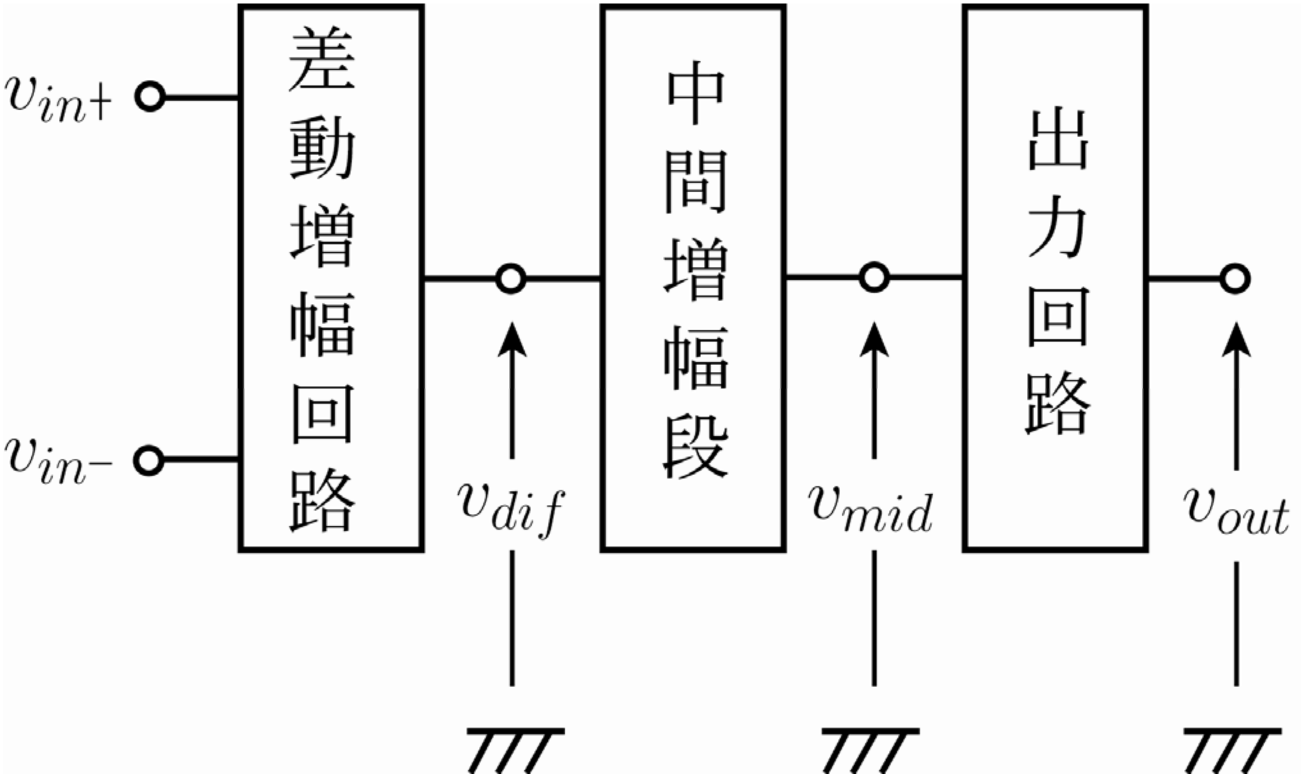
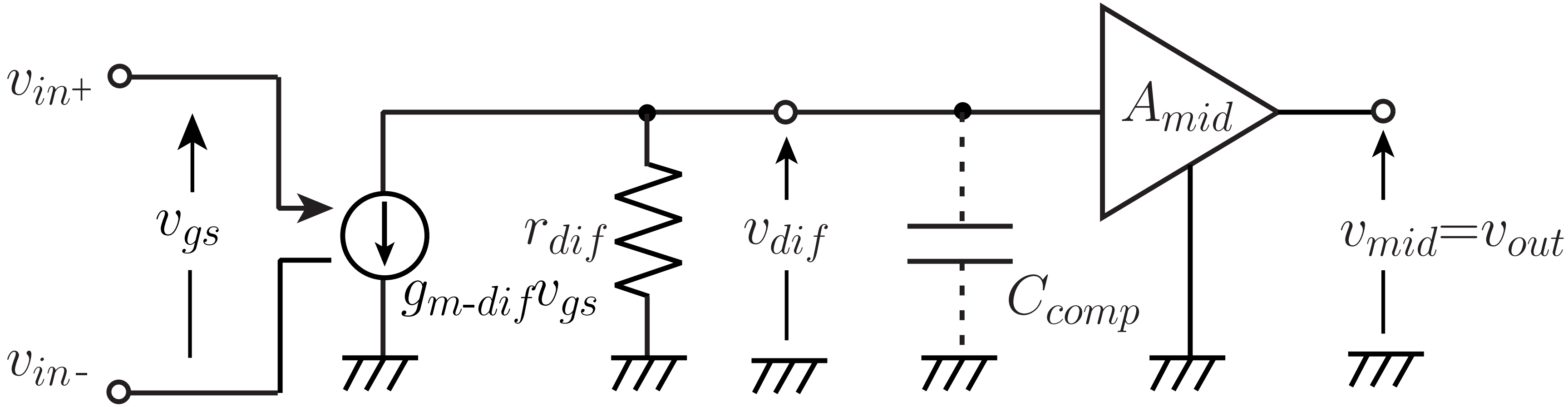
演算増幅器

演算増幅器の基本構成



基本演算増幅器の近似表現



$$v_{out}=A_{mid}\frac{g_{m-dif}\,r_{dif}}{1+sC_{comp}\,r_{dif}}\left(v_{in+}-v_{in-}\right)$$

$$A_d = A_{mid} \frac{g_{m-dif}\, r_{dif}}{1 + sC_{comp}\, r_{dif}} = \frac{A_{d0}}{1 + j\dfrac{f}{f_c}}$$

$$g_{m-dif} \approx 2\sqrt{K I_D} \qquad r_{dif} \approx \frac{1}{\lambda I_D}$$

$$A_{d0} = A_{mid}\, g_{m-dif}\, r_{dif} \approx A_{mid} \frac{2}{\lambda} \sqrt{\frac{K}{I_D}}$$

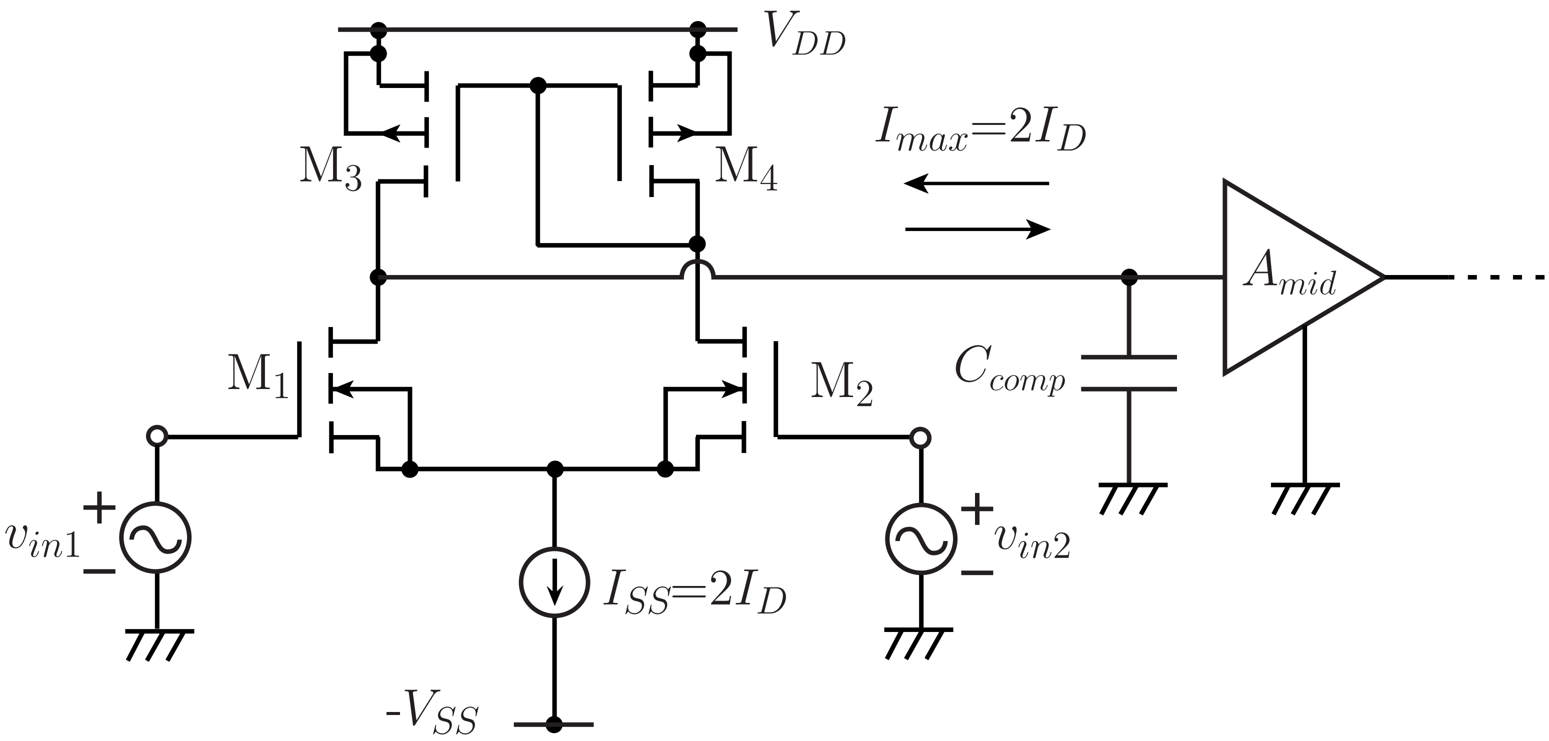
$$A_d = A_{mid}\frac{g_{m-dif}\, r_{dif}}{1+sC_{comp}\, r_{dif}} = \frac{A_{d0}}{1+j\dfrac{f}{f_c}}$$

