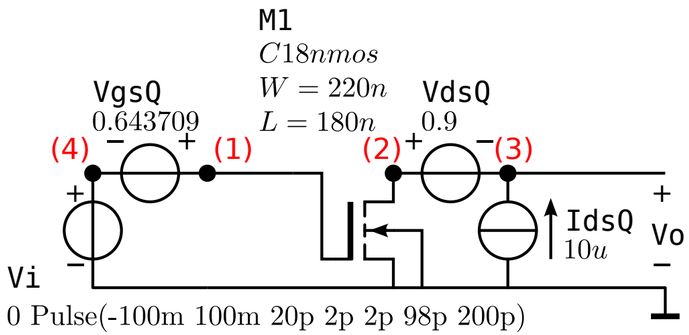

+/- 100mV:
7uA source
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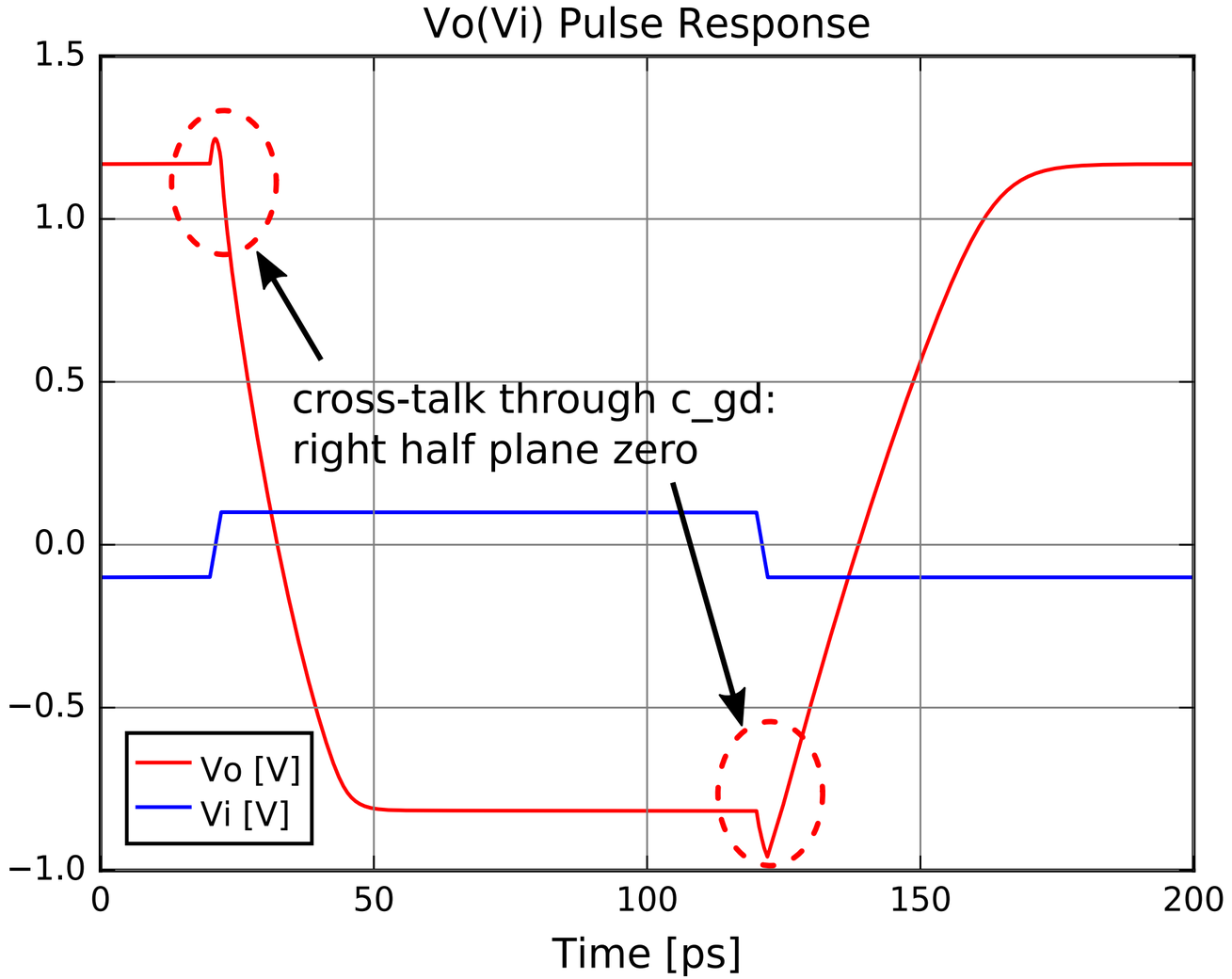

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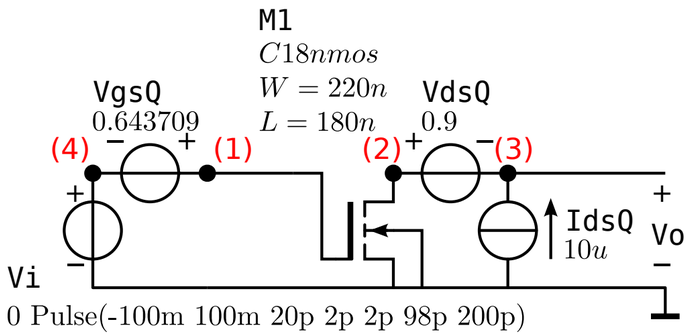

+/- 100mV:
7uA source
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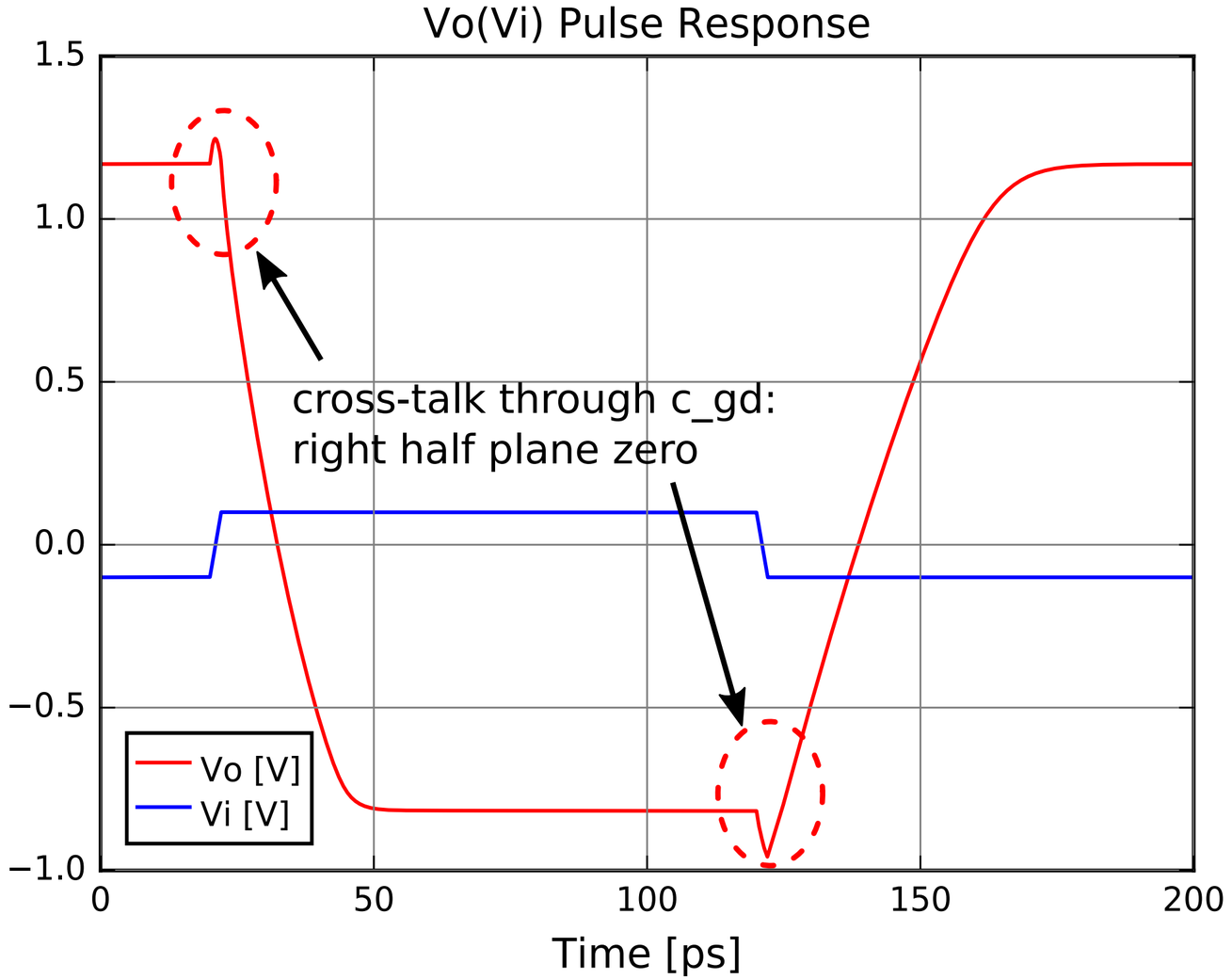
Poll:
Which parasitic capacitance(s) cause the slope limitation?

c_{gs}, c_{ds}, c_{db}?



