低雑音増幅回路

通信機器システムの要

雑音の評価

雑音の定式化

瞬時値での評価→困難（不可）

↓

統計的な評価

2乗平均値：$\overline{v_n{}^2} = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} v_n{}^2(t)\,dt$

複数の雑音源の取り扱い

$$\lim_{T\to\infty}\left[\frac{1}{T}\int_{-T/2}^{T/2}\{v_{n1}(t)+v_{n2}(t)\}^2 dt\right]$$

$$=\lim_{T\to\infty}\left[\frac{1}{T}\left\{\int_{-T/2}^{T/2} {v_{n1}}^2(t)+2v_{n1}(t)v_{n2}(t)+{v_{n2}}^2(t)dt\right\}\right]$$

$$=\overline{{v_{n1}}^2}+\lim_{T\to\infty}\frac{2}{T}\underline{\underline{\int_{-T/2}^{T/2} v_{n1}(t)v_{n2}(t)dt}}+\overline{{v_{n2}}^2}$$

$v_{n1}(t)$と$v_{n2}(t)$が全く独立：無相関

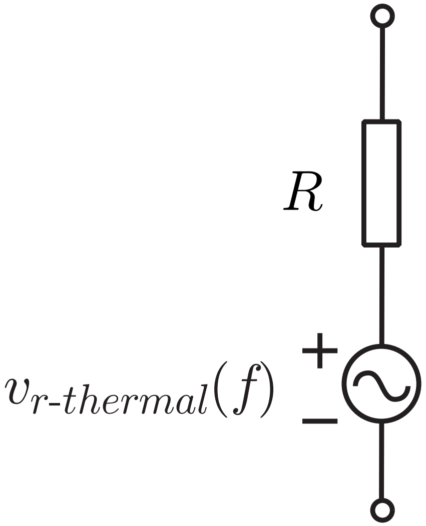
$$\int_0^{\tau} v_{n1}(t)v_{n2}(t)dt=0$$

雑音源を考慮した回路素子モデル

熱雑音，1/f雑音，ショット雑音

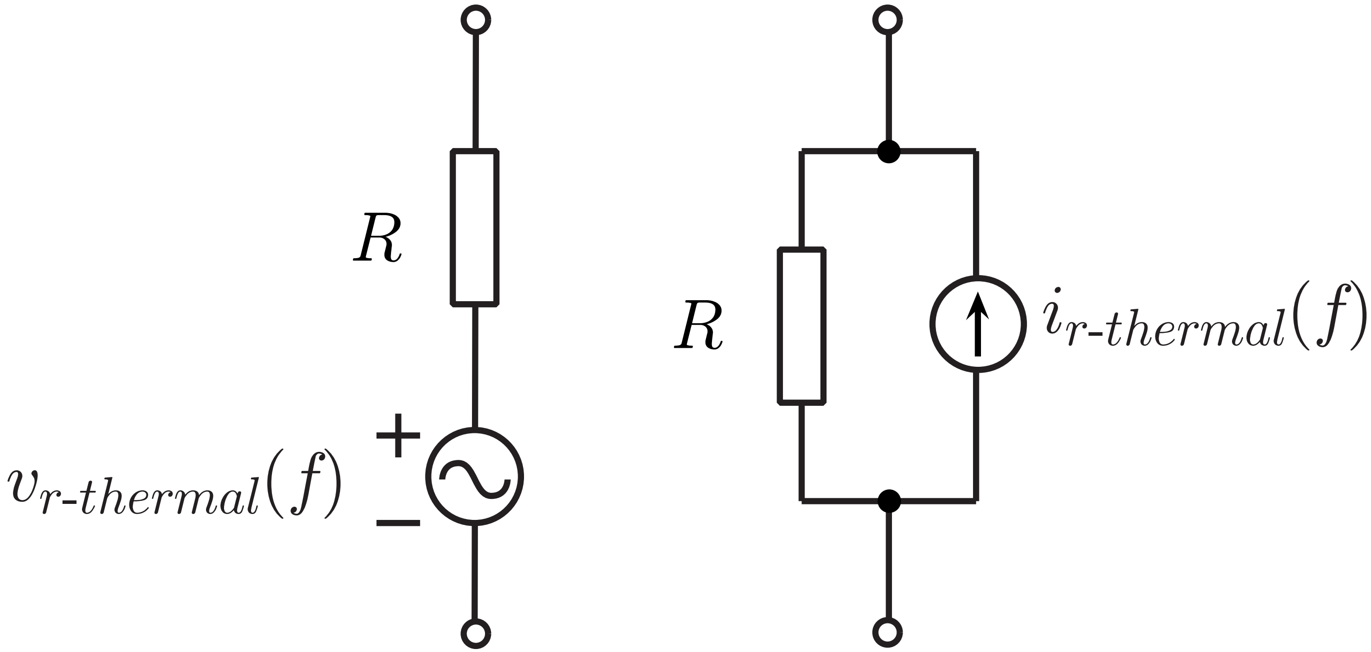
熱雑音：キャリアが移動する際のランダムな動きによって
生じる雑音

抵抗の熱雑音



$$\overline{v_{r-thermal}{}^2(f)} = 4kTR\,[\mathrm{V}^2/\mathrm{Hz}]$$

問　「電源の等価性」の定理を用いて
下記に示す抵抗の等価回路の雑音を
表している電流源の値を求めよ.



(a)　(b)

$$\overline{v_{r-thermal}}^{2}(f) = 4kTR[\mathrm{V}^2/\mathrm{Hz}]$$

MOSトランジスタの熱雑音

キャリアがチャネルを通過する際に発生

$$\overline{v_{mos-thermal}{}^2} = 4kT\gamma_n \frac{1}{g_m}$$

$$\overline{i_{mos-thermal}{}^2} = 4kT\gamma_n g_m$$

$\gamma_n \approx \dfrac{2}{3}$ （最小線幅が短くなると増加）

バイポーラトランジスタの熱雑音

ベース広がり抵抗： $\overline{v_{b-thermal}(f)^2} = 4kTr_b$

エミッタ抵抗，コレクタ・エミッタ間抵抗：仮想の抵抗

↓

熱雑音の発生無し

スペクトラム強度が一定：白色雑音

1/f雑音：シリコンの汚れや結晶欠陥によりキャリアが
捕らわれたり，捕らわれたキャリアが離されたりを
繰り返すというランダムな過程によって生じる雑音

直流電流がないと発生しない

$$\overline{v_{mos-1/f}^{\,2}(f)} = \frac{\alpha_{1/f}}{C_{OX} W L f}$$

$$\overline{i_{b-1/f}^{\,2}(f)} = \frac{K_{1/f} I_B{}^{a}}{f}$$

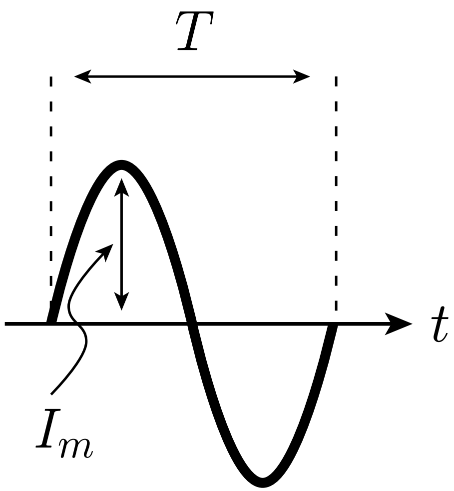
ショット雑音：

電流＝キャリアによる電流パルスの和の平均値

電流の平均値からの揺らぎ

$$\overline{i_{b-shot}^{\,2}}(f)=2qI_B$$

$$\overline{i_{c-shot}^{\,2}}(f)=2qI_C$$



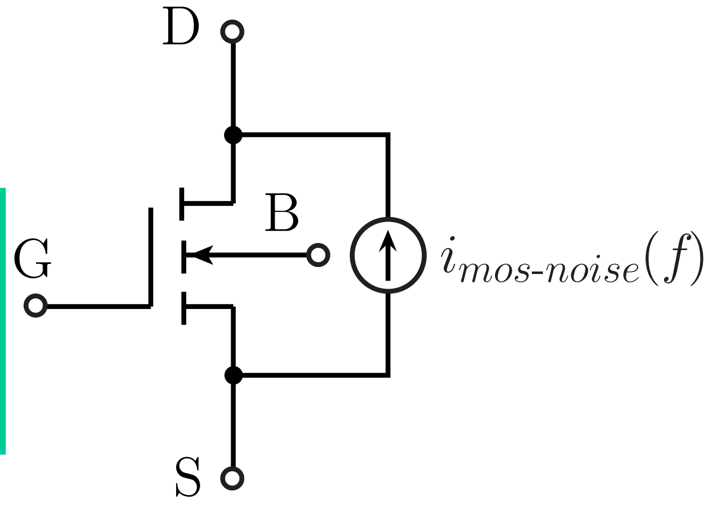
$$Q=\int_0^{T/2} I_m \sin(2\pi\frac{t}{T})=\frac{I_m T}{\pi}$$

1nA@1GHz→1.6×10^{-19}C×2個

雑音源を含むトランジスタモデル

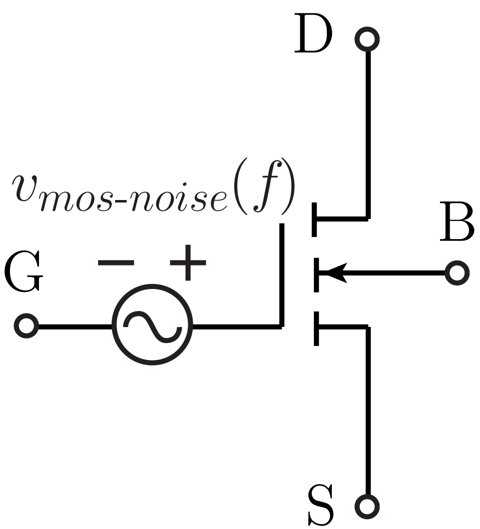
MOSトランジスタモデル

$$\overline{i_{mos\text{–}noise}^{\,2}(f)} = 4kT\gamma_n g_m + \frac{\alpha_{1/f}\, {g_m}^2}{C_{OX} W L f}$$