$$g_{m-dif} \approx 2\sqrt{K I_D} \qquad r_{dif} \approx \frac{1}{\lambda I_D}$$

$\dfrac{f}{f_c} >> 1$と仮定

$$|A_d| \approx \frac{A_{d0} f_c}{f} = 1 \rightarrow f = A_{d0} f_c = GB$$

$$GB = \frac{A_{mid}\, g_{m-dif}}{2\pi C_{comp}} = \frac{A_{mid}\sqrt{K I_D}}{\pi C_{comp}}$$



$$SR = \frac{2I_D}{C_{comp}} = \frac{g_{m-dif}^{\ 2}}{2KC_{comp}}$$

特性のトレードオフ

$$A_{d0} = A_{mid} g_{m-dif} r_{dif} \approx A_{mid} \frac{2}{\lambda} \sqrt{\frac{K}{I_D}}$$

$$GB = \frac{A_{mid} g_{m-dif}}{2\pi C_{comp}} = \frac{A_{mid} \sqrt{K I_D}}{\pi C_{comp}}$$

$$SR = \frac{2 I_D}{C_{comp}} = \frac{g_{m-dif}^{\ 2}}{2 K C_{comp}}$$

バイポーラトランジスタを用いた演算増幅器の場合

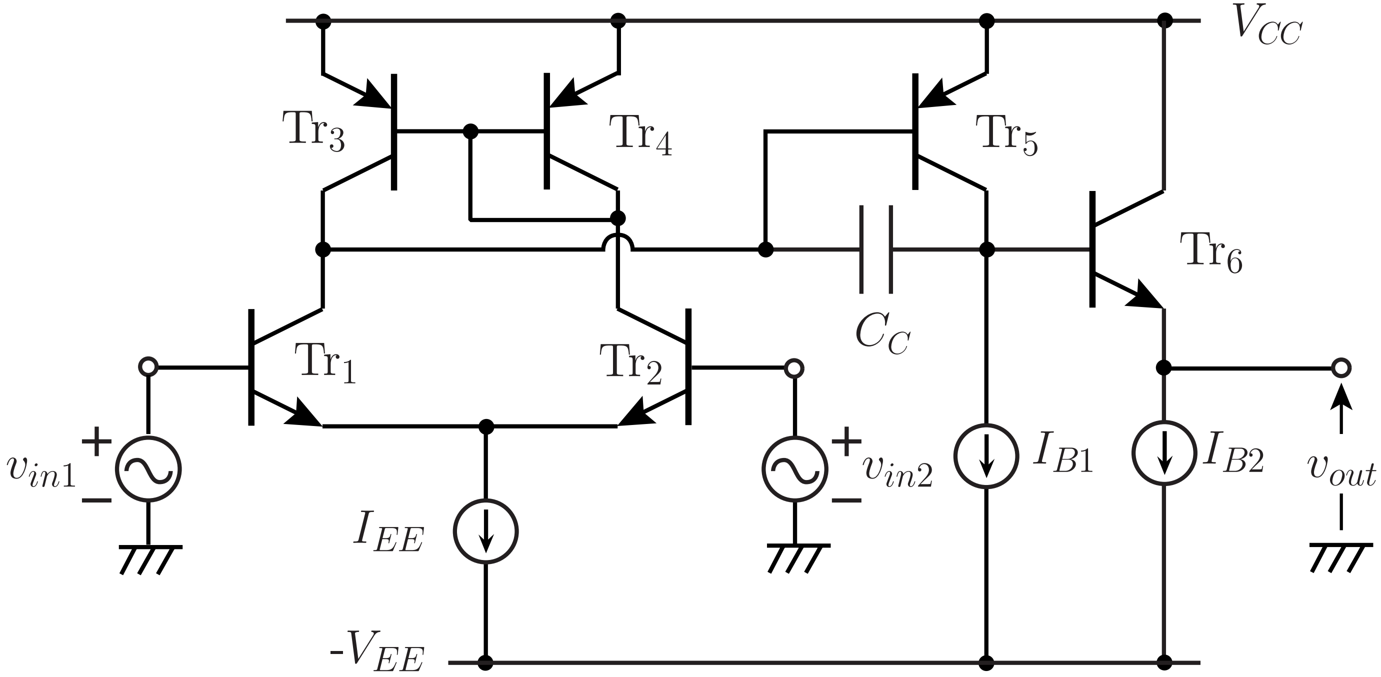
$$g_{m-dif} \approx \frac{\alpha_0 q I_E}{kT} \qquad r_{dif} \approx \frac{V_A}{I_C} = \frac{V_A}{\alpha_0 I_E}$$

$$A_{d0} = A_{mid} g_{m-dif} r_{dif} \approx A_{mid} \frac{qV_A}{kT}$$

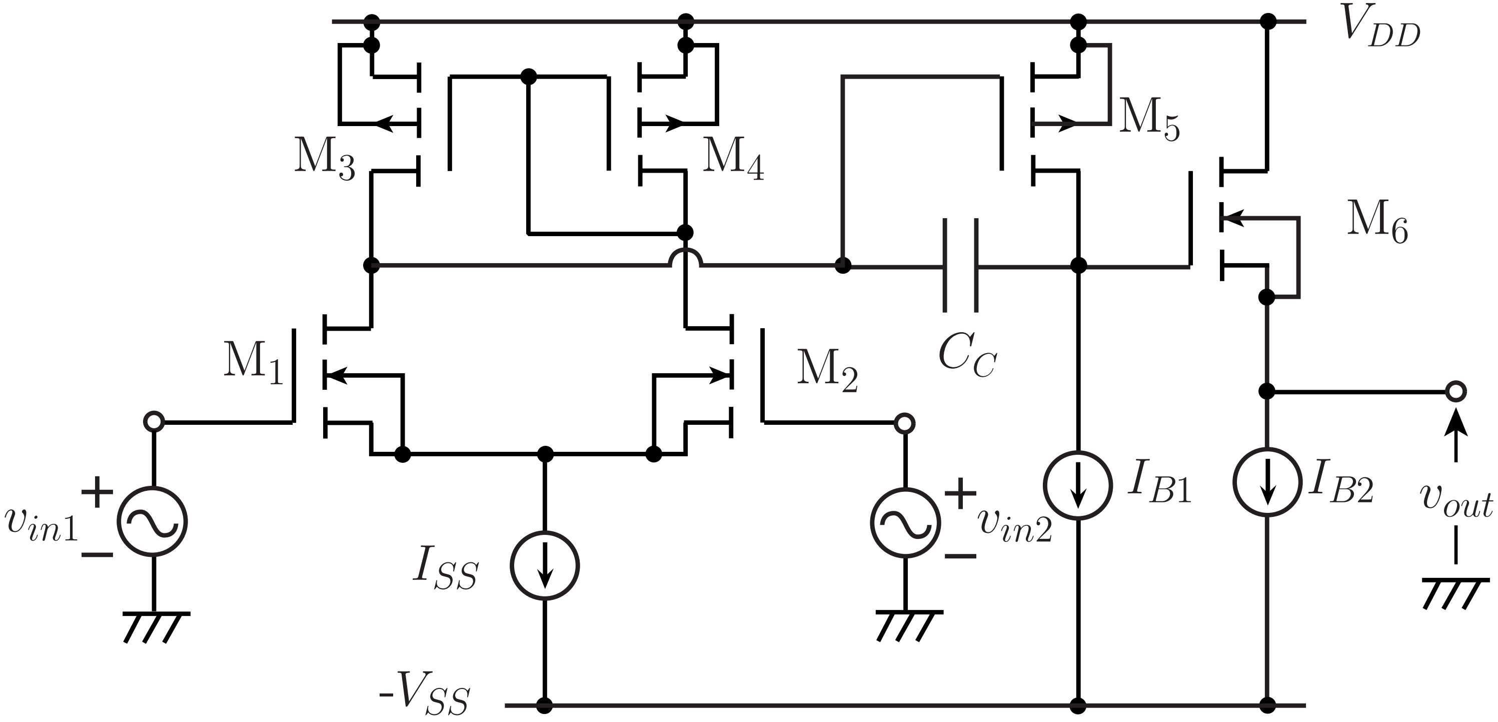
$$GB = \frac{A_{mid} g_{m-dif}}{2\pi C_{comp}} = \frac{A_{mid} \alpha_0 q I_E}{2\pi C_{comp} kT}$$

$$SR = \frac{2\alpha_0 I_E}{C_{comp}} = \frac{2kT g_{m-dif}}{q C_{comp}} = \frac{4\pi GB}{q}$$