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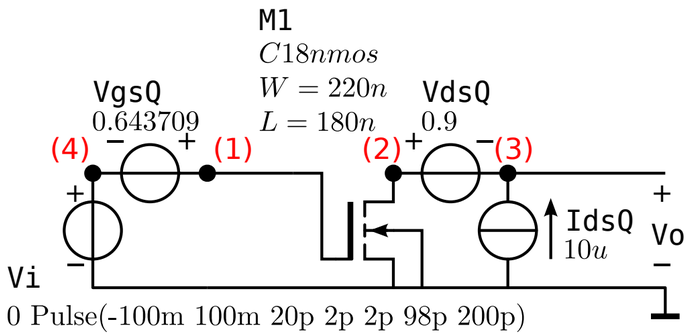

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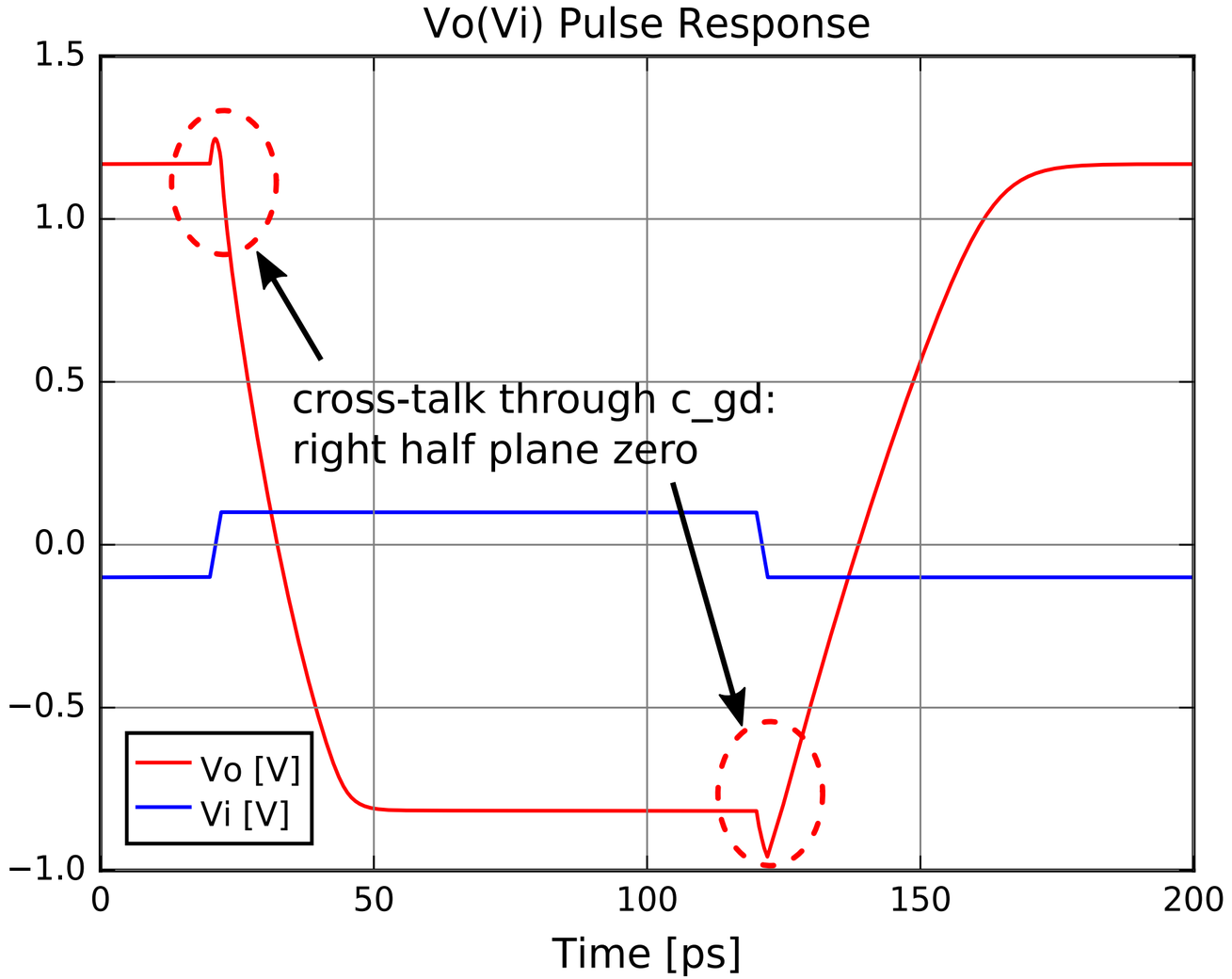

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Small-signal dynamic performance

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CS stage small-signal T1 matrix parameters

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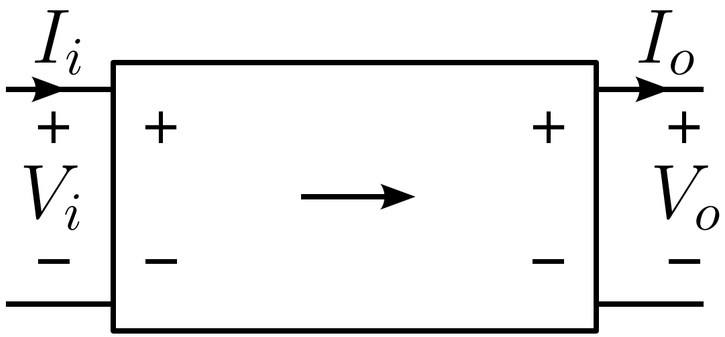

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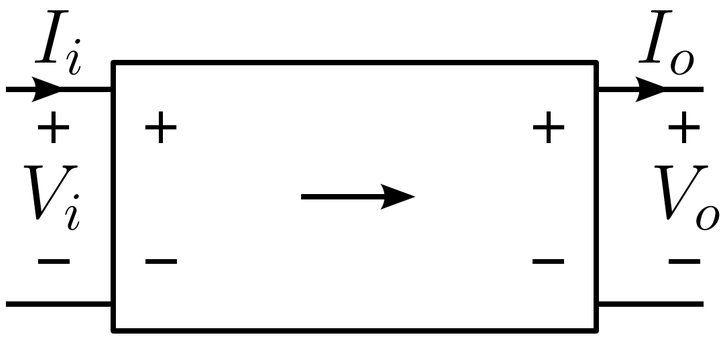

$$\begin{pmatrix} V_i \\ I_i \end{pmatrix} = \begin{pmatrix} A & B \\ C & C \end{pmatrix} \begin{pmatrix} V_o \\ I_o \end{pmatrix}$$

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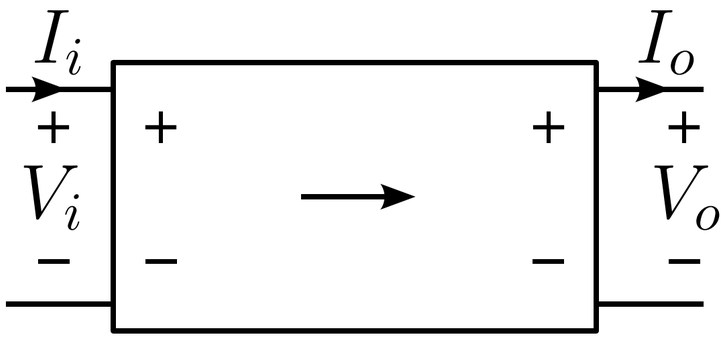