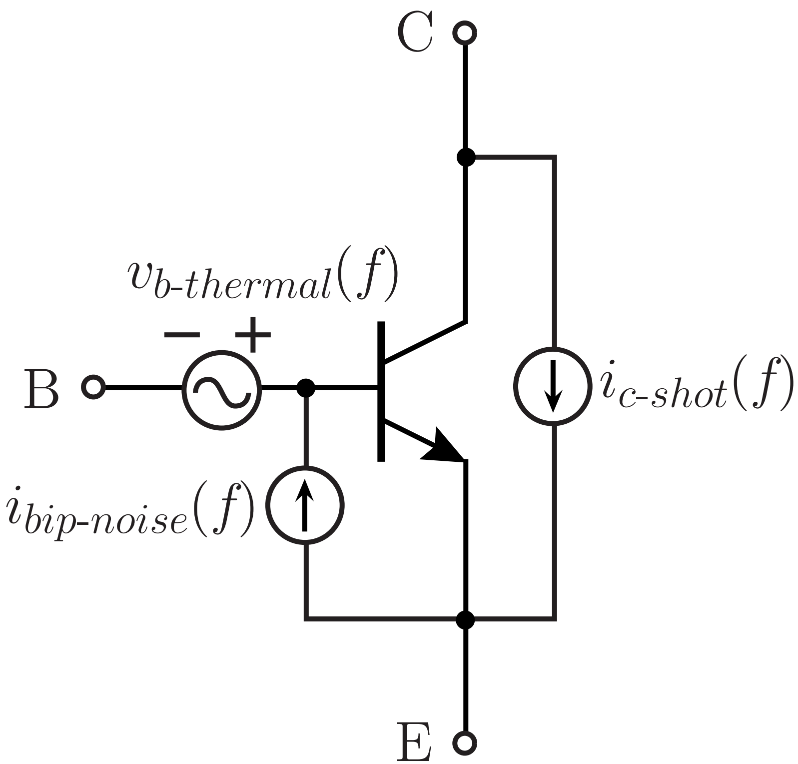
(a)

$$\overline{v_{mos\text{–}noise}^{\,2}(f)} = 4kT\gamma_n \frac{1}{g_m} + \frac{\alpha_{1/f}}{C_{OX} W L f}$$



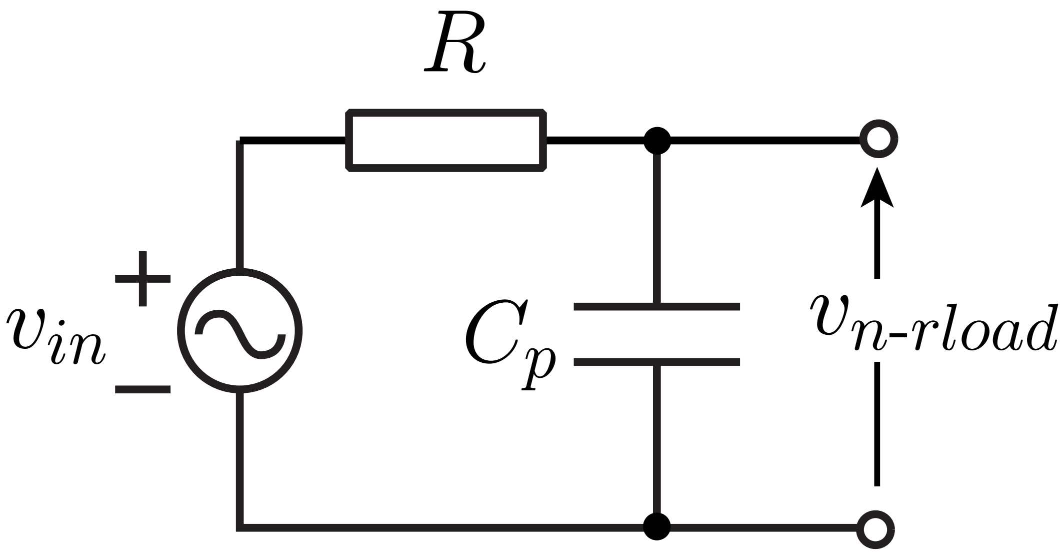
(b)

バイポーラトランジスタモデル



$$\overline{{i_{bip-noise}}^2(f)}=\frac{K_{1/f}{I_B}^a}{f}+2qI_B$$

雑音解析の例(抵抗が発生する雑音)

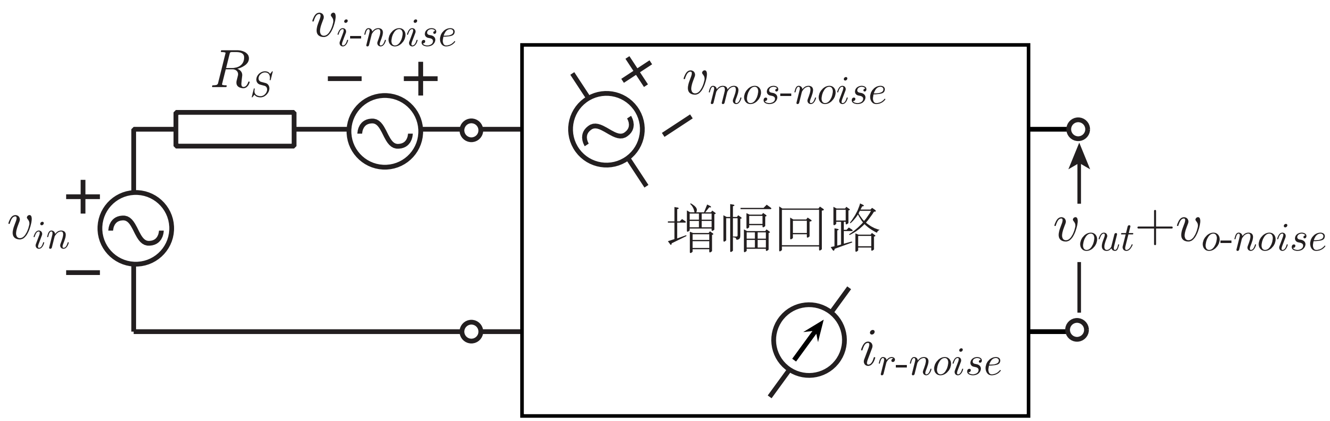


問１　上の回路の伝達関数$T_{rload}(s)=\dfrac{v_{n-rload}}{\sqrt{4kTR}}$を求めよ.

問２　$\overline{v_{n-rload}}^{2}=\int_0^{\infty}\left|T_{rload}(j\omega)\right|^2\dfrac{4kTR}{2\pi}d\omega$を求めよ.

増幅回路と雑音

雑音係数と雑音指数

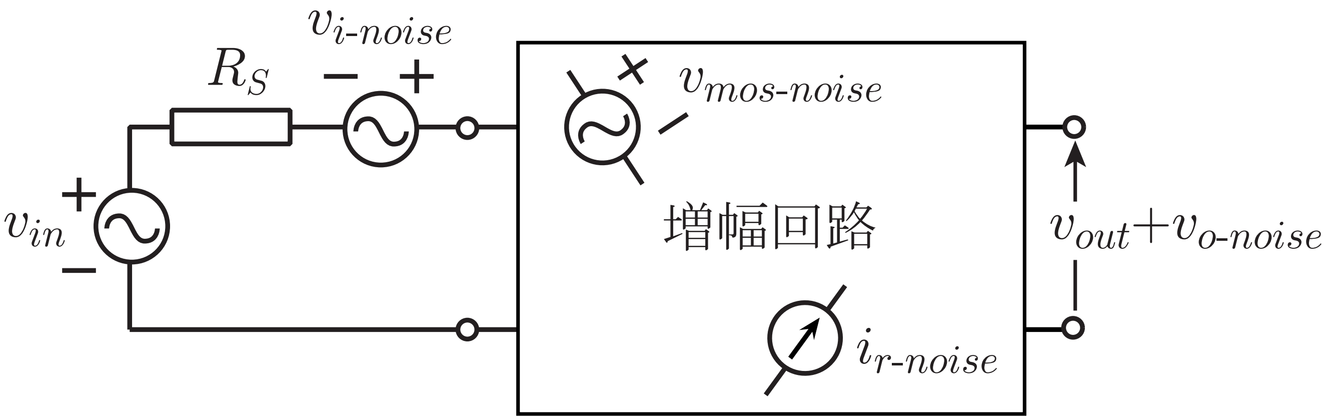


$$SNR_{in}=\frac{\overline{v_{in}{}^2}}{\overline{v_{i-noise}{}^2}}$$

$$SNR_{out}=\frac{A^2\overline{v_{in}{}^2}}{\overline{v_{o-noise}{}^2}}$$

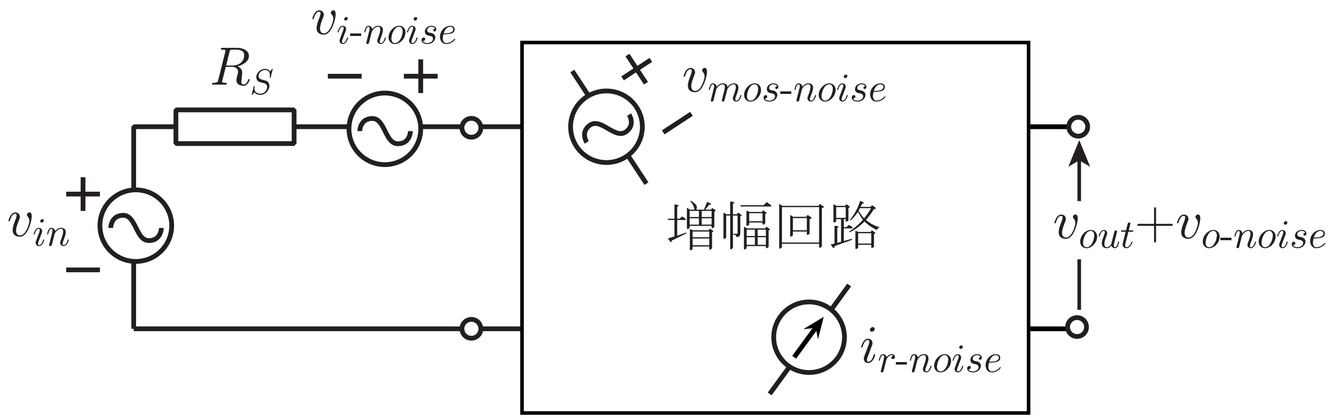
$$F=\frac{SNR_{in}}{SNR_{out}}$$: 雑音係数

$NF=10\log F$: 雑音指数



$$\overline{v_{o-noise}^{\ 2}}=A^2\,\overline{v_{i-noise}^{\ 2}}+\overline{v_{inner-noise}^{\ 2}}$$