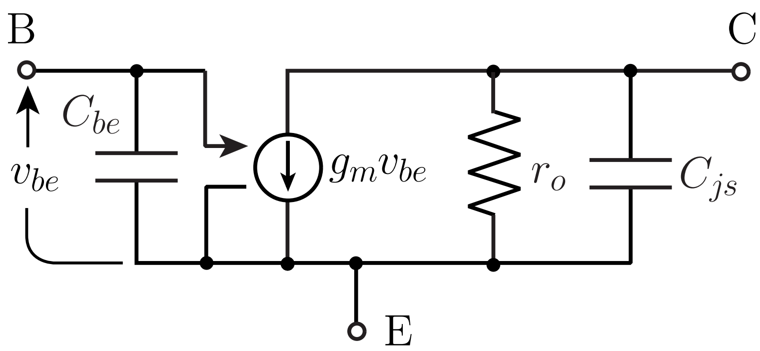
バイポーラトランジスタによる演算増幅器の構成例



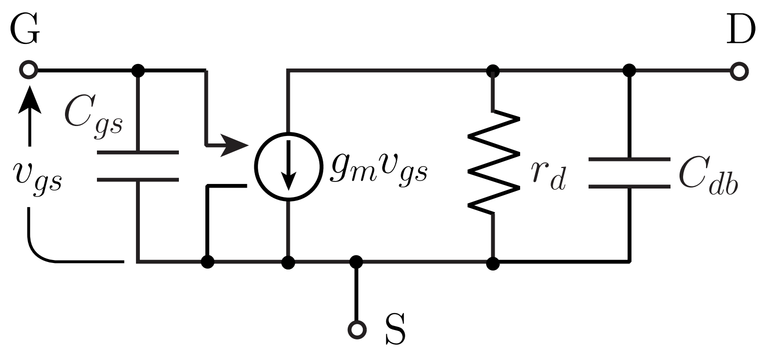
MOSトランジスタによる演算増幅器の構成例



トランジスタの等価回路

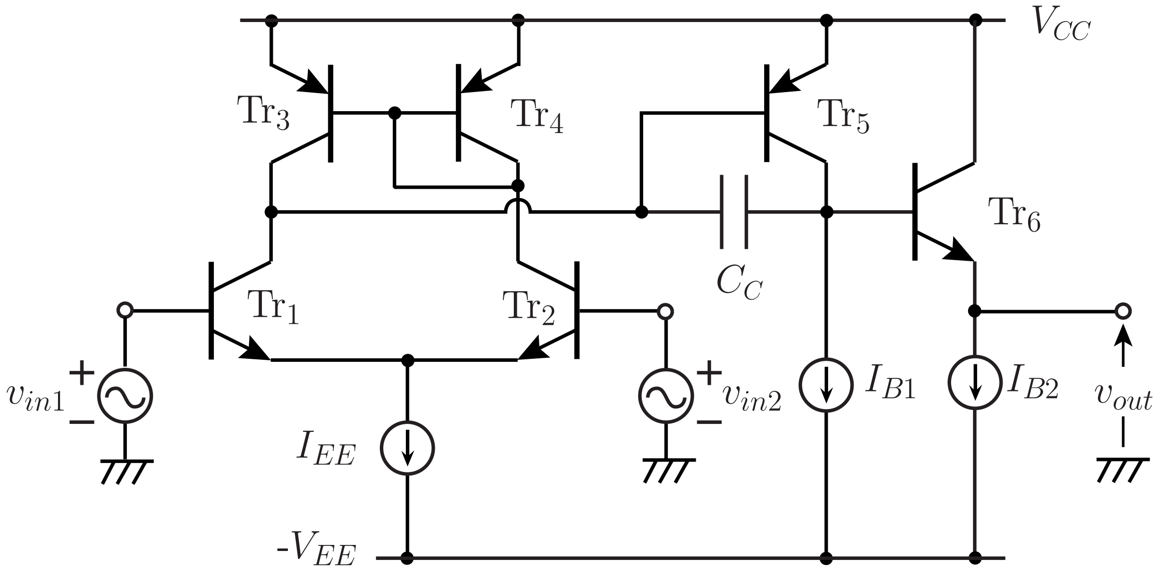


バイポーラトランジスタ

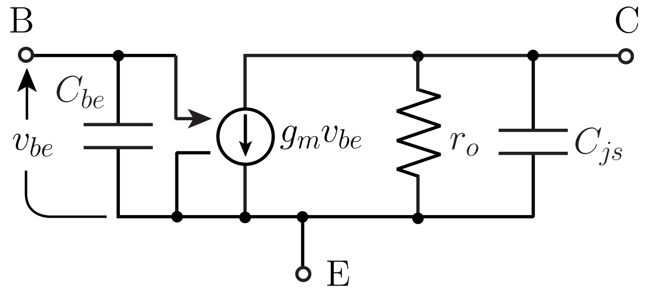


MOSトランジスタ

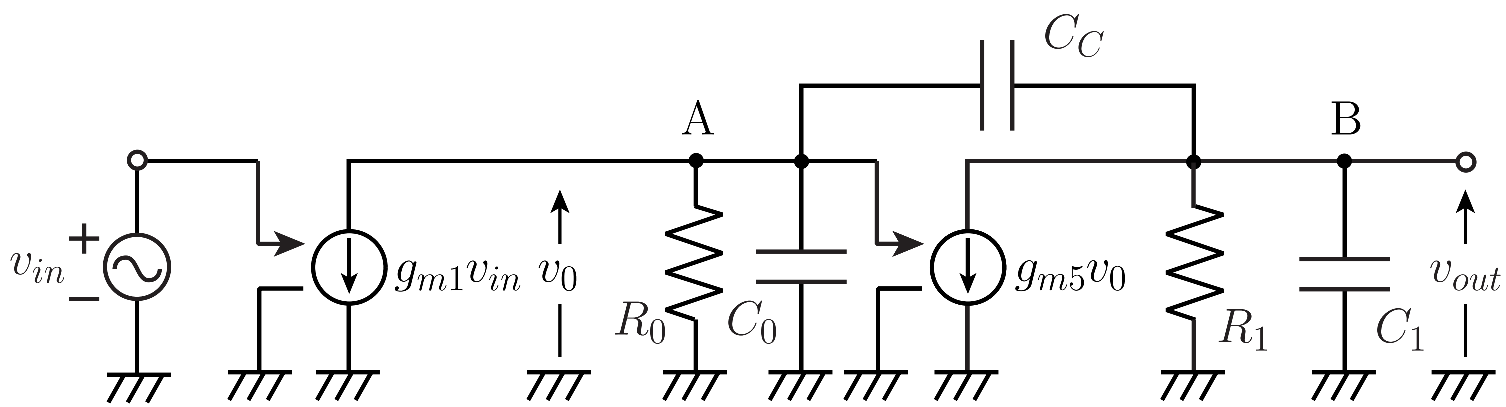
演算増幅器の等価回路



V_{CC}
Tr_3
Tr_4
Tr_5
Tr_6
C_C
Tr_1
Tr_2
v_{in1}
v_{in2}
I_{EE}
I_{B1}
I_{B2}
v_{out}
$-V_{EE}$