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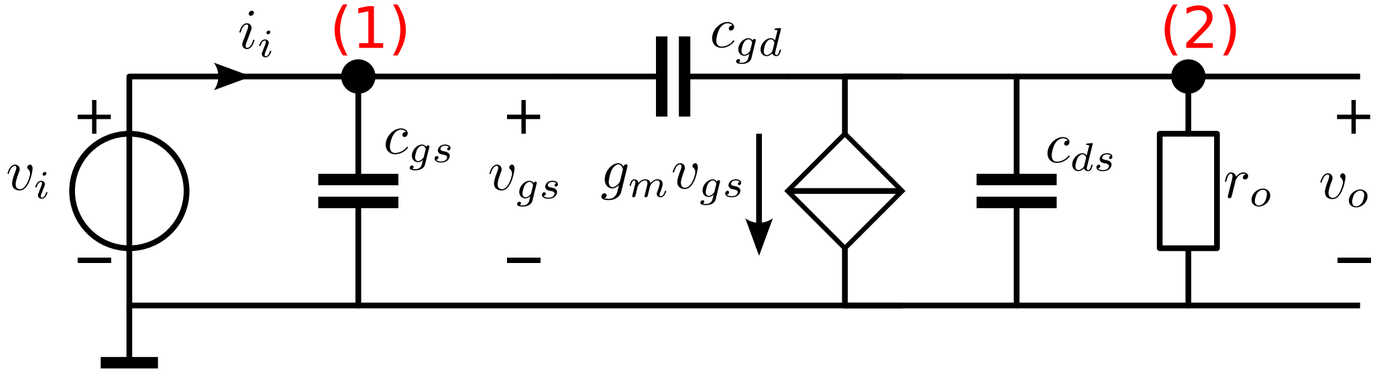

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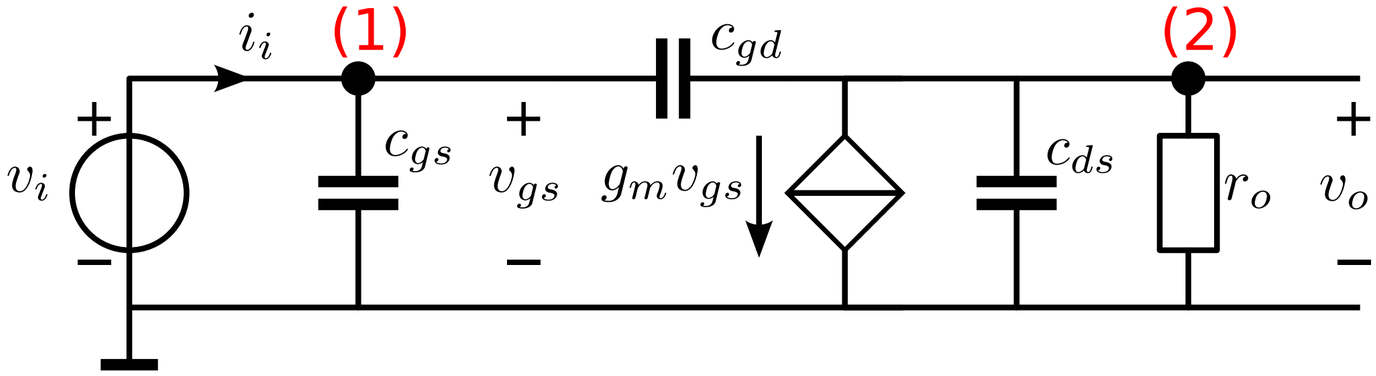
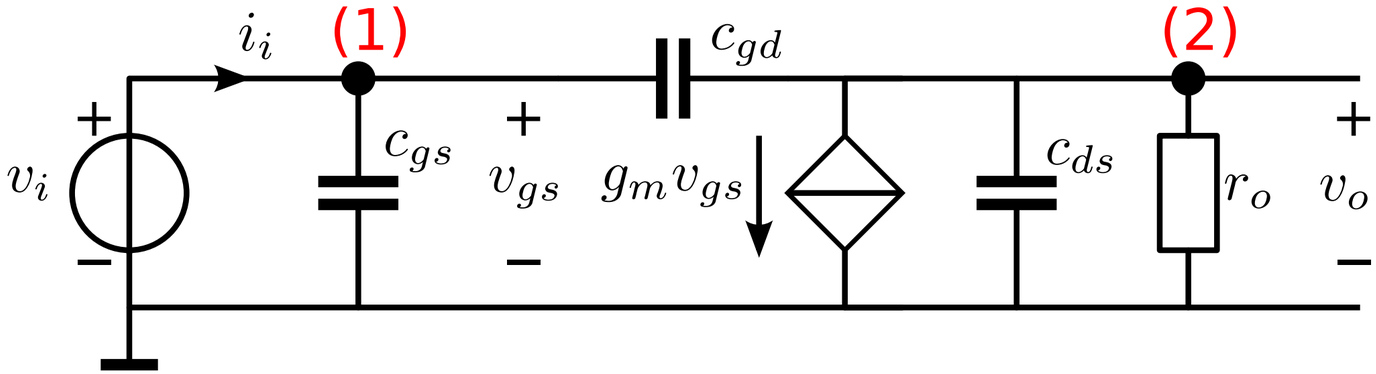


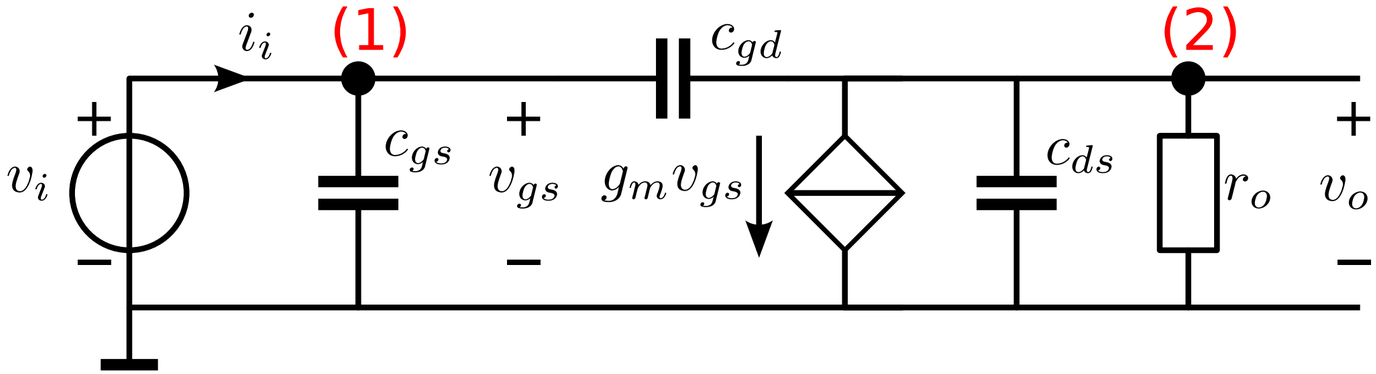
Poll: How many poles?