$v_{mos-noise}$や$i_{r-noise}$などの増幅回路内部の雑音に起因する成分



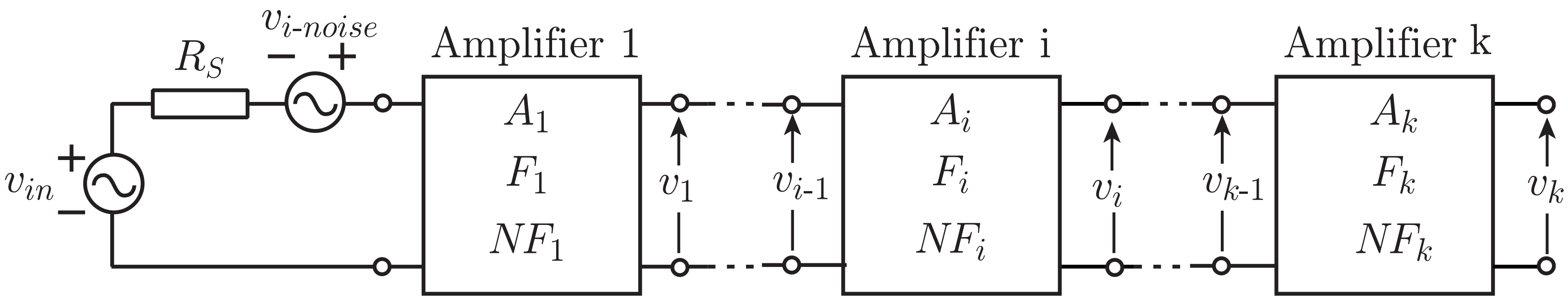
$$\overline{v_{o-noise}^{\,2}}=A^2\,\overline{v_{i-noise}^{\,2}}+\overline{v_{inner-noise}^{\,2}}$$

$$SNR_{out}=\frac{A^2\,\overline{v_{in}^{\,2}}}{\overline{v_{o-noise}^{\,2}}}=\frac{\overline{v_{in}^{\,2}}}{\overline{v_{i-noise}^{\,2}}+\overline{v_{inner-noise}^{\,2}}/A^2}$$

$$SNR_{in}=\frac{\overline{v_{in}^{\,2}}}{\overline{v_{i-noise}^{\,2}}}\geq SNR_{out}$$

$$F=1+\frac{\overline{v_{inner-noise}^{\,2}}}{A^2\,\overline{v_{i-noise}^{\,2}}}$$

縦続接続型システムの評価

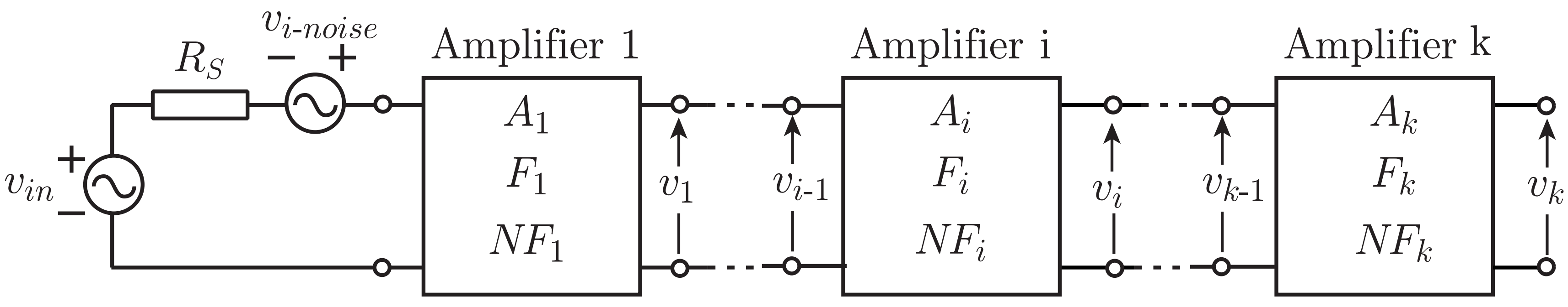


$$v_i = v_{S,i} + v_{N,i}$$

$$\overline{v_{o-noise}^{\,2}} = A^2\,\overline{v_{i-noise}^{\,2}} + \overline{v_{inner-noise}^{\,2}}$$

$$F = 1 + \frac{\overline{v_{inner-noise}^{\,2}}}{A^2\,\overline{v_{i-noise}^{\,2}}}$$

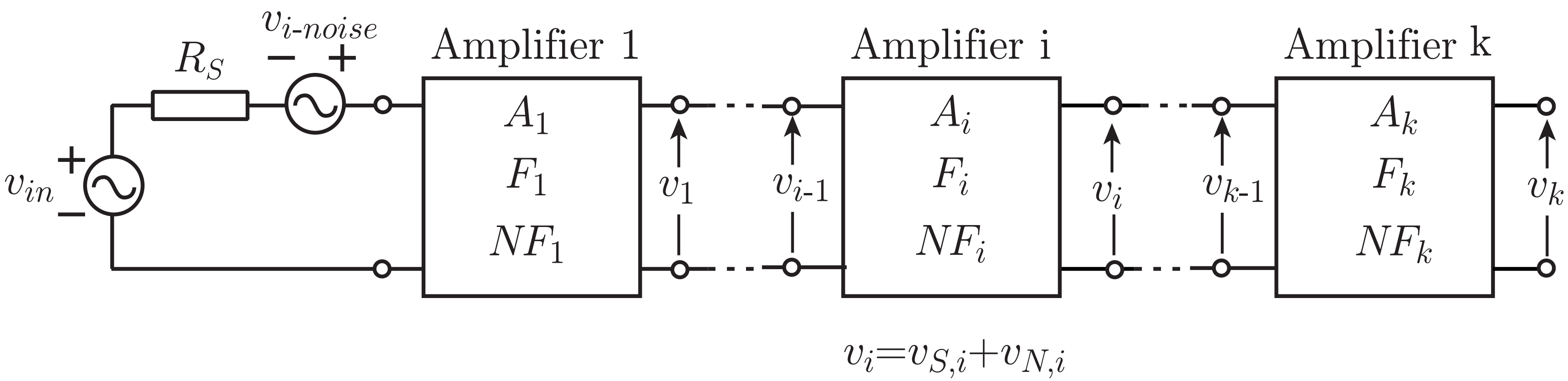
$$\overline{v_{N,i}^{\,2}} = A_i^{\,2} F_i\,\overline{v_{N,i-1}^{\,2}}$$



$$v_i = v_{S,i} + v_{N,i}$$

$$\overline{v_{N,i}^{\;2}} = A_i^{\,2} F_i \overline{v_{N,i-1}^{\;2}} \qquad \overline{v_{S,i}^{\;2}} = A_i^{\,2} \overline{v_{S,i-1}^{\;2}}$$

$$F_{total} = \frac{\dfrac{\overline{v_{in}^{\;2}}}{\overline{v_{i-noise}^{\;2}}}}{\dfrac{\overline{v_{S,k}^{\;2}}}{\overline{v_{N,k}^{\;2}}}} = \frac{\dfrac{\overline{v_{in}^{\;2}}}{\overline{v_{i-noise}^{\;2}}}}{\dfrac{A_1^{\,2} A_2^{\,2} \cdots A_k^{\,2} \overline{v_{in}^{\;2}}}{A_1^{\,2} F_1 A_2^{\,2} F_2 \cdots A_k^{\,2} F_k \overline{v_{i-noise}^{\;2}}}} = \underline{\underline{F_1 F_2 \cdots F_k}}$$



$$\overline{v_{N,i}^{\ 2}} = A_i^{\ 2}\,\overline{v_{N,i-1}^{\ 2}} + \overline{v_{inner-noise,i}^{\ 2}}$$

$$\begin{aligned}\overline{v_{N,k}^{\ 2}} &= A_k^{\ 2} A_{k-1}^{\ 2} \cdots A_1^{\ 2}\,\overline{v_{i-noise}^{\ 2}} \\ &+ A_k^{\ 2} A_{k-1}^{\ 2} \cdots A_2^{\ 2}\,\overline{v_{inner-noise,1}^{\ 2}} \\ &+ A_k^{\ 2} A_{k-1}^{\ 2} \cdots A_3^{\ 2}\,\overline{v_{inner-noise,2}^{\ 2}} + \cdots \\ &+ A_k^{\ 2}\,\overline{v_{inner-noise,k-1}^{\ 2}} + \overline{v_{inner-noise,k}^{\ 2}}\end{aligned}$$

$$\overline{v_{N,k}^2} = A_k^2 A_{k-1}^2 \cdots A_1^2 \overline{v_{i-noise}^2}$$

$$+ A_k^2 A_{k-1}^2 \cdots A_2^2 \overline{v_{inner-noise,1}^2}$$

$$+ A_k^2 A_{k-1}^2 \cdots A_3^2 \overline{v_{inner-noise,2}^2} + \cdots$$

$$+ A_k^2 \overline{v_{inner-noise,k-1}^2} + \overline{v_{inner-noise,k}^2}$$

$$F_{total} = \frac{\overline{v_{in}^2}}{\overline{v_{i-noise}^2}} \cdot \frac{\overline{v_{N,k}^2}}{\overline{v_{S,k}^2}} = 1 + \frac{\overline{v_{inner-noise,1}^2}}{A_1^2 \overline{v_{i-noise}^2}} + \frac{\overline{v_{inner-noise,2}^2}}{A_1^2 A_2^2 \overline{v_{i-noise}^2}}$$

$$+ \cdots + \frac{\overline{v_{inner-noise,k-1}^2}}{A_1^2 A_2^2 \cdots A_{k-1}^2 \overline{v_{i-noise}^2}} + \frac{\overline{v_{inner-noise,k}^2}}{A_1^2 A_2^2 \cdots A_k^2 \overline{v_{i-noise}^2}}$$