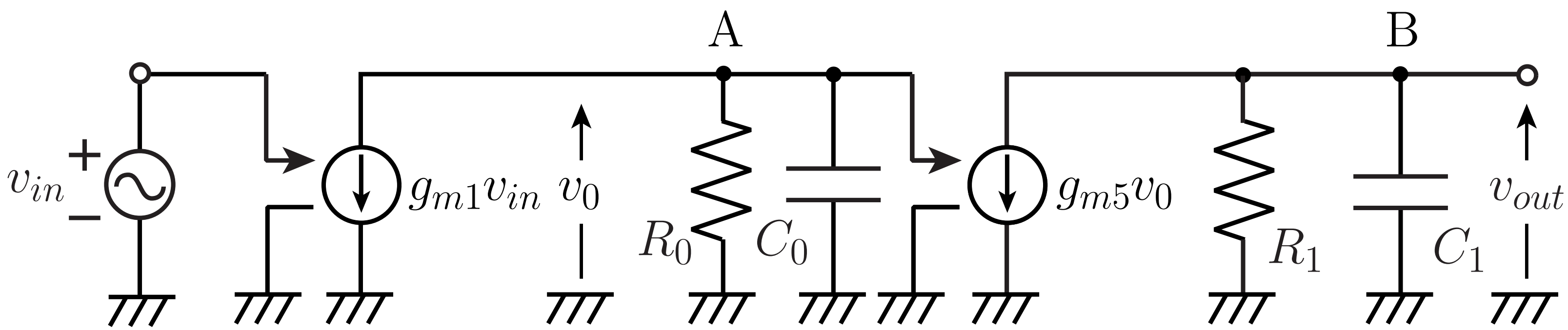


B
C
C_{be}
v_{be}
$g_m v_{be}$
r_o
C_{js}
E



C_C
A
B
v_{in}
$g_{m1}v_{in}$
v_0
R_0
C_0
$g_{m5}v_0$
R_1
C_1
v_{out}

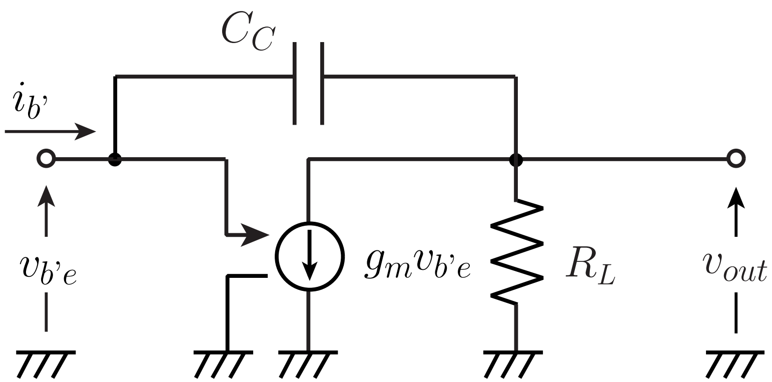
$C_C = 0$のとき（零時定数解析）



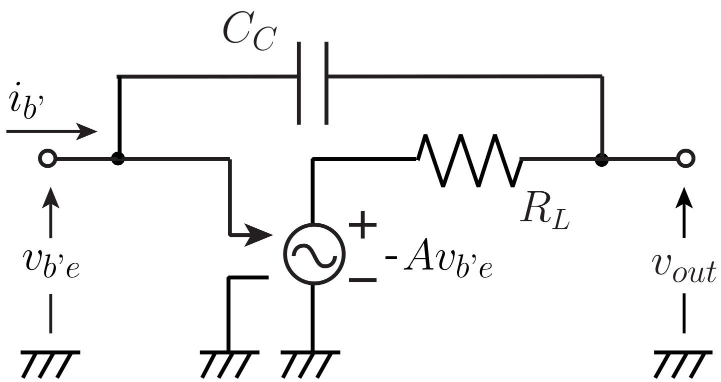
$$\tau_A = C_0 R_0$$

$$\tau_B = C_1 R_1$$

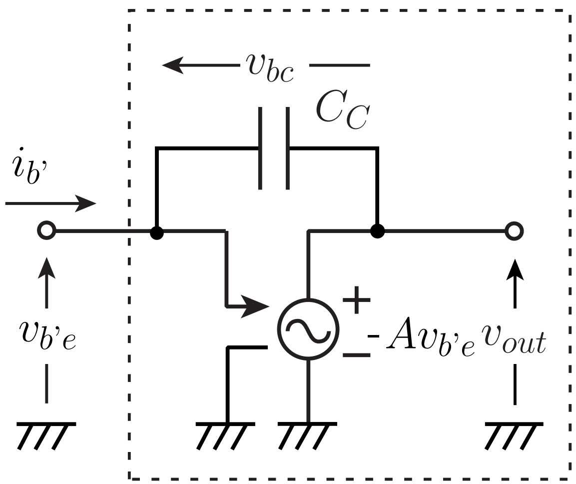
$C_C \neq 0$のとき（零時定数解析）



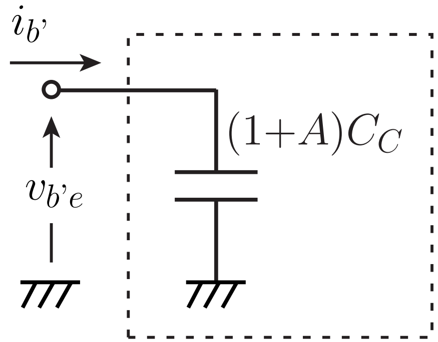
(a)



(b)

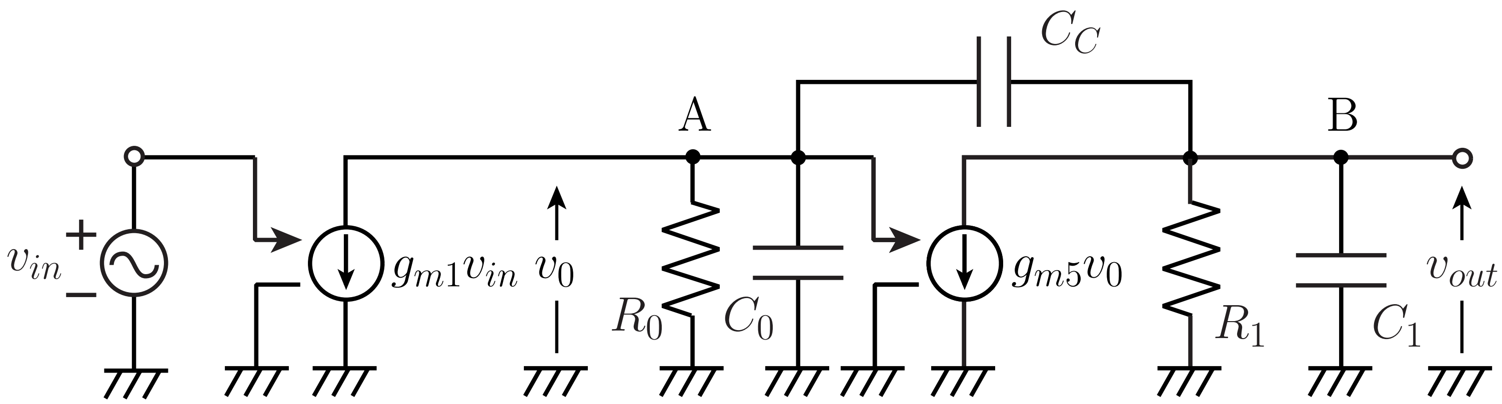


(c)



(d)

$C_C \neq 0$のとき（零時定数解析）

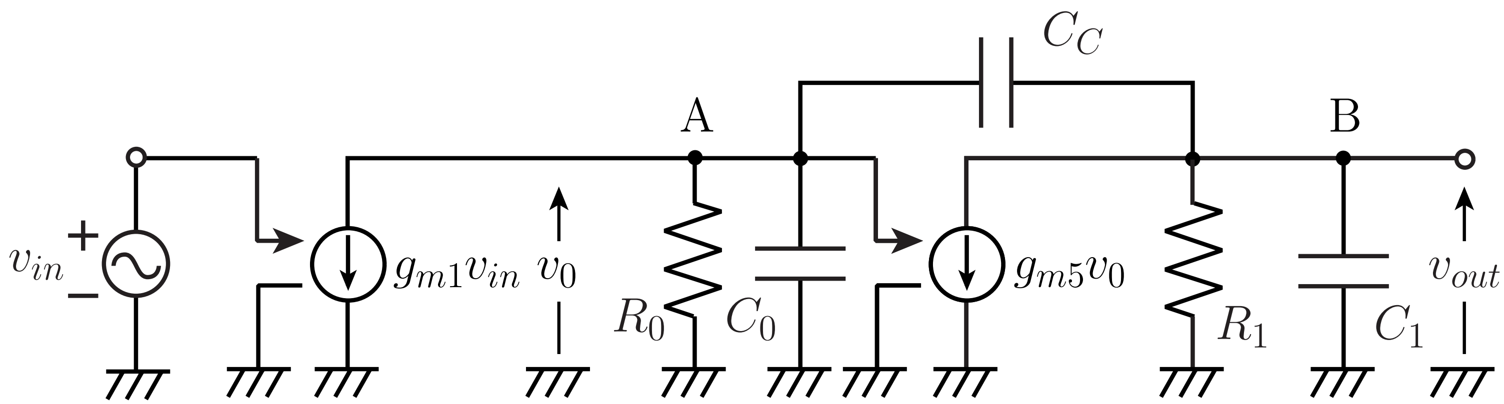


$$\tau_A' = \{C_0 + C_C(1 + g_{m5}R_1)\}R_0$$

$$R_{fb} = \frac{1}{\dfrac{C_C}{C_0 + C_C} g_{m5}} = \frac{C_0 + C_C}{C_C g_{m5}}$$

$$\tau'_B = \left(C_1 + \frac{C_0 C_C}{C_0 + C_C}\right) \frac{R_1 R_{fb}}{R_1 + R_{fb}}$$

差動利得の解析



$$A_d = \frac{g_{m1}R_0R_1(g_{m5} - sC_C)}{D_{Ad}(s)}$$

$$D(j\omega) = 1 + s\{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1\}$$
$$+ s^2(C_CC_0 + C_0C_1 + C_1C_C)R_0R_1$$

$$A_d = A_{d0}\frac{1-\frac{s}{z_1}}{(1-\frac{s}{p_1})(1-\frac{s}{p_2})} \approx A_{d0}\frac{1-\frac{s}{z_1}}{1-\frac{s}{p_1}+\frac{s^2}{p_1 p_2}}$$

$$A_d = \frac{g_{m1}R_0R_1(g_{m5}-sC_C)}{D_{Ad}(s)}$$

$$D(j\omega) = 1 + s\{C_C(R_0+R_1+g_{m5}R_0R_1)+C_0R_0+C_1R_1\}$$
$$+s^2(C_CC_0+C_0C_1+C_1C_C)R_0R_1$$

$$A_d = \frac{g_{m1}R_0R_1(g_{m5} - sC_C)}{D_{Ad}(s)}$$

$$D_{Ad}(s) = 1 + s\{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1\} + s^2(C_CC_0 + C_0C_1 + C_1C_C)R_0R_1$$

$$A_{d0} = g_{m1}R_0R_1g_{m5}$$

$$z_1 = \frac{g_{m5}}{C_C}$$

$$p_1 = \frac{-1}{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1}$$

$$p_2 = \frac{-\{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1\}}{(C_CC_0 + C_0C_1 + C_1C_C)R_0R_1}$$