CS stage small-signal: A



$$\mu = \frac{1}{A} = \left.\frac{v_o}{v_i}\right|_{i_o=0} = -g_m r_o \frac{1 - s\frac{c_{gd}}{g_m}}{1 + s r_o (c_{gd} + c_{ds})}$$

CS stage small-signal: A



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CS stage small-signal: B

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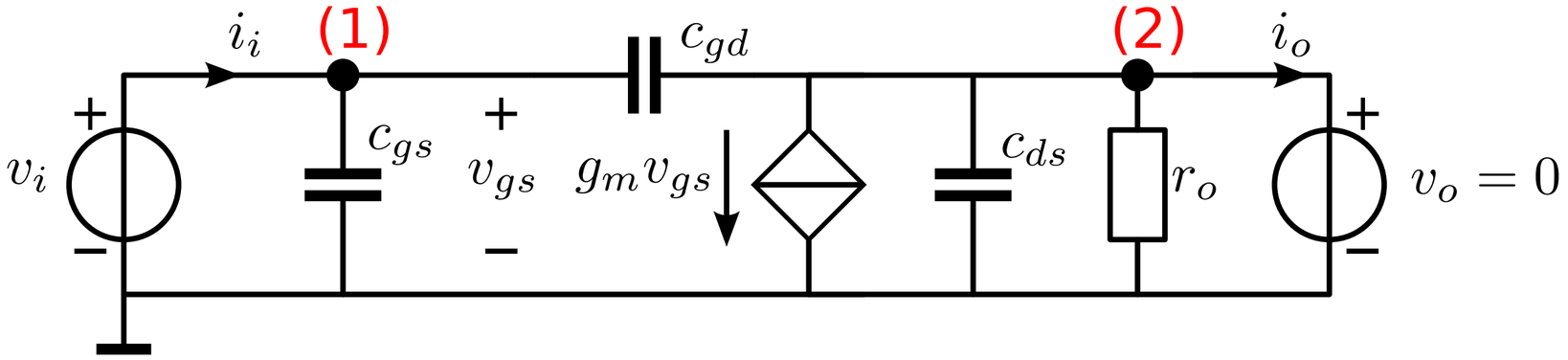
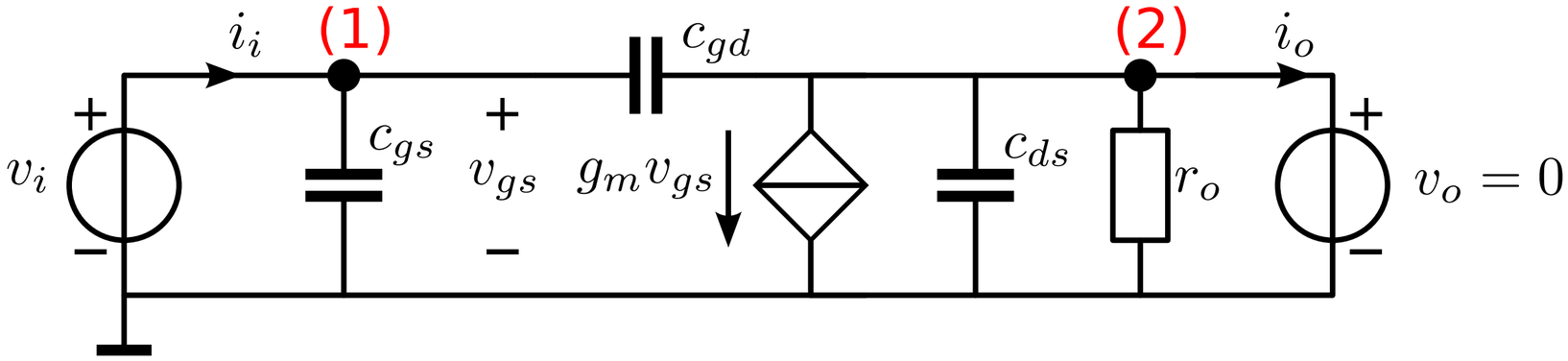
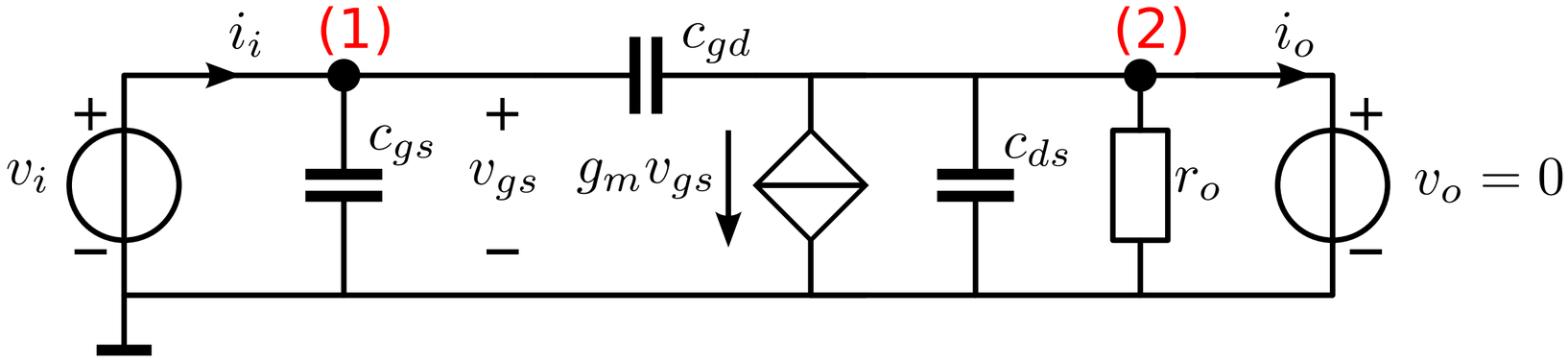


CS stage small-signal: B



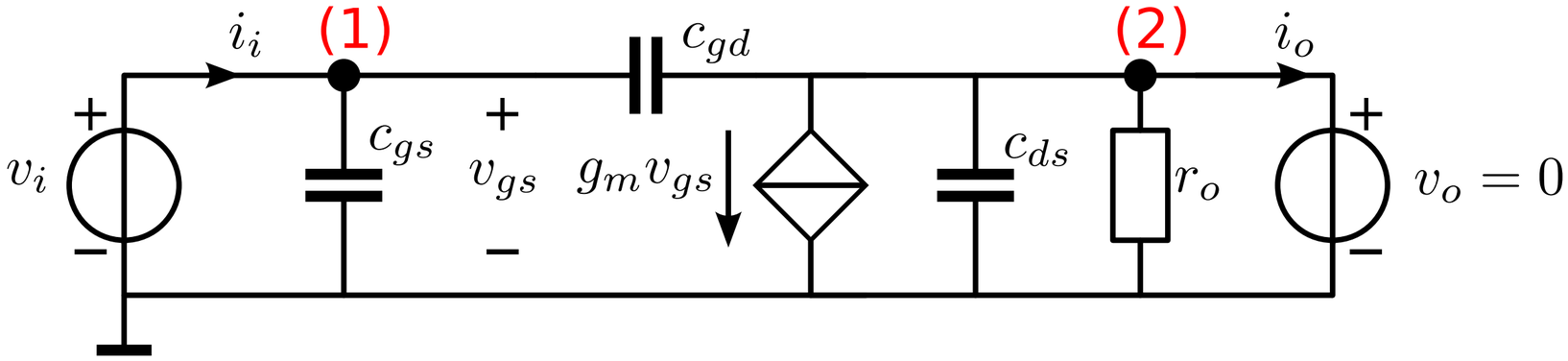
Poll: How many poles?

CS stage small-signal: B



$$\gamma = \frac{1}{B} = \left.\frac{i_o}{v_i}\right|_{v_o=0} = -g_m\left(1 - s\frac{c_{gd}}{g_m}\right)$$