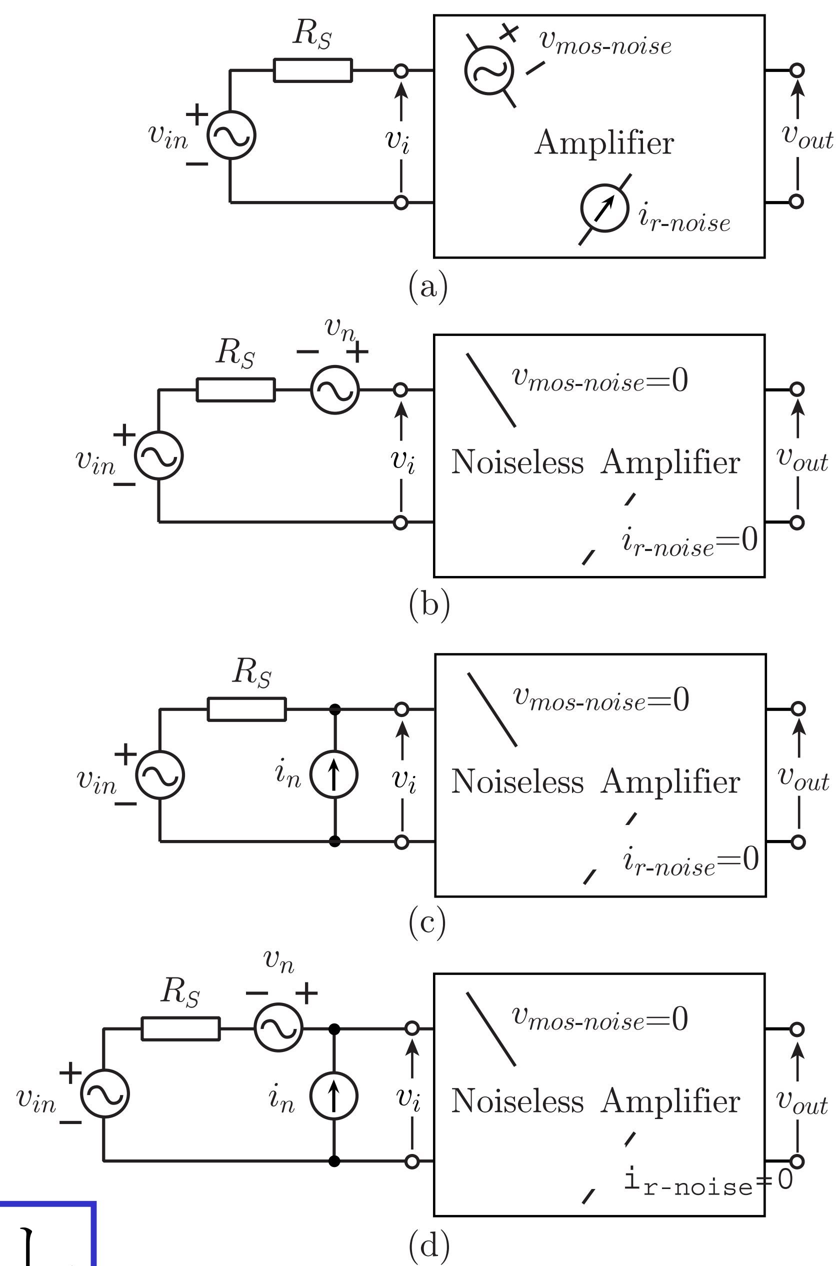
低雑音増幅回路の設計

増幅回路内部で発生する雑音の等価表現

(b): R_Sが無限大のとき矛盾

(c): R_Sが零のとき矛盾

(d): 任意のR_Sについて矛盾無し

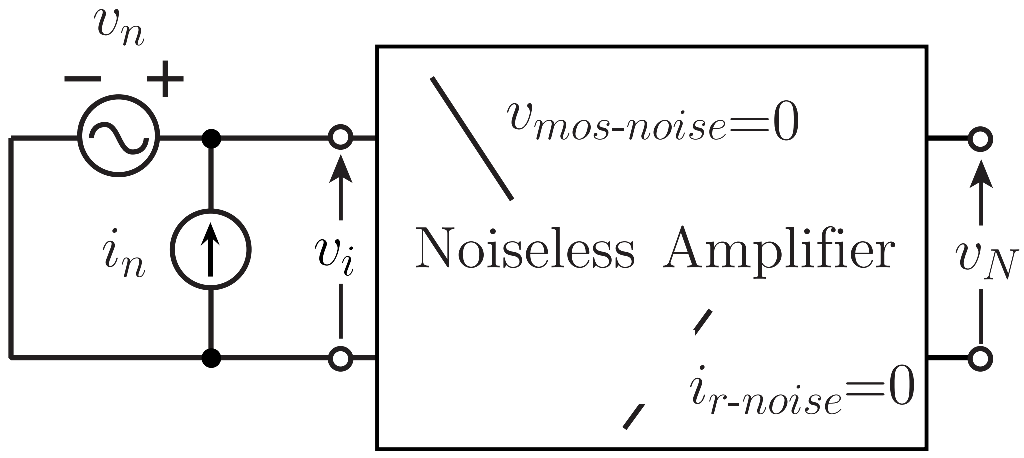


増幅回路の出力雑音のみ考慮

v_nの求め方

$$v_n = \frac{v_N}{A}$$

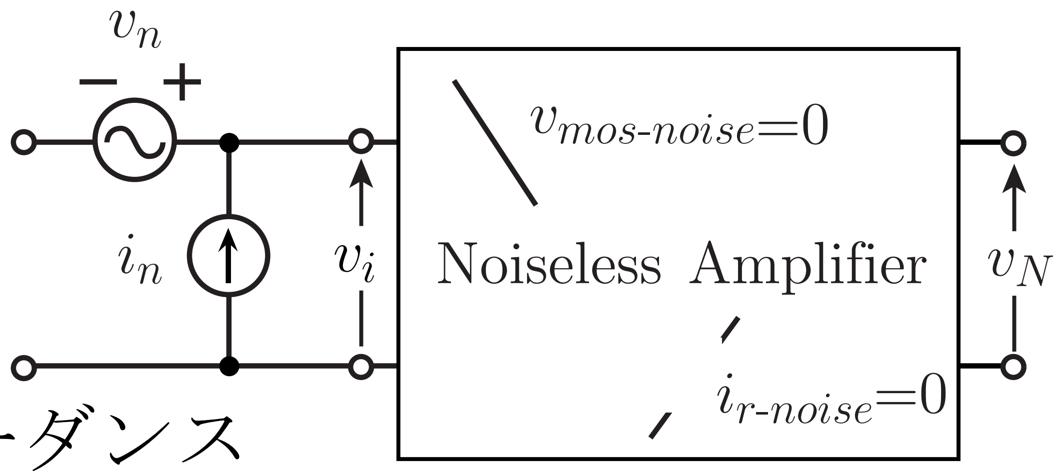
A：電圧利得



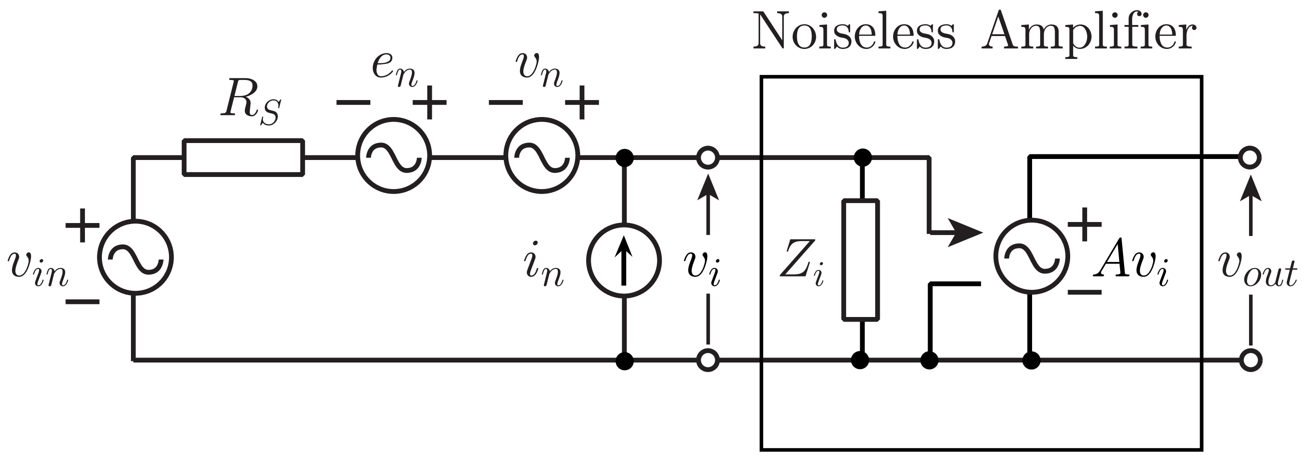
i_nの求め方

$$i_n = \frac{v_N}{Z_T}$$

Z_T: 伝達インピーダンス

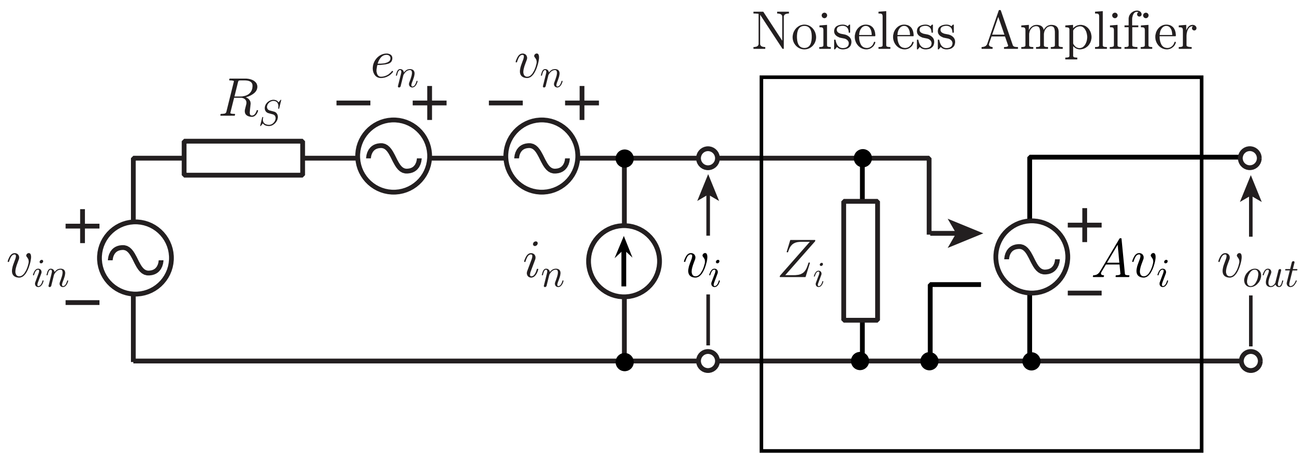


雑音整合



$$\overline{e_n{}^2} = 4kTR_S$$

$$v_S = \frac{AZ_i}{R_S + Z_i} v_{in}$$



e_nとv_n，e_nとi_nは無相関

v_nとi_nも無相関と仮定

$$\overline{v_N{}^2} = \frac{A^2 Z_i{}^2}{|R_S + Z_i|^2}(\overline{e_n{}^2} + \overline{v_n{}^2} + R_S{}^2\overline{i_n{}^2})$$

$$\overline{e_n^2} = 4kTR_S \qquad v_S = \frac{AZ_{in}}{R_S + Z_{in}} v_{in}$$

$$\overline{v_N^2} = \frac{A^2 Z_{in}^2}{|R_S + Z_{in}|^2} \left(\overline{e_n^2} + \overline{v_n^2} + R_S^2 \overline{i_n^2} \right)$$