零時定数と極の比較

$$p_1 = \frac{-1}{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1} \approx \frac{-1}{C_C g_{m5} R_0 R_1}$$

$$\tau_A{}' = \{C_0 + C_C(1 + g_{m5}R_1)\}R_0 \approx C_C g_{m5} R_0 R_1$$

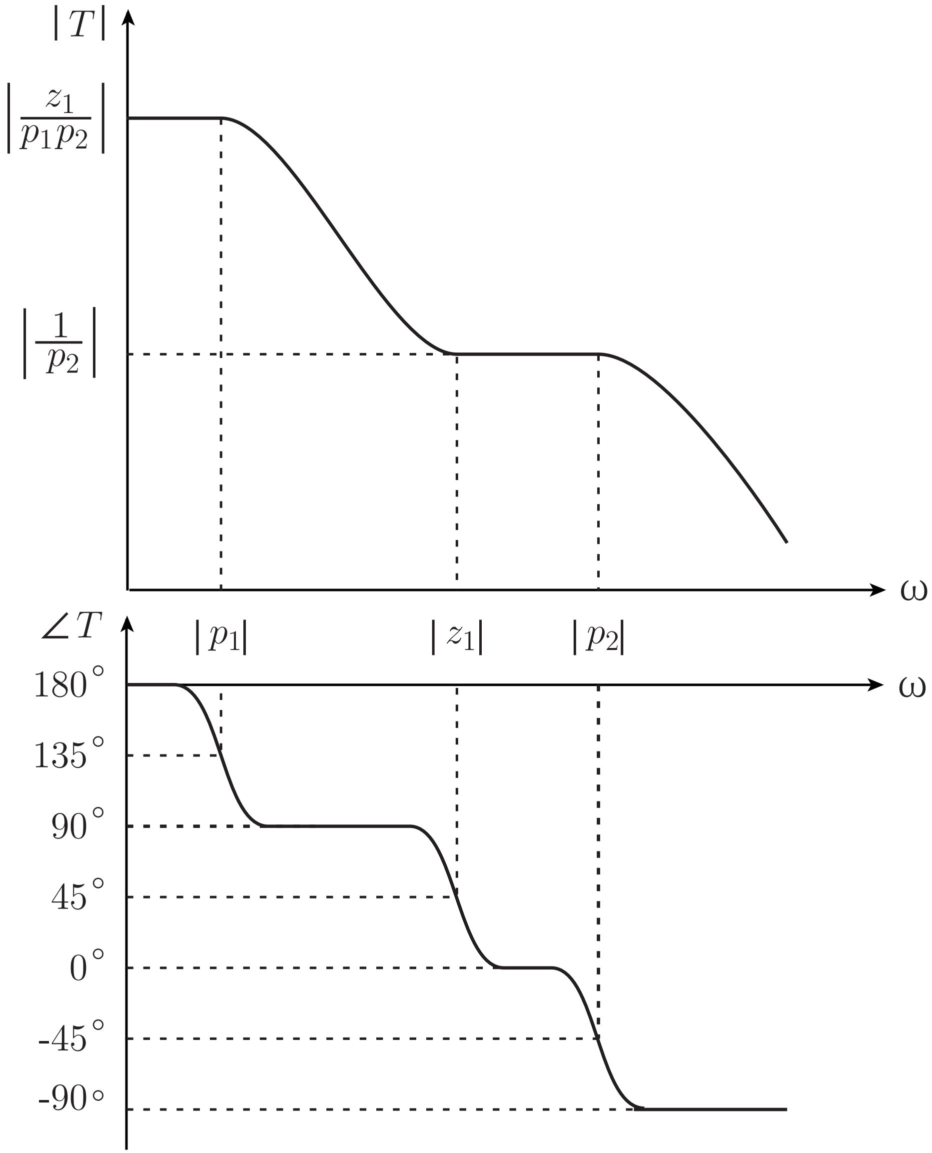
$$p_2 = \frac{-\{C_C(R_0 + R_1 + g_{m5}R_0R_1) + C_0R_0 + C_1R_1\}}{(C_CC_0 + C_0C_1 + C_1C_C)R_0R_1} \approx \frac{-g_{m5}}{C_0 + C_1}$$

$$\tau'_B = (C_1 + \frac{C_0C_C}{C_0 + C_C})\frac{R_1R_{fb}}{R_1 + R_{fb}}$$

$$\approx (C_1 + \frac{C_0C_C}{C_0 + C_C})R_{fb} = (\frac{C_1C_0 + C_1C_C + C_0C_C}{C_0 + C_C})\frac{C_0 + C_C}{C_C g_{m5}}$$

$$\approx \frac{C_1 + C_0}{g_{m5}}$$

$$A_{d0} = g_{m1} R_0 R_1 g_{m5} \qquad z_1 = \frac{g_{m5}}{C_C} \qquad p_1 \approx \frac{-1}{C_C g_{m5} R_0 R_1} \qquad p_2 \approx \frac{-g_{m5}}{C_0 + C_1}$$



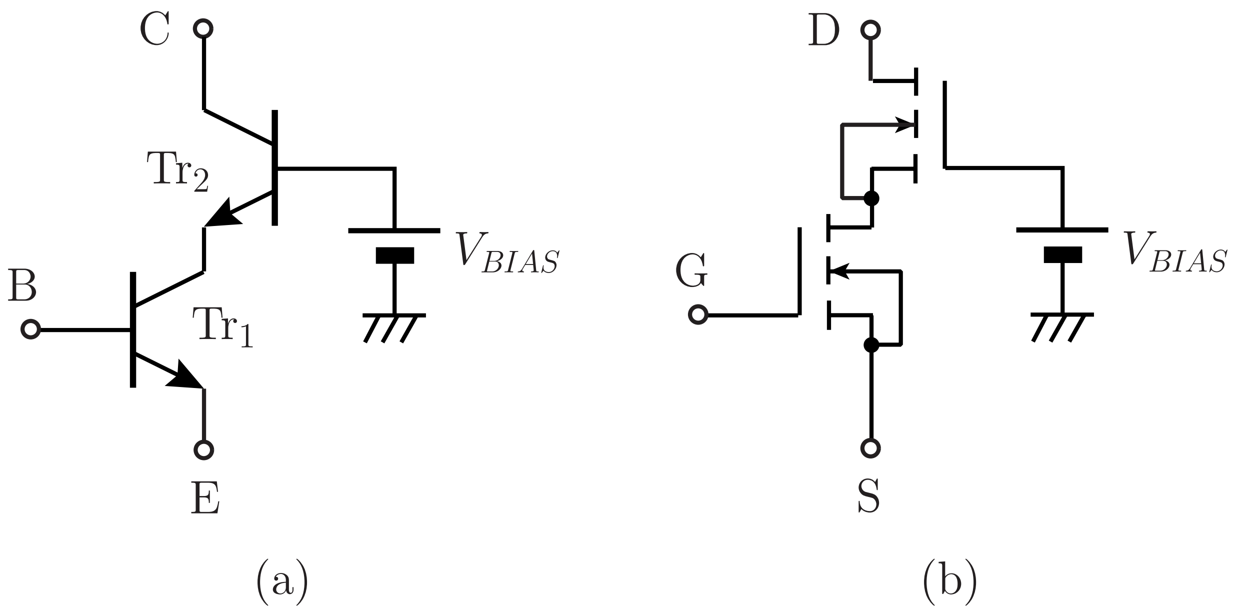
$$A_d = \frac{g_{m1} R_0 R_1 (g_{m5} - sC_C)}{D_{Ad}(s)}$$

$$\downarrow$$

$$A_d = \frac{g_{m1} R_0 R_1 \left(g_{m5} - \dfrac{sC_C}{1 + sC_C R_C}\right)}{D_{Ad}(s)}$$