CS stage small-signal dynamic behavior



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CS stage small-signal: C

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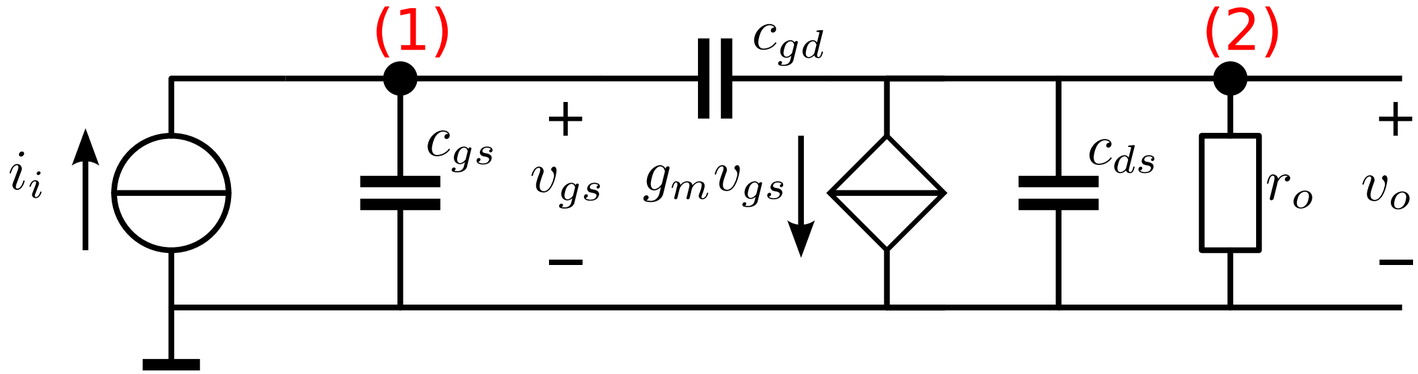
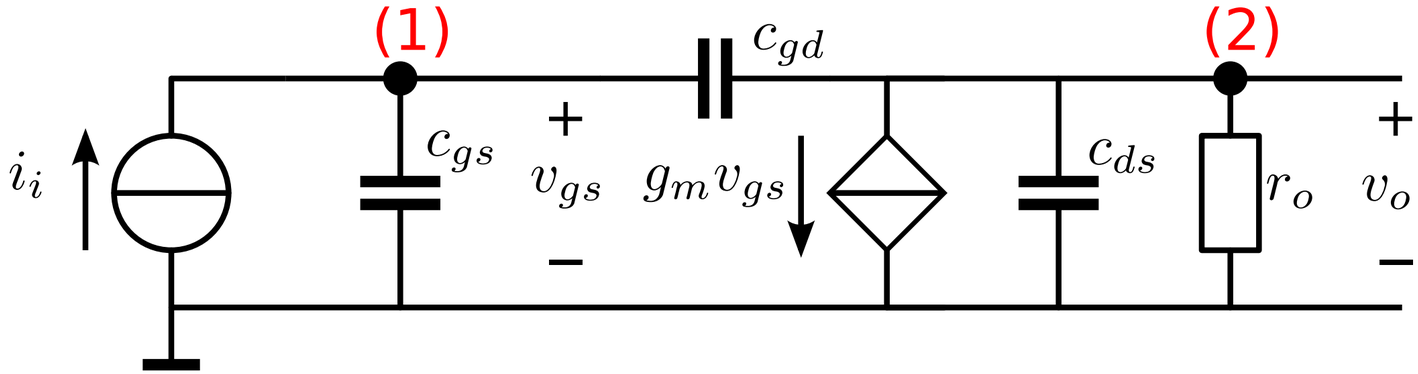
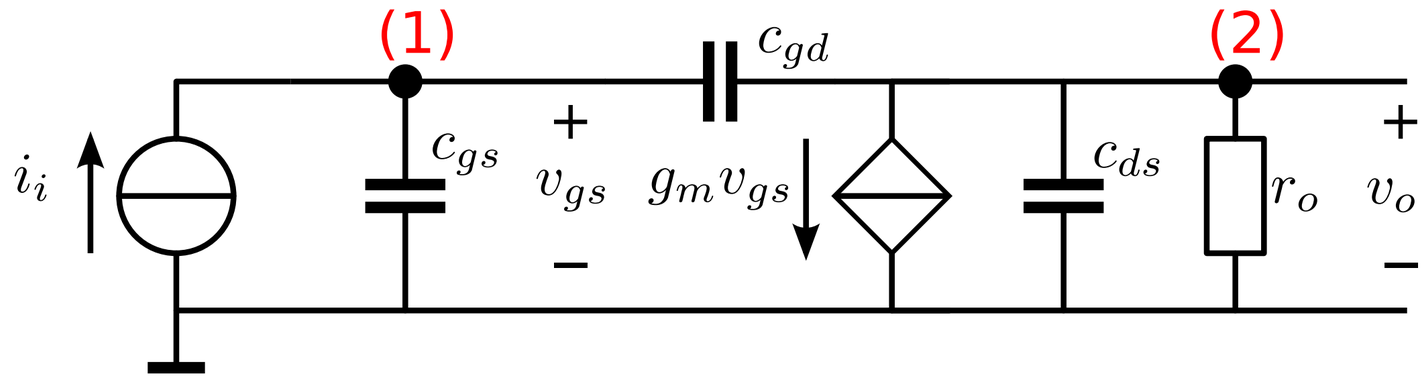


CS stage small-signal: C



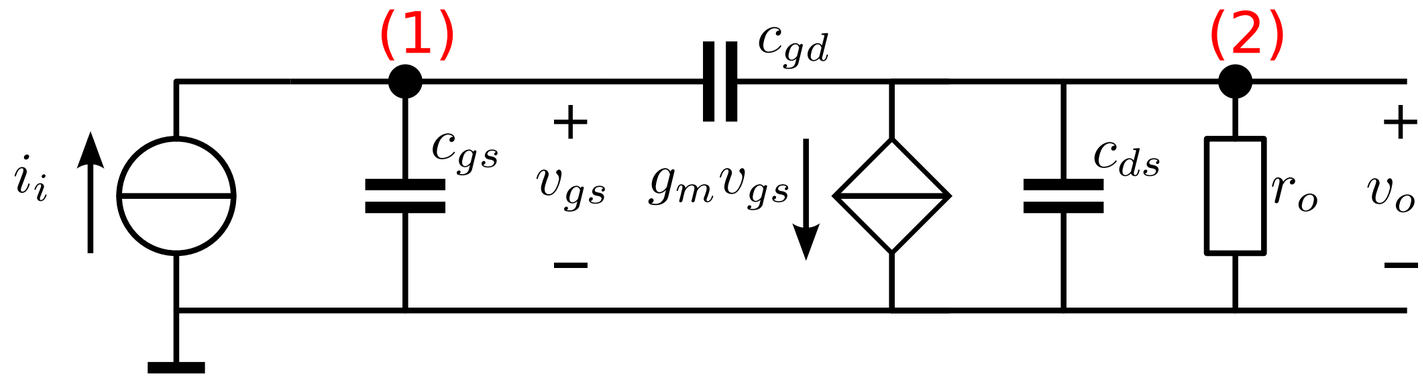
Poll: How many poles?

CS stage small-signal: C



$$\zeta = \frac{1}{C} = \left.\frac{v_o}{i_i}\right|_{i_o=0} = -g_m r_o \frac{1-s\frac{c_{gd}}{g_m}}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

CS stage small-signal: C



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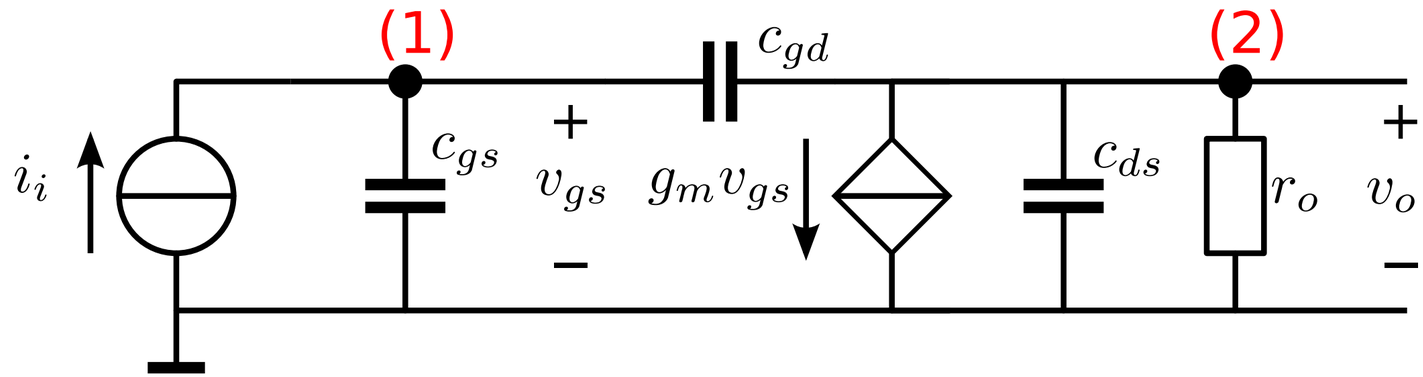
poles:

CS stage small-signal: C



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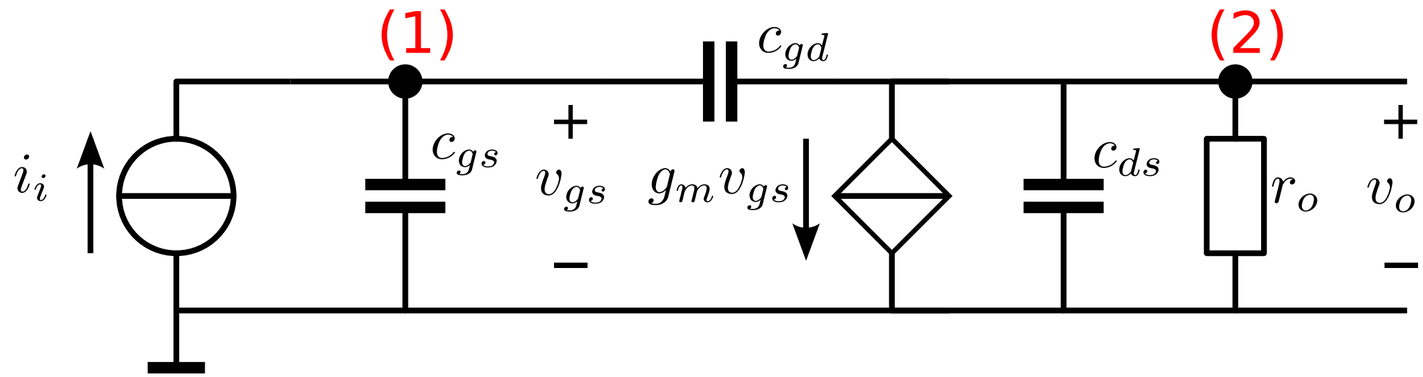
poles: $s = 0,\ s = -\frac{c_{gs}+(1+g_m r_o)c_{gd}}{r_o(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd})}$

CS stage small-signal: C



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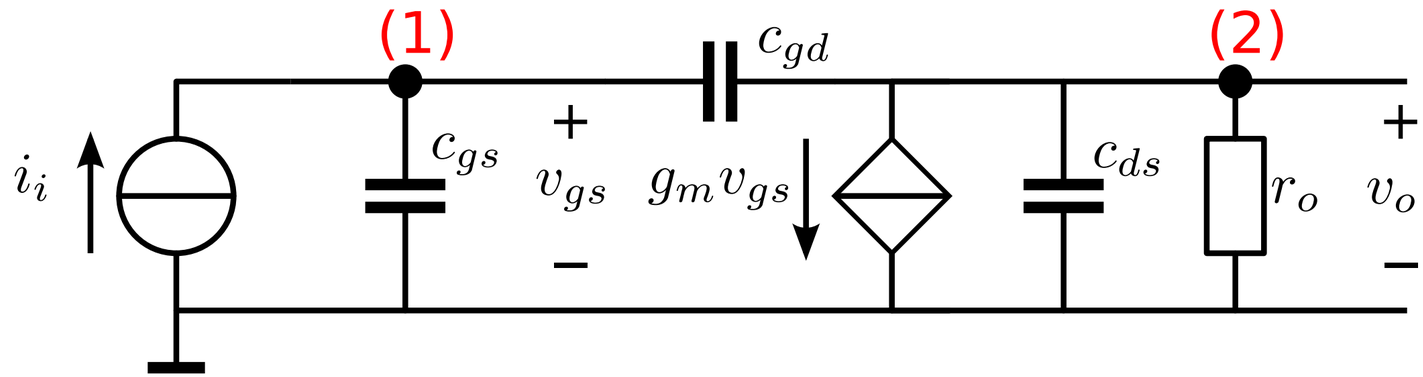
poles: $s = 0,\ s = -\frac{c_{gs}+(1+g_m r_o)c_{gd}}{r_o(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd})}$ ←

Higher frequency with increasing c_{gd}

If: $c_{gd} \ll c_{gs}$ and $c_{gd} \ll c_{ds}$

CS stage small-signal: C



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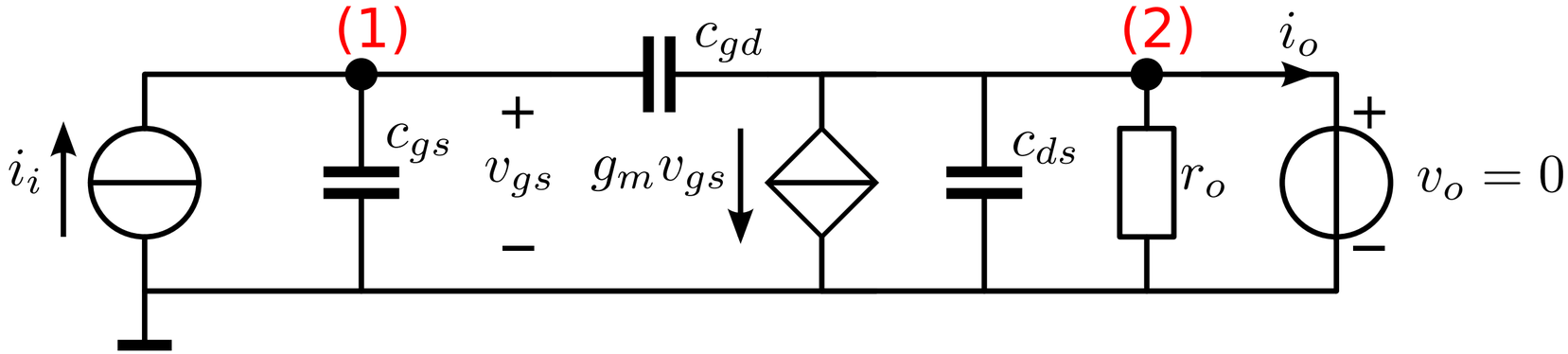
poles: $s = 0,\ s = -\frac{c_{gs}+(1+g_m r_o)c_{gd}}{r_o(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd})}$ ←

Higher frequency with increasing c_{gd}

If: $c_{gd} \ll c_{gs}$ and $c_{gd} \ll c_{ds}$

CS stage small-signal dynamic behavior



How many poles?

$$\alpha = \frac{1}{D} = \left.\frac{i_o}{i_i}\right|_{v_o=0} = -\frac{g_m\left(1-s\frac{c_{gd}}{g_m}\right)}{s(c_{gs}+c_{gd})}$$

Unity-gain frequency: $\omega_T = \dfrac{g_m}{c_{gs}+c_{gd}}$

Structured Electronic Design

Intrinsic CS stage
Input and output impedance

Anton J.M. Montagne

CS stage small-signal dynamic behavior

CS stage small-signal dynamic behavior

Input impedance with shorted output

CS stage small-signal dynamic behavior

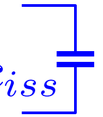
Input impedance with shorted output

$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$

CS stage small-signal dynamic behavior

Input impedance with shorted output

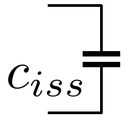
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



CS stage small-signal dynamic behavior

Input impedance with shorted output

$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$

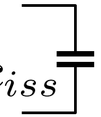


Input impedance with open output

CS stage small-signal dynamic behavior

Input impedance with shorted output

$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



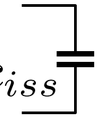
Input impedance with open output

$$z_i\big|_{i_o=0} = \left.\frac{v_i}{i_i}\right|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

CS stage small-signal dynamic behavior

Input impedance with shorted output

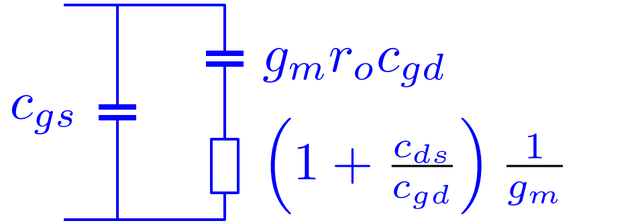
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

$$z_i\big|_{i_o=0} = \left.\frac{v_i}{i_i}\right|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

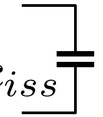
$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



CS stage small-signal dynamic behavior

Input impedance with shorted output

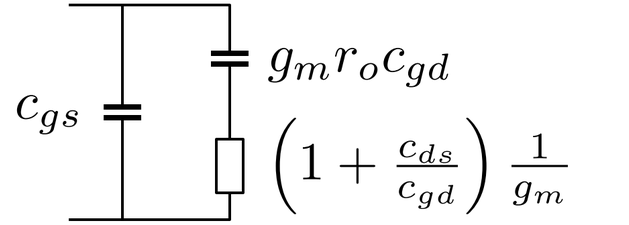
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

$$z_i\big|_{i_o=0} = \frac{v_i}{i_i}\bigg|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$