$$SNR_{in} = \frac{\overline{v_{in}^2}}{\overline{e_n^2}}$$

$$SNR_{out} = \frac{\overline{v_S^2}}{\overline{v_N^2}} = \frac{\overline{v_{in}^2}}{\overline{e_n^2} + \overline{v_n^2} + R_S^2 \overline{i_n^2}}$$

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{\overline{e_n^2} + \overline{v_n^2} + R_S^2 \overline{i_n^2}}{\overline{e_n^2}} = 1 + \frac{\overline{v_n^2} + R_S^2 \overline{i_n^2}}{4kTR_S}$$

$$F = 1 + \frac{\overline{v_n{}^2} + R_S{}^2 \overline{i_n{}^2}}{4kTR_S}$$

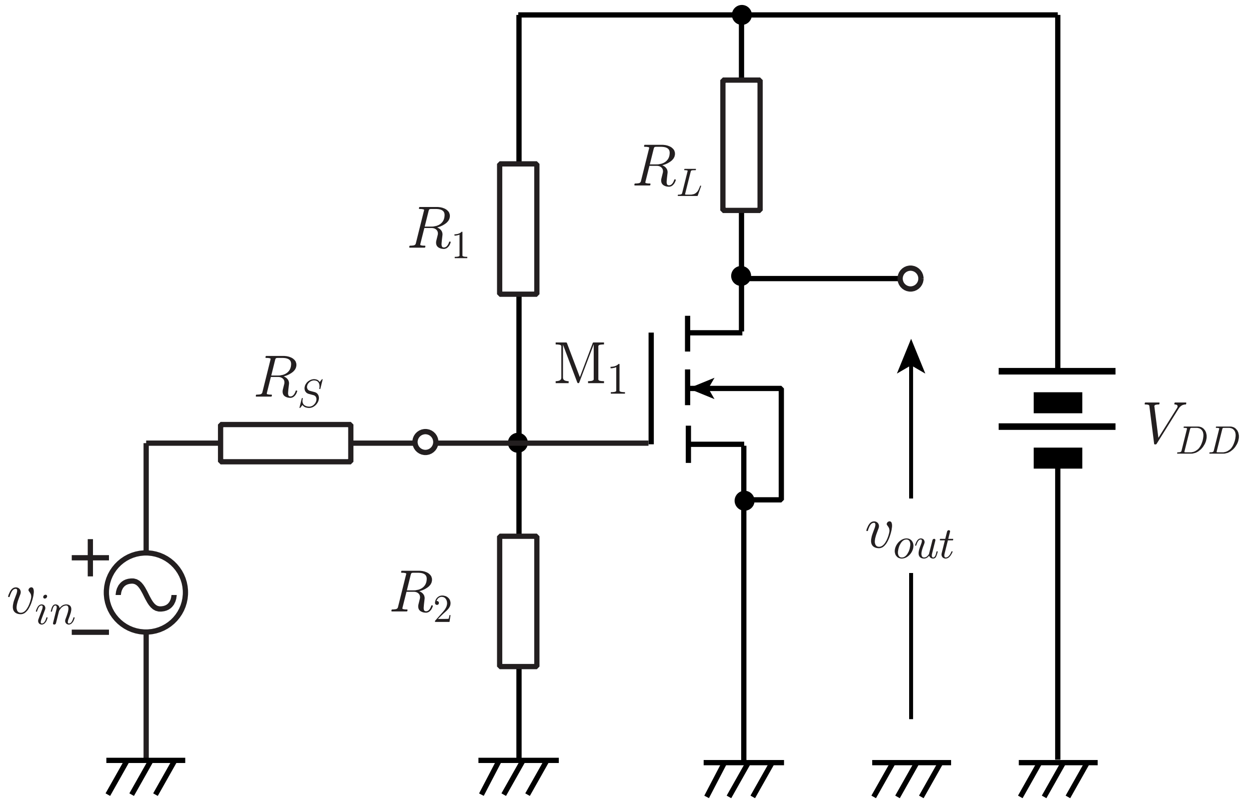
相加・相乗平均の定理　$a + b \geq 2\sqrt{ab}$

$$\frac{\overline{v_n{}^2}}{R_S} = R_S \overline{i_n{}^2} \text{のとき} F \text{が最小}$$

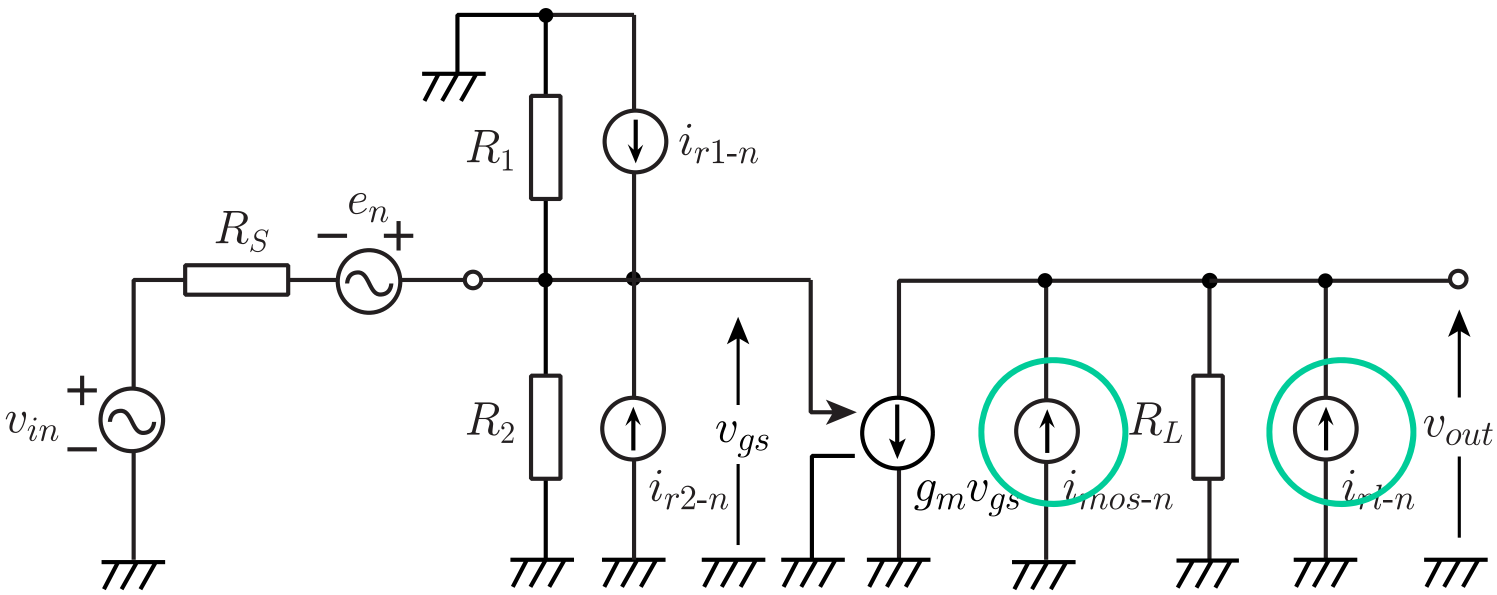
$$R_S = \sqrt{\frac{\overline{v_n{}^2}}{\overline{i_n{}^2}}}$$