$$z_1 = \frac{g_{m5}}{C_C(1 - g_{m5} R_C)}$$

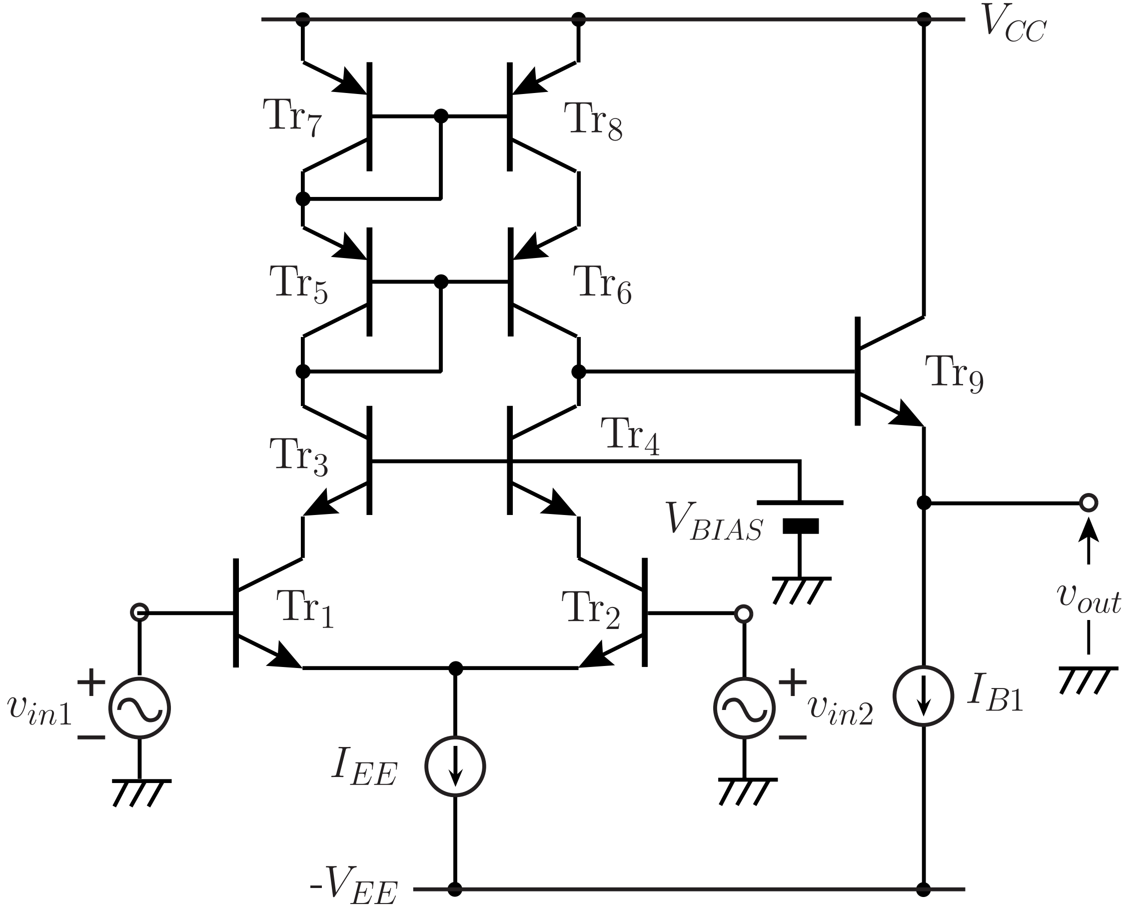
カスコード型演算増幅器



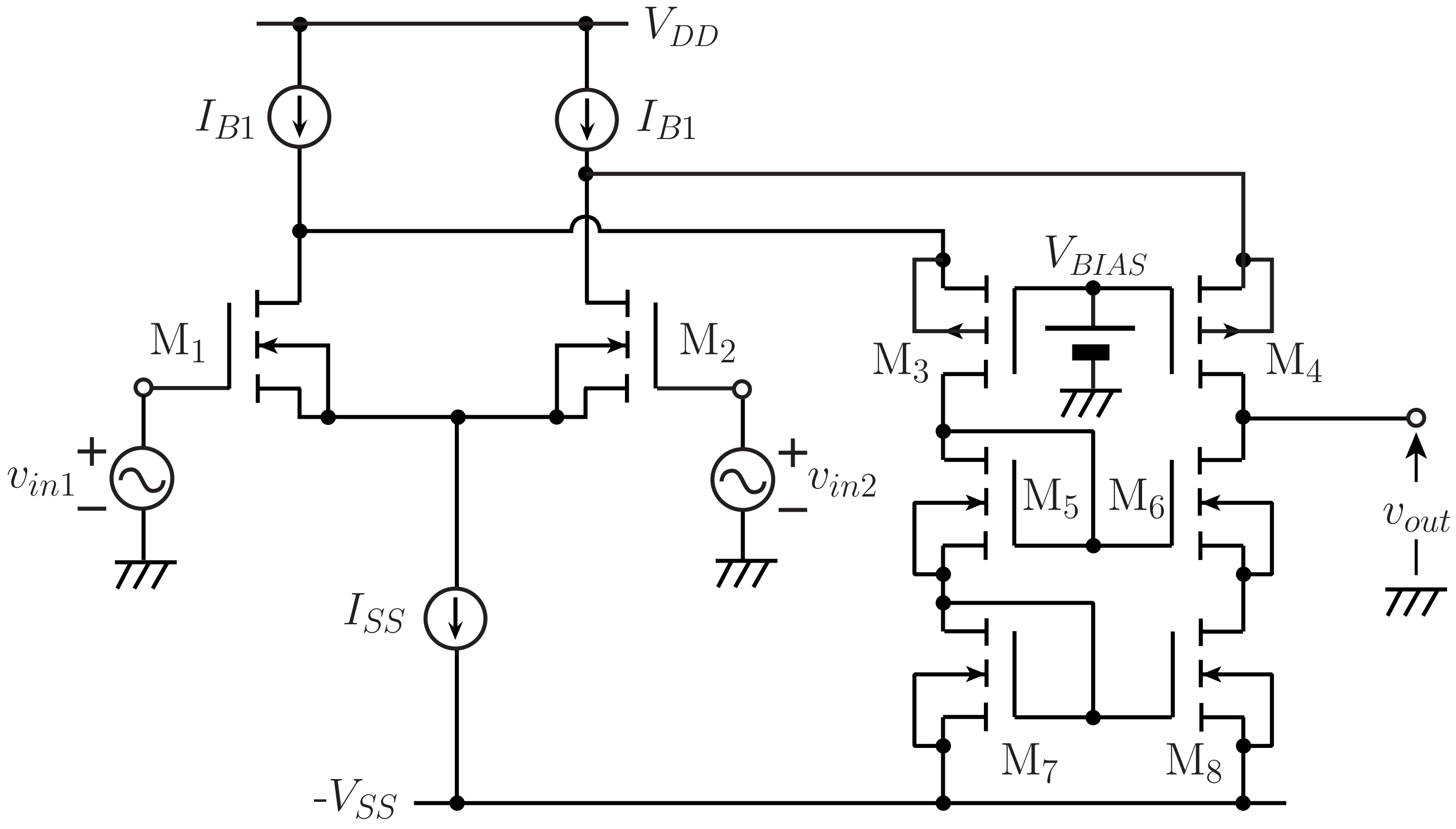
カスコード接続

出力抵抗の増加

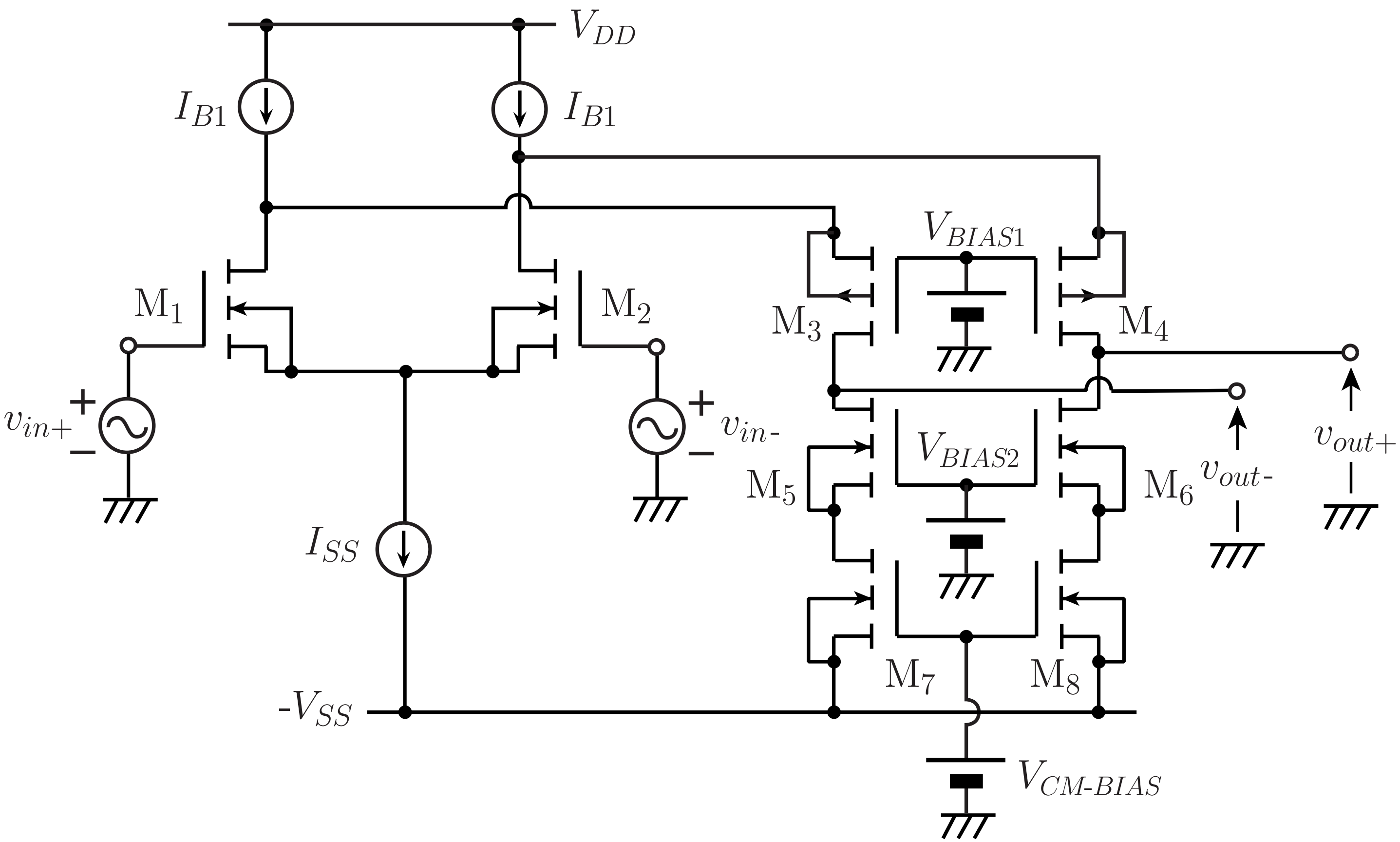
バイポーラトランジスタを用いたカスコード型演算増幅器

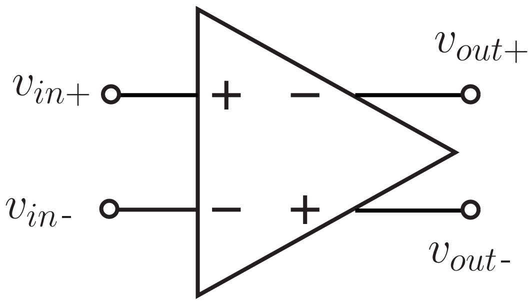