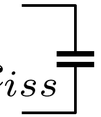


Output impedance with shorted input

CS stage small-signal dynamic behavior

Input impedance with shorted output

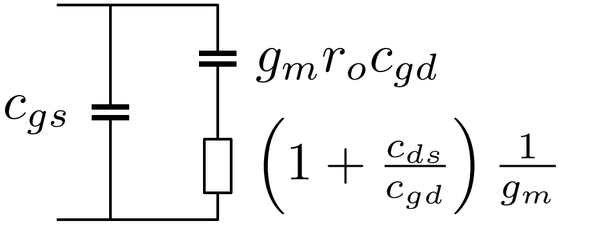
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

$$z_i\big|_{i_o=0} = \frac{v_i}{i_i}\bigg|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



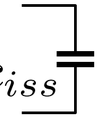
Output impedance with shorted input

$$z_o\big|_{v_i=0} = \frac{B}{A} = \frac{r_o}{1+sr_o(c_{gd}+c_{ds})} = \frac{r_o}{1+sr_o c_{oss}}$$

CS stage small-signal dynamic behavior

Input impedance with shorted output

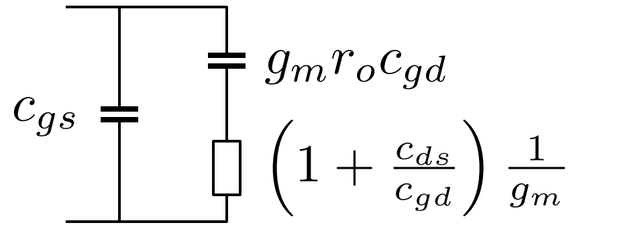
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

$$z_i\big|_{i_o=0} = \frac{v_i}{i_i}\bigg|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Output impedance with shorted input

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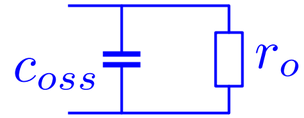
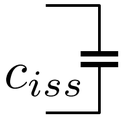


CS stage small-signal dynamic behavior

Input impedance with shorted output

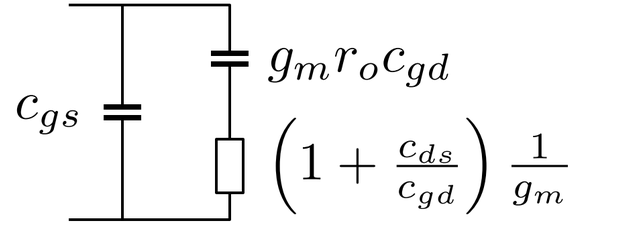
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

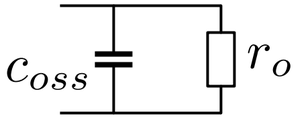
$$z_i\big|_{i_o=0} = \frac{v_i}{i_i}\bigg|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Output impedance with shorted input

$$z_o\big|_{v_i=0} = \frac{B}{A} = \frac{r_o}{1+sr_o(c_{gd}+c_{ds})} = \frac{r_o}{1+sr_o c_{oss}}$$

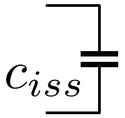


Output impedance with open input

CS stage small-signal dynamic behavior

Input impedance with shorted output

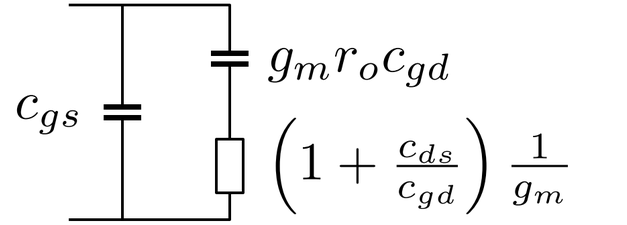
$$z_i|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

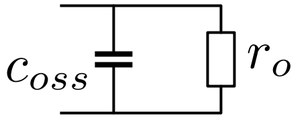
$$z_i|_{i_o=0} = \left.\frac{v_i}{i_i}\right|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Output impedance with shorted input

$$z_o|_{v_i=0} = \frac{B}{A} = \frac{r_o}{1+sr_o(c_{gd}+c_{ds})} = \frac{r_o}{1+sr_o c_{oss}}$$



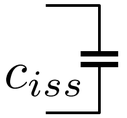
Output impedance with open input

$$z_o|_{i_i=0} = r_o \frac{c_{gs}+c_{gd}}{c_{gs}+(1+g_m r_o)c_{gd}} \frac{1}{1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}}$$

CS stage small-signal dynamic behavior

Input impedance with shorted output

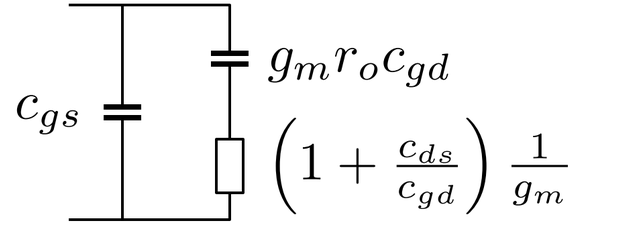
$$z_i|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

$$z_i|_{i_o=0} = \left.\frac{v_i}{i_i}\right|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Output impedance with shorted input

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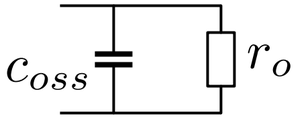
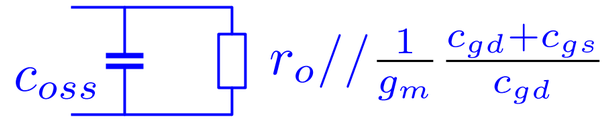


Output impedance with open input

$$z_o|_{i_i=0} = r_o\frac{c_{gs}+c_{gd}}{c_{gs}+(1+g_m r_o)c_{gd}}\frac{1}{1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}}$$

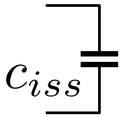
$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



CS stage small-signal dynamic behavior

Input impedance with shorted output

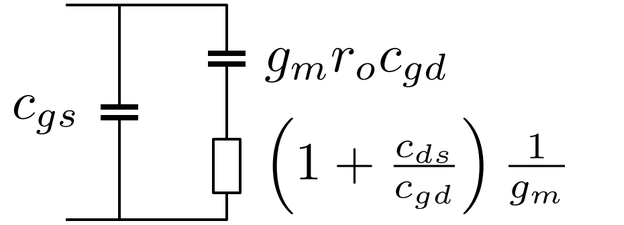
$$z_i\big|_{v_o=0} = \frac{B}{D} = \frac{1}{s(c_{gs}+c_{gd})} = \frac{1}{sc_{iss}}$$



Input impedance with open output

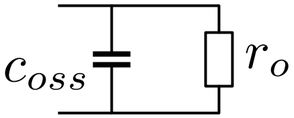
$$z_i\big|_{i_o=0} = \frac{v_i}{i_i}\bigg|_{i_o=0} = \frac{A}{C} = \frac{1+sr_o(c_{gd}+c_{ds})}{s(c_{gs}+(1+g_m r_o)c_{gd})\left(1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}\right)}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Output impedance with shorted input

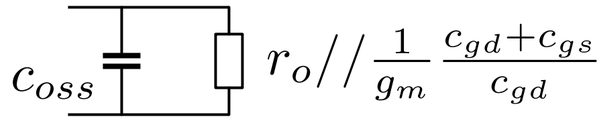
$$z_o\big|_{v_i=0} = \frac{B}{A} = \frac{r_o}{1+sr_o(c_{gd}+c_{ds})} = \frac{r_o}{1+sr_o c_{oss}}$$



Output impedance with open input

$$z_o\big|_{i_i=0} = r_o\frac{c_{gs}+c_{gd}}{c_{gs}+(1+g_m r_o)c_{gd}}\frac{1}{1+s\frac{r_o\left(c_{gs}c_{ds}+c_{gs}c_{gd}+c_{ds}c_{gd}\right)}{c_{gs}+(1+g_m r_o)c_{gd}}}$$