実際の増幅回路の雑音解析例

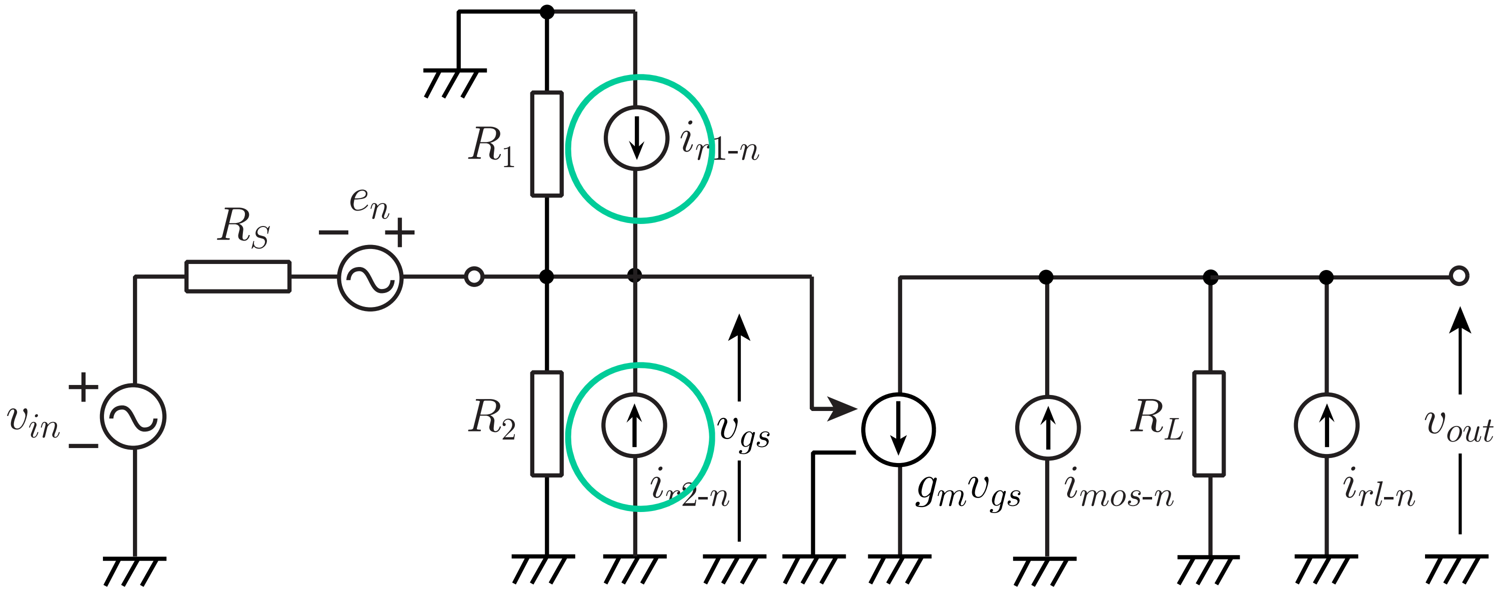
ソース接地増幅回路



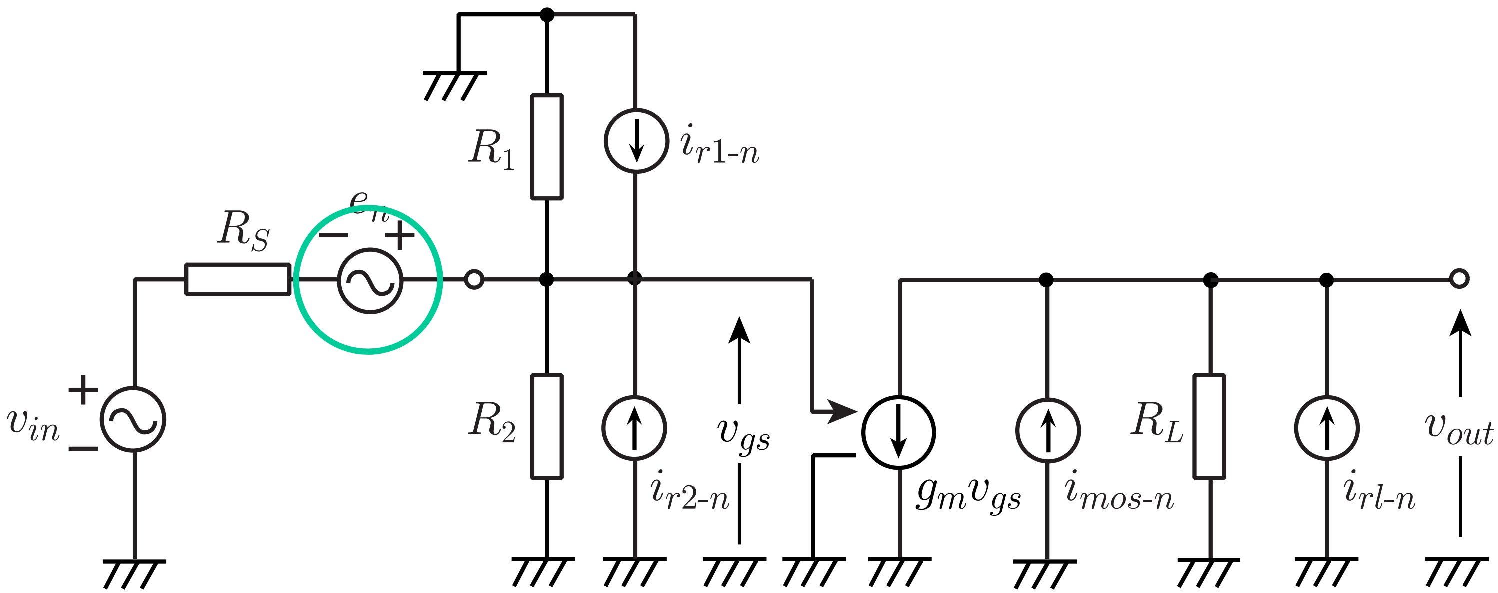
ソース接地増幅回路の小信号モデル



$$\overline{v_{o\text{-}n1}^{\,2}} = R_L^{\,2}\left(\overline{i_{rl\text{-}n}^{\,2}} + \overline{i_{mos\text{-}n}^{\,2}}\right)$$



$$\overline{v_{o\text{-}n2}^{\,2}} = \left| g_m R_L \frac{R_1 R_2 R_S}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 \left(\overline{i_{r1\text{-}n}^{\,2}} + \overline{i_{r2\text{-}n}^{\,2}} \right)$$



$$\overline{v_{o\text{-}n3}{}^2} = \left| g_m R_L \frac{R_1 R_2}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 \overline{e_n{}^2}$$

$$\overline{v_N{}^2} = \overline{v_{o\text{-}n1}{}^2} + \overline{v_{o\text{-}n2}{}^2} + \overline{v_{o\text{-}n3}{}^2}$$

$$= R_L{}^2 (\overline{i_{rl-n}{}^2} + \overline{i_{mos-n}{}^2})$$

$$+ \left| g_m R_L \frac{R_1 R_2 R_S}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 (\overline{i_{r1\text{-}n}{}^2} + \overline{i_{r2\text{-}n}{}^2})$$

$$+ \left| g_m R_L \frac{R_1 R_2}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 \overline{e_n{}^2}$$

$$\overline{v_S{}^2} = \left| g_m R_L \frac{R_1 R_2}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 \overline{v_{in}{}^2}$$

$$SNR_{in} = \frac{\overline{v_{in}{}^2}}{\overline{e_n{}^2}}$$

$$\overline{v_N^{\,2}} = \overline{v_{o\text{-}n1}^{\,2}} + \overline{v_{o\text{-}n2}^{\,2}} + \overline{v_{o\text{-}n3}^{\,2}}$$

$$\overline{v_S^{\,2}} = \left| g_m R_L \frac{R_1 R_2}{R_1 R_2 + R_2 R_S + R_S R_1} \right|^2 \overline{v_{in}^{\,2}}$$

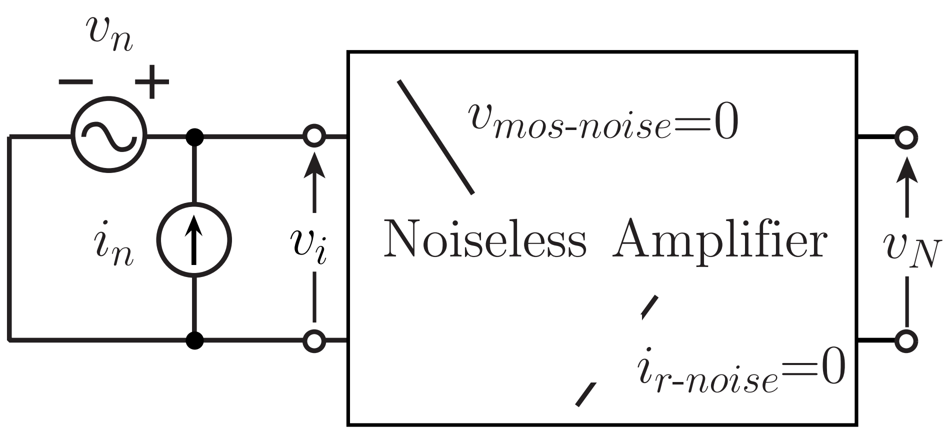
$$SNR_{in} = \frac{\overline{v_{in}^{\,2}}}{\overline{e_n^{\,2}}} \qquad e_n^{\,2} = 4kTR_S$$