MOSトランジスタを用いたカスコード型演算増幅器

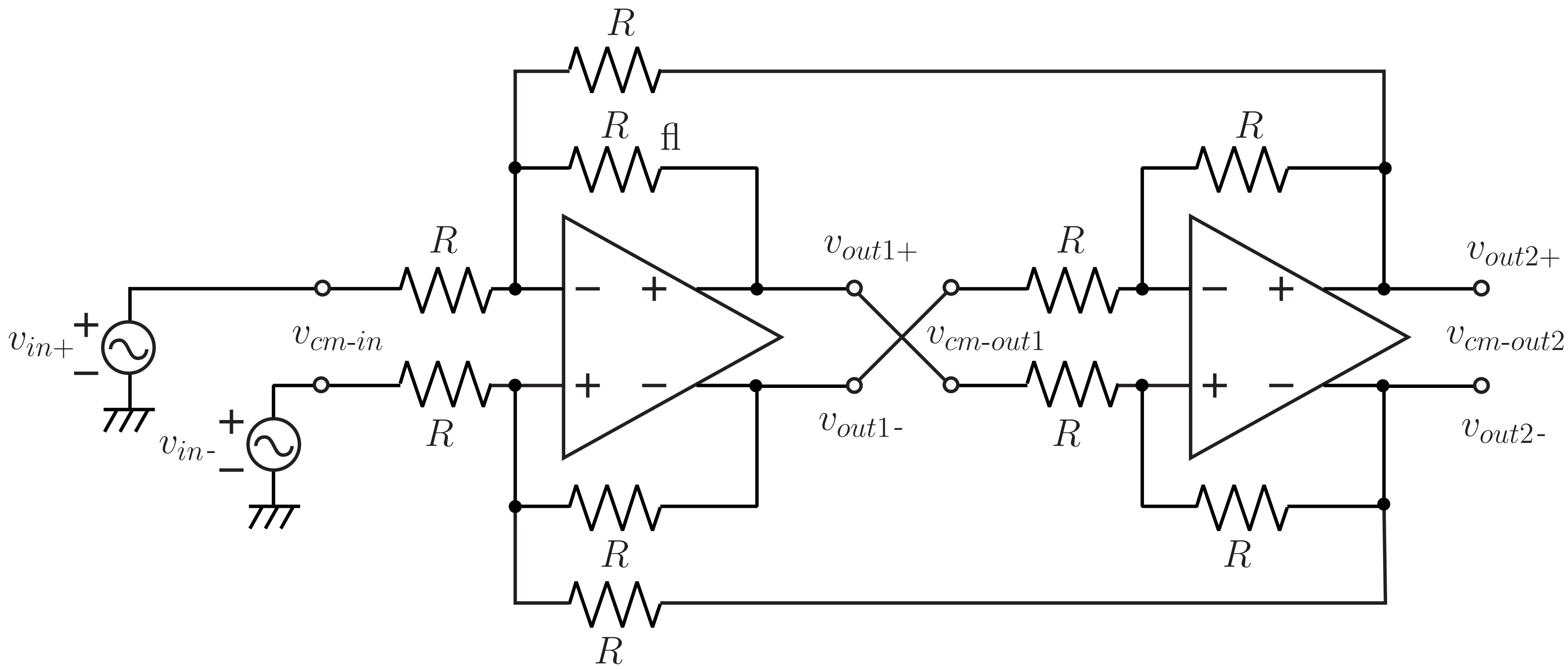


平衡型演算増幅器

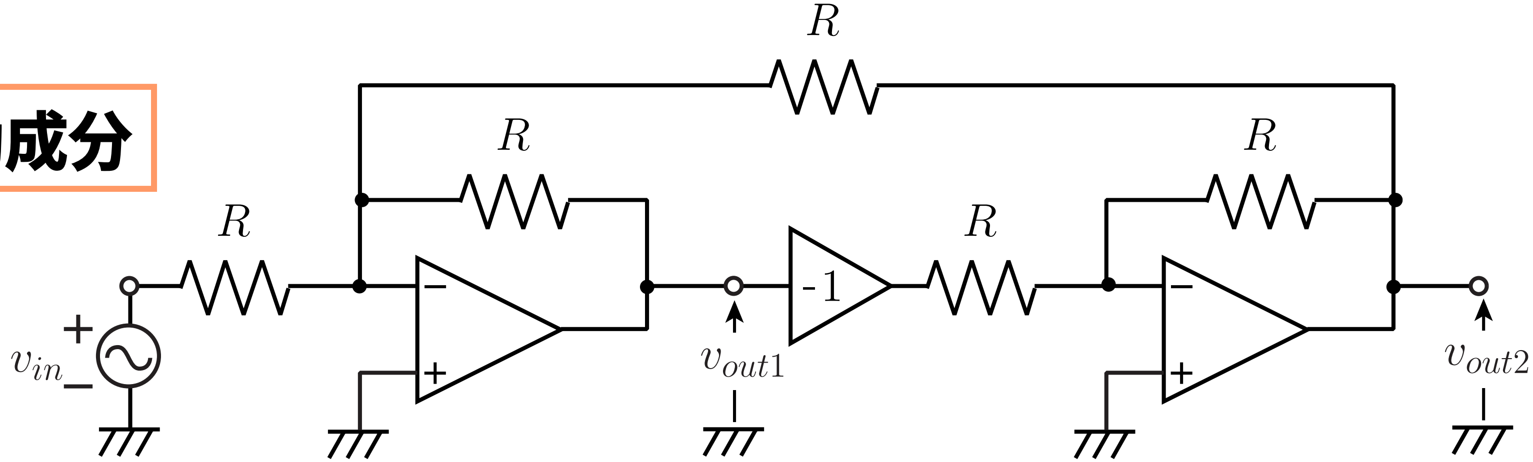

V_{DD}
I_{B1}
I_{B1}
V_{BIAS1}
M_1
M_2
M_3
M_4
v_{in+}
v_{in-}
V_{BIAS2}
M_5
M_6
v_{out-}
v_{out+}
I_{SS}
M_7
M_8
$-V_{SS}$
$V_{CM\text{-}BIAS}$