$c_{gd} \ll c_{gs}$ and $c_{ds} \ll c_{gs}$



Structured Electronic Design

Intrinsic CS stage
Geometry and current scaling

Anton J.M. Montagne

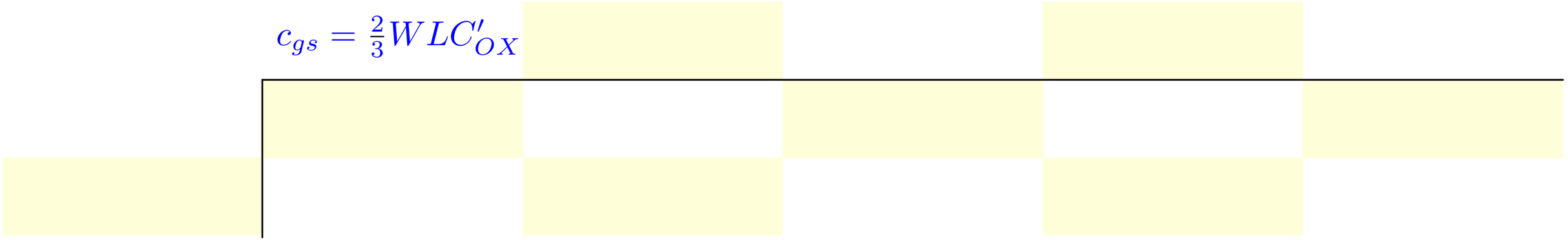
CS stage scaling

Saturation region approximations

CS stage scaling

Saturation region approximations

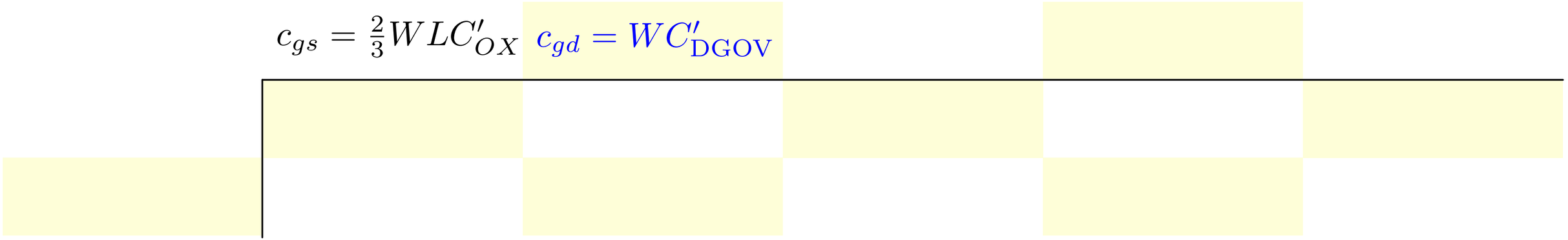
$$c_{gs} = \frac{2}{3} W L C'_{OX}$$



CS stage scaling

Saturation region approximations

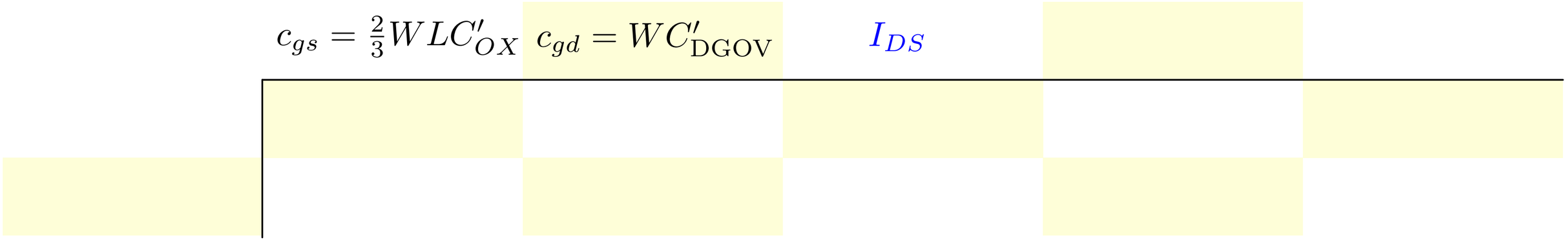
$c_{gs} = \frac{2}{3} W L C'_{OX}$ $c_{gd} = W C'_{\mathrm{DGOV}}$



CS stage scaling

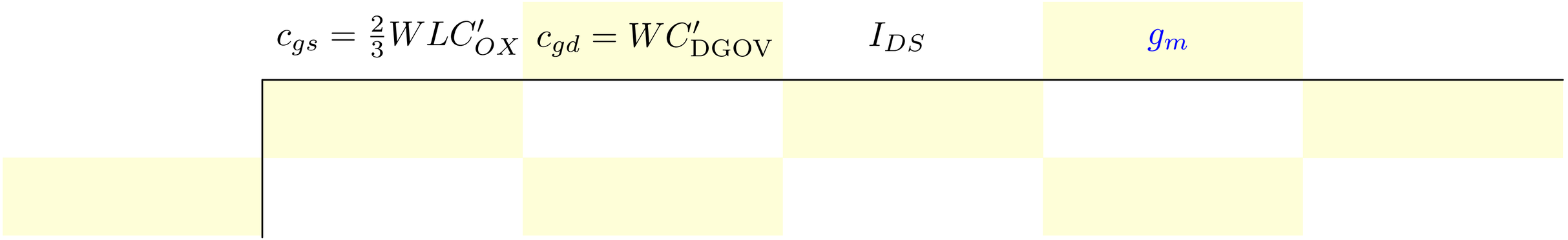
Saturation region approximations

$c_{gs} = \frac{2}{3} W L C'_{OX}$ $c_{gd} = W C'_{\mathrm{DGOV}}$ I_{DS}



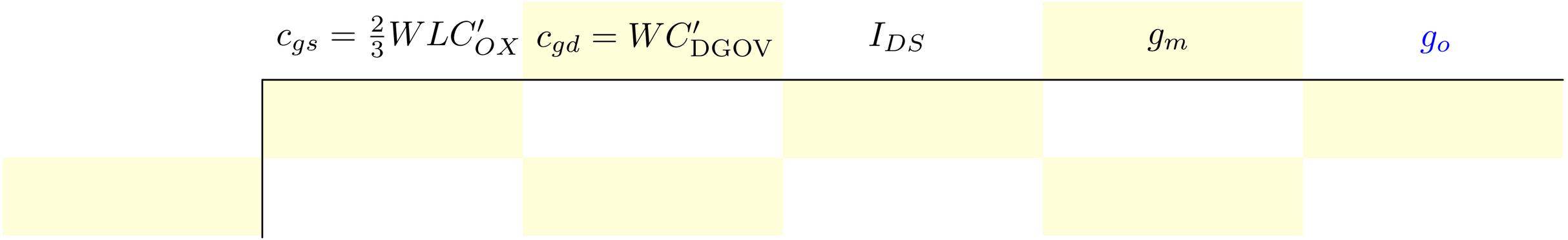
CS stage scaling

Saturation region approximations



CS stage scaling

Saturation region approximations



CS stage scaling

Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient					

$\propto$: proportional with

$\Uparrow$: strongly increases with increasing

$\uparrow$: increases with increasing

$\downarrow$: decreases with increasing

$\Downarrow$: strongly decreases with increasing

CS stage scaling

Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W$, $\propto L$				

$\propto$: proportional with

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CS stage scaling

Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W$, $\propto L$	$\propto W$			

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CS stage scaling

Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W$, $\propto L$	$\propto W$	$\uparrow W$, $\downarrow L$		

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Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W$, $\propto L$	$\propto W$	$\uparrow W$, $\downarrow L$	$\uparrow W$, $\downarrow L$	

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	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$

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	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current					

$\propto$: proportional with

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CS stage scaling

Saturation region approximations

	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current	$\propto W, \propto L$				

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	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current	$\propto W, \propto L$	$\propto W$			

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	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current	$\propto W, \propto L$	$\propto W$		$\downarrow W, \downarrow L$	

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	$c_{gs} = \frac{2}{3} W L C'_{OX}$	$c_{gd} = W C'_{\mathrm{DGOV}}$	I_{DS}	g_m	g_o
Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current	$\propto W, \propto L$	$\propto W$		$\downarrow W, \downarrow L$	$\downarrow W, \Downarrow L$

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Maintain Inversion coefficient	$\propto W, \propto L$	$\propto W$	$\uparrow W, \downarrow L$	$\uparrow W, \downarrow L$	$\uparrow W, \Downarrow L$
Maintain Drain current	$\propto W, \propto L$	$\propto W$		$\downarrow W, \downarrow L$	$\downarrow W, \Downarrow L$

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