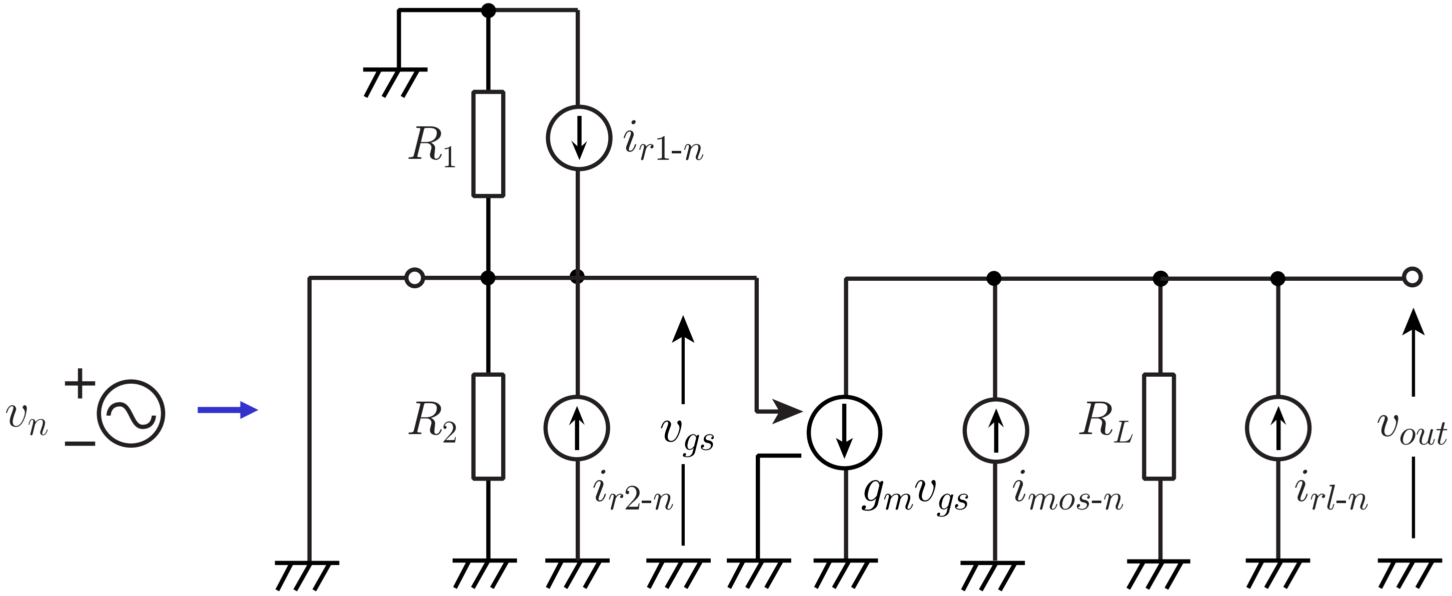
$$F = \frac{SNR_{in}}{SNR_{out}}$$

$$= 1 + \frac{1}{4kTR_S} \left\{ \left| \frac{R_1 R_2 + R_2 R_S + R_S R_1}{g_m R_1 R_2} \right|^2 \left(\overline{i_{rl\text{-}n}^{\,2}} + \overline{i_{mos\text{-}n}^{\,2}} \right) \right.$$

$$\left. + R_S^{\,2} \left(\overline{i_{r1\text{-}n}^{\,2}} + \overline{i_{r2\text{-}n}^{\,2}} \right) \right\}$$

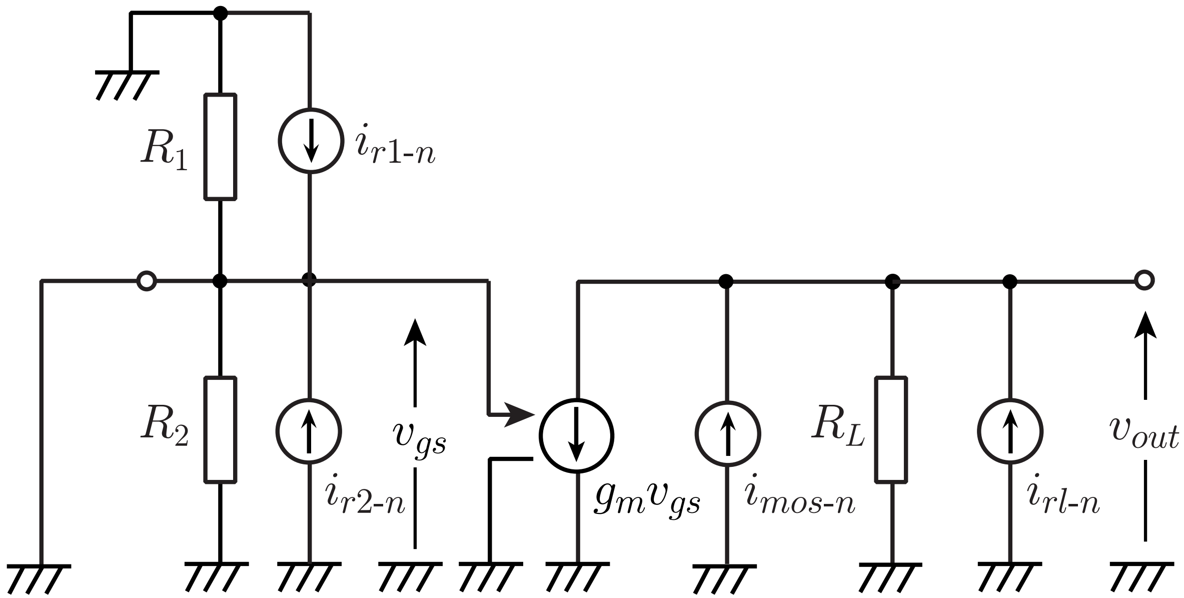
v_nの求め方





$$A=\frac{v_{out}}{v_n}=-g_m R_L$$

$$\overline{v_n^{\,2}}=\frac{\overline{v_N^{\,2}}}{A^2}$$

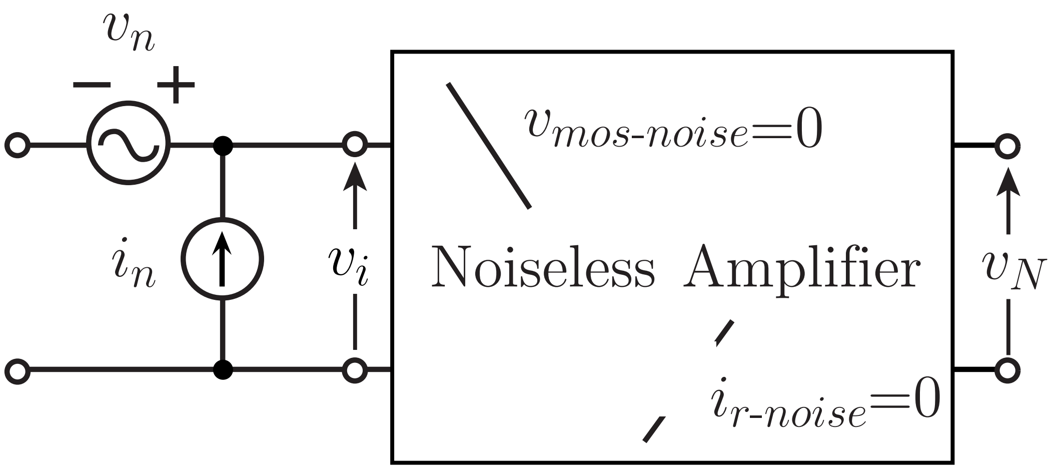


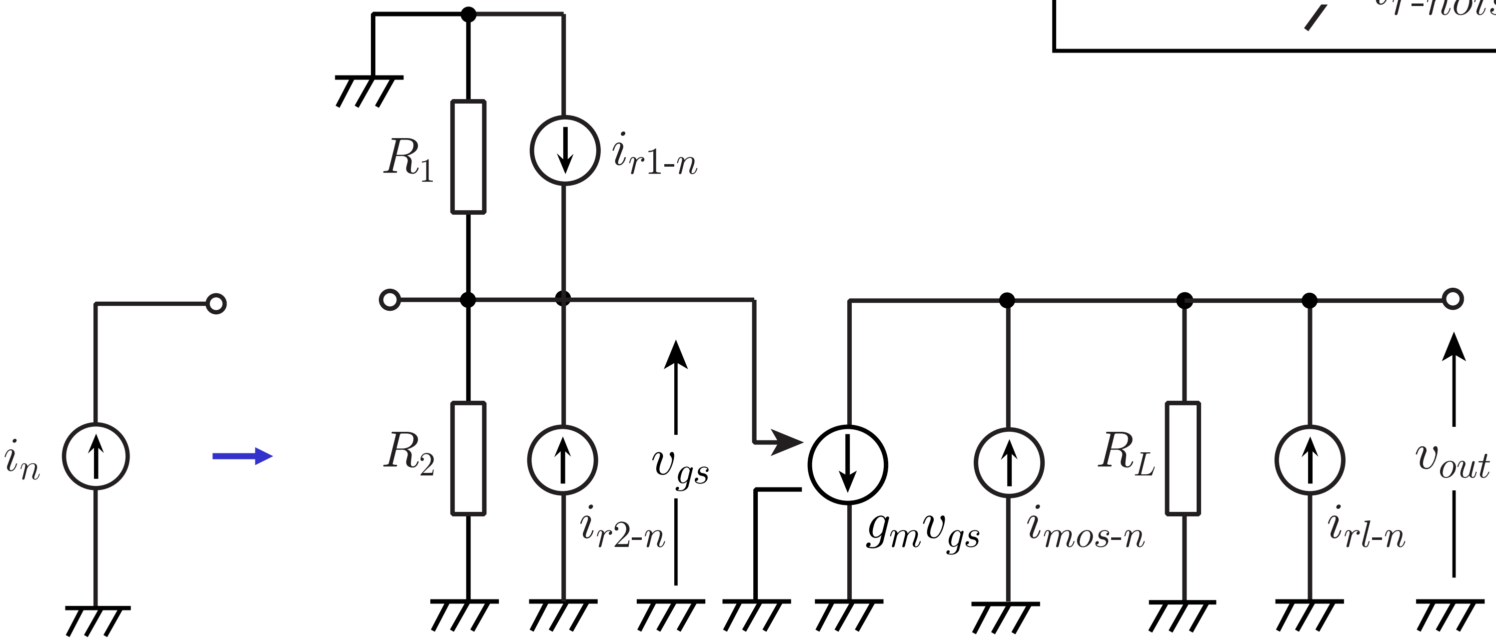
$$\overline{v_N{}^2} = R_L{}^2\left(\overline{i_{rl\text{-}n}{}^2} + \overline{i_{mos\text{-}n}{}^2}\right)$$

$$A = \frac{v_{out}}{v_n} = -g_m R_L$$

$$\overline{v_n{}^2} = \frac{1}{g_m{}^2}\left(\overline{i_{rl\text{-}n}{}^2} + \overline{i_{mos\text{-}n}{}^2}\right)$$