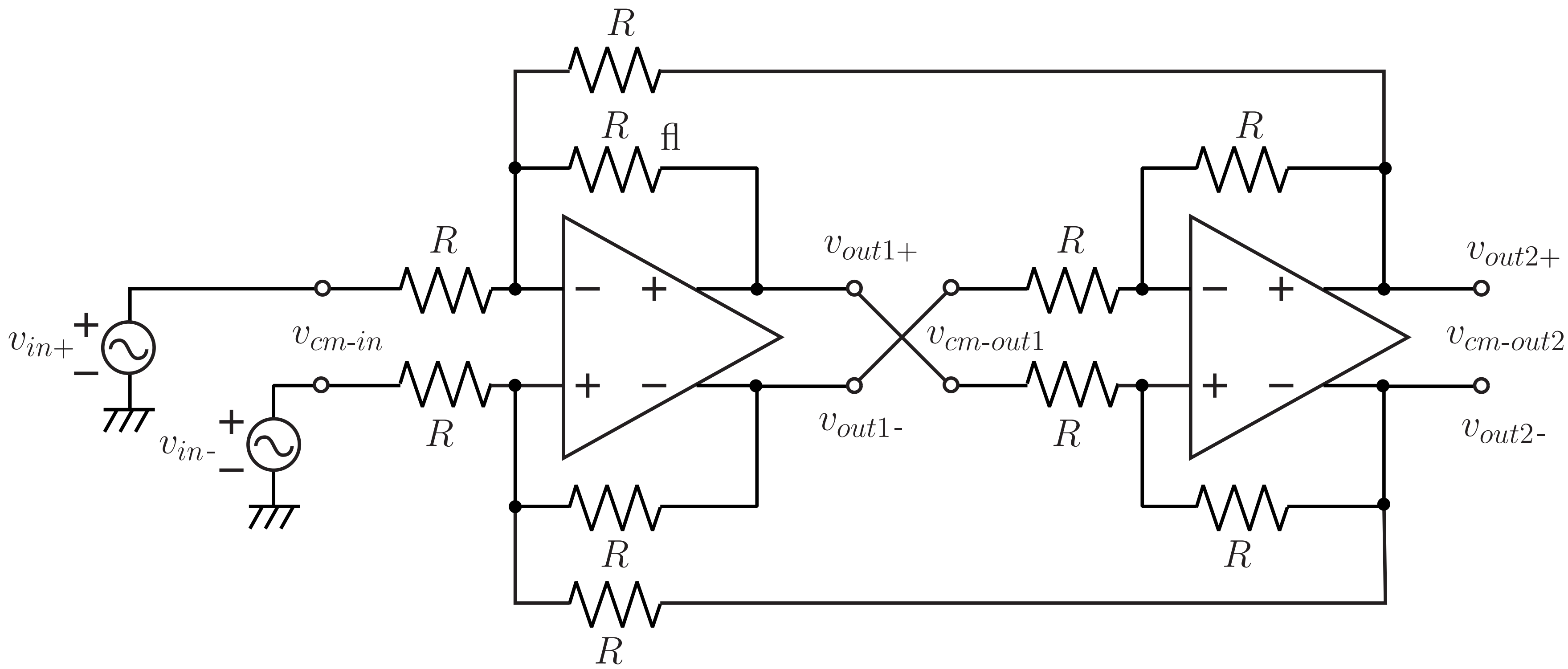

v_{in+}
v_{out+}
v_{in-}
v_{out-}

平衡型回路における同相帰還

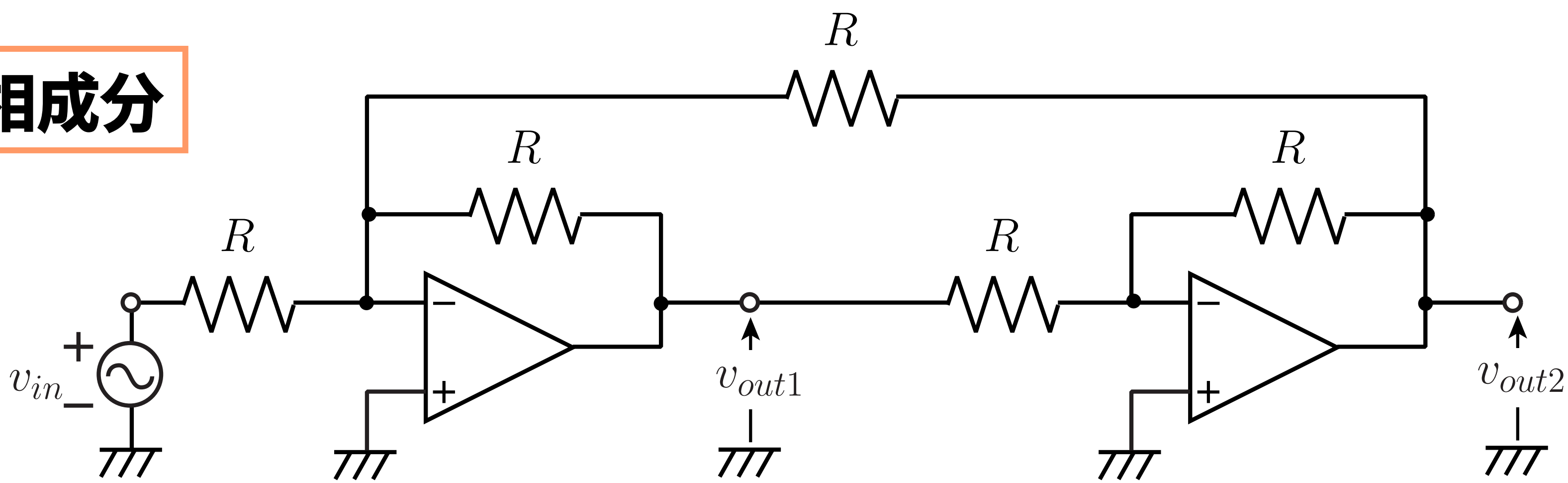


差動成分

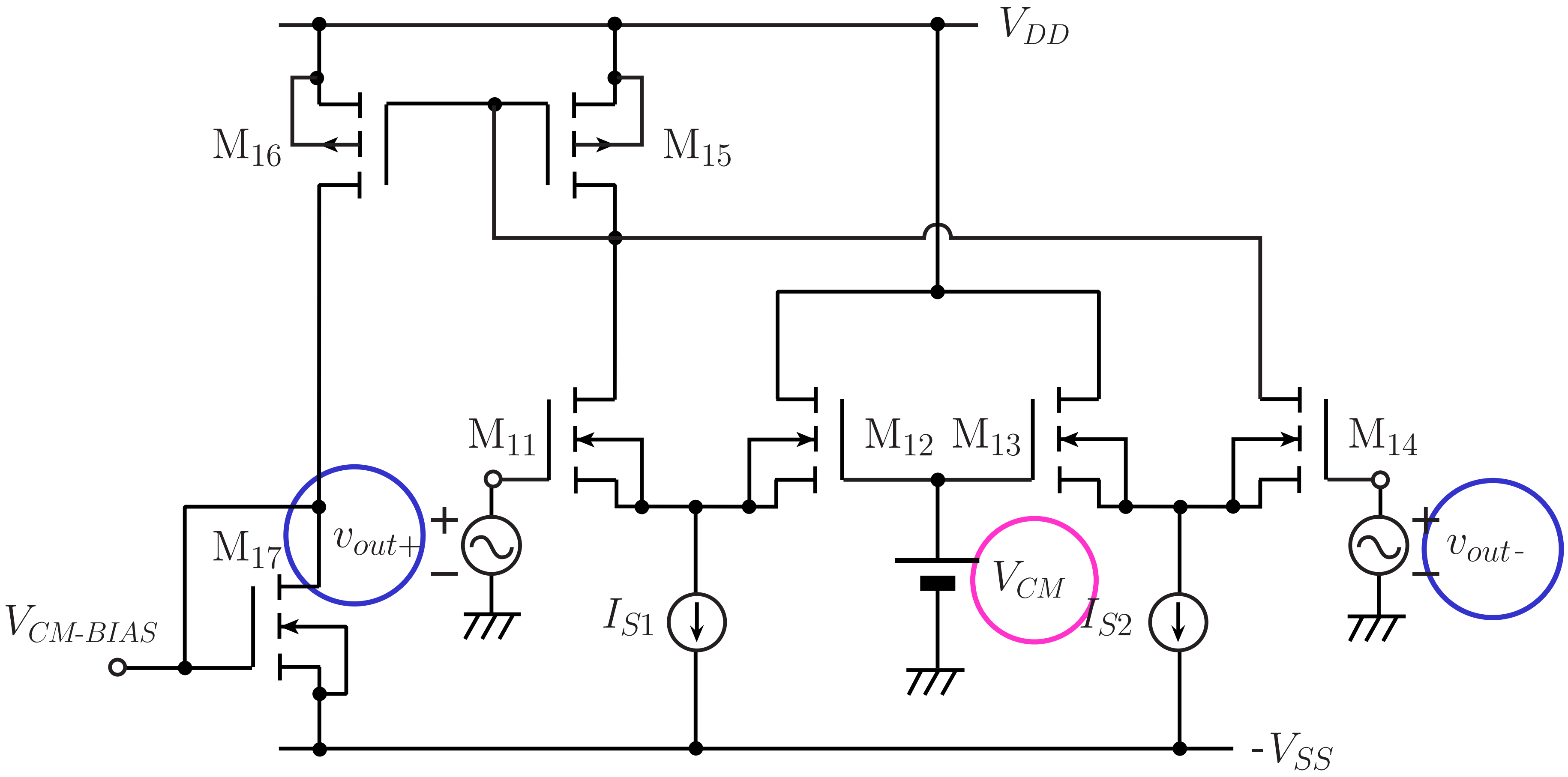



R
R
ﬂ
R
R
R
R
R
R
R
R
R
R
v_{in+}
$v_{in\text{-}}$
$v_{cm\text{-}in}$
v_{out1+}
$v_{out1\text{-}}$
$v_{cm\text{-}out1}$
v_{out2+}
$v_{out2\text{-}}$
$v_{cm\text{-}out2}$

同相成分


R
R
R
R
R
v_{in}
v_{out1}
v_{out2}

バイアスの安定化



VDD
M16
M15
M11
M12
M13
M14
M17
vout+
vout-
VCM
VCM-BIAS
IS1
IS2
-VSS

平衡型演算増幅器 (全回路)