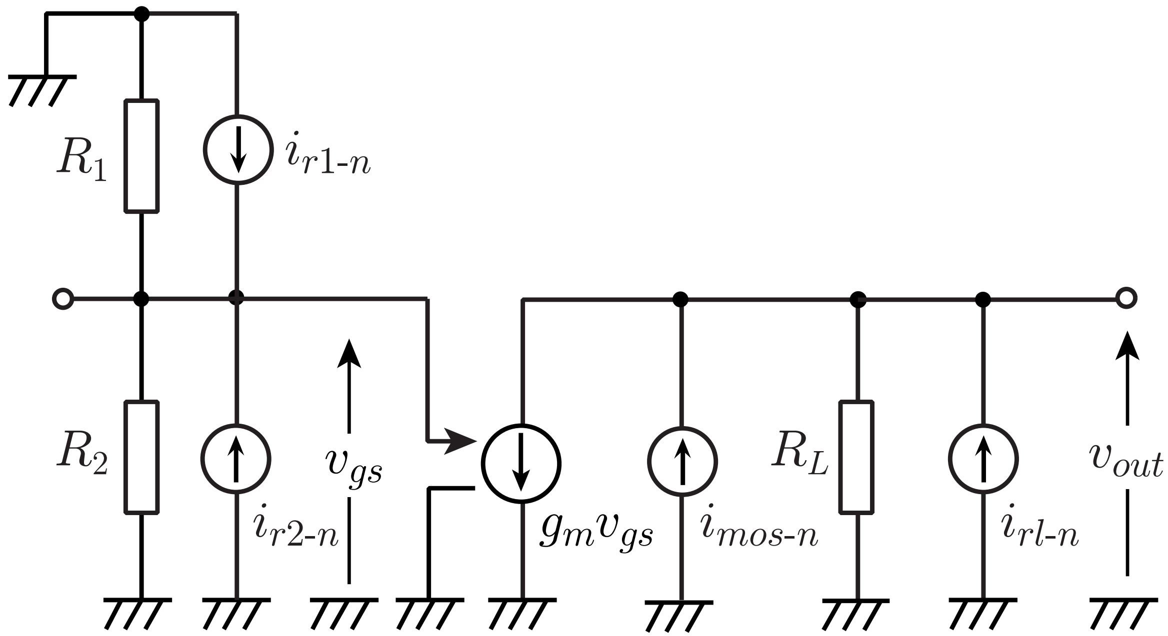
i_nの求め方





$$Z_T = -g_m R_L \frac{R_1 R_2}{R_2 + R_1}$$

$$\overline{{i_n}^2} = \frac{\overline{{v_N}^2}}{{Z_T}^2}$$

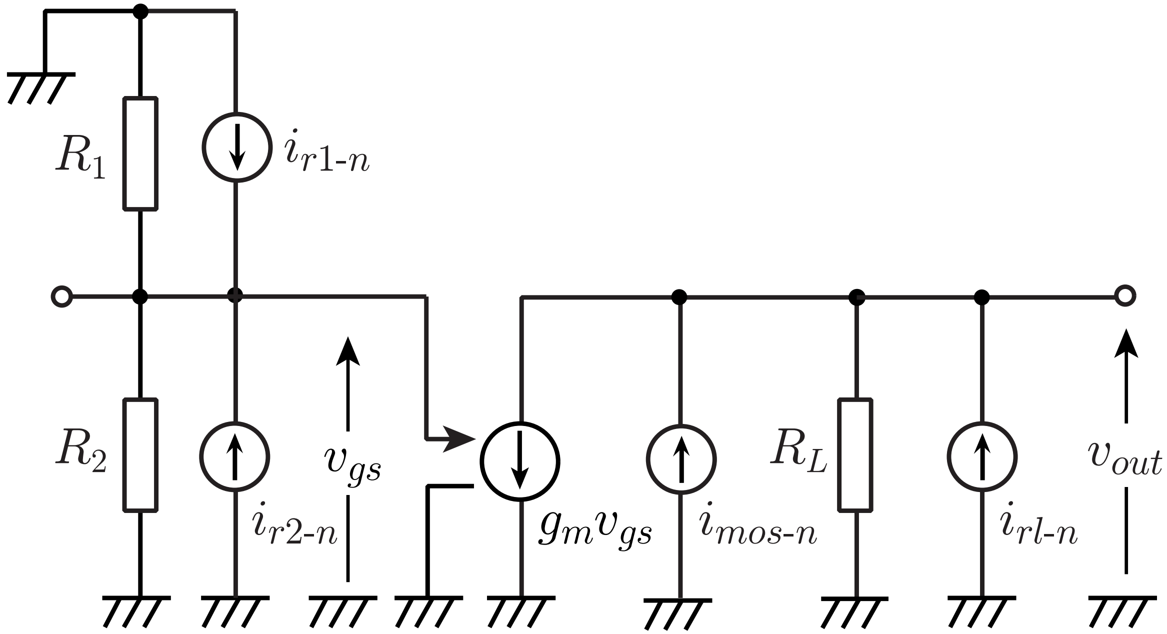


$$\overline{v_{o\text{-}n1}^{\,2}} = R_L^{\,2}\left(\overline{i_{rl\text{-}n}^{\,2}} + \overline{i_{mos\text{-}n}^{\,2}}\right)$$

$$\overline{v_{o\text{-}n2}^{\,2}} = \left| g_m R_L \frac{R_1 R_2}{R_2 + R_1} \right|^2 \left(\overline{i_{r1\text{-}n}^{\,2}} + \overline{i_{r2\text{-}n}^{\,2}}\right)$$

$$\overline{v_{out}^{\,2}} = \overline{v_{o\text{-}n1}^{\,2}} + \overline{v_{o\text{-}n2}^{\,2}}$$

$$\overline{v_N^{\,2}}=R_L^{\,2}\left(\overline{i_{rl-n}^{\,2}}+\overline{i_{mos-n}^{\,2}}\right)+\left|g_m R_L\frac{R_1R_2}{R_2+R_1}\right|^2\left(\overline{i_{r1\text{-}n}^{\,2}}+\overline{i_{r2\text{-}n}^{\,2}}\right)$$



$$i_n=\frac{v_N}{Z_T}$$

$$Z_T=-g_m R_L\frac{R_1R_2}{R_2+R_1}$$

$$\overline{i_n^{\,2}}=\left|\frac{R_1+R_2}{g_m R_2 R_1}\right|^2\left(\overline{i_{rl\text{-}n}^{\,2}}+\overline{i_{mos\text{-}n}^{\,2}}\right)+\left(\overline{i_{r1\text{-}n}^{\,2}}+\overline{i_{r2\text{-}n}^{\,2}}\right)$$

$$\overline{v_n^{\,2}}=\frac{1}{g_m^{\,2}}(\overline{i_{rl\text{-}n}^{\,2}}+\overline{i_{mos\text{-}n}^{\,2}})$$

$$\overline{i_n^{\,2}}=\left|\frac{R_1+R_2}{g_m R_2 R_1}\right|^2(\overline{i_{rl\text{-}n}^{\,2}}+\overline{i_{mos\text{-}n}^{\,2}})+(\overline{i_{r1\text{-}n}^{\,2}}+\overline{i_{r2\text{-}n}^{\,2}})$$

$$F=1+\frac{\overline{v_n^{\,2}}+R_S^{\,2}\,\overline{i_n^{\,2}}}{4kTR_S}$$ より

$$F=1+\frac{1}{4kTR_S}\left[\left\{\frac{1}{g_m^{\,2}}+\left|\frac{(R_1+R_2)R_S}{g_m R_1 R_2}\right|^2\right\}(\overline{i_{rl\text{-}n}^{\,2}}+\overline{i_{mos\text{-}n}^{\,2}})+R_S^{\,2}(\overline{i_{r1\text{-}n}^{\,2}}+\overline{i_{r2\text{-}n}^{\,2}})\right]$$

v_nとi_nの間の相関も考慮

$$F = 1 + \frac{1}{4kTR_S}\left\{\left|\frac{R_1R_2+R_2R_S+R_SR_1}{g_mR_1R_2}\right|^2 (\overline{i_{rl\text{-}n}^{\ 2}} + \overline{i_{mos\text{-}n}^{\ 2}}) + R_S^{\ 2}(\overline{i_{r1\text{-}n}^{\ 2}} + \overline{i_{r2\text{-}n}^{\ 2}})\right\}$$

v_nとi_nは無相関と仮定

$$F = 1 + \frac{1}{4kTR_S}\left[\left\{\frac{1}{g_m^{\ 2}} + \left|\frac{(R_1+R_2)R_S}{g_mR_1R_2}\right|^2\right\}(\overline{i_{rl\text{-}n}^{\ 2}} + \overline{i_{mos\text{-}n}^{\ 2}}) + R_S^{\ 2}(\overline{i_{r1\text{-}n}^{\ 2}} + \overline{i_{r2\text{-}n}^{\ 2}})\right]$$

低雑音増幅回路の設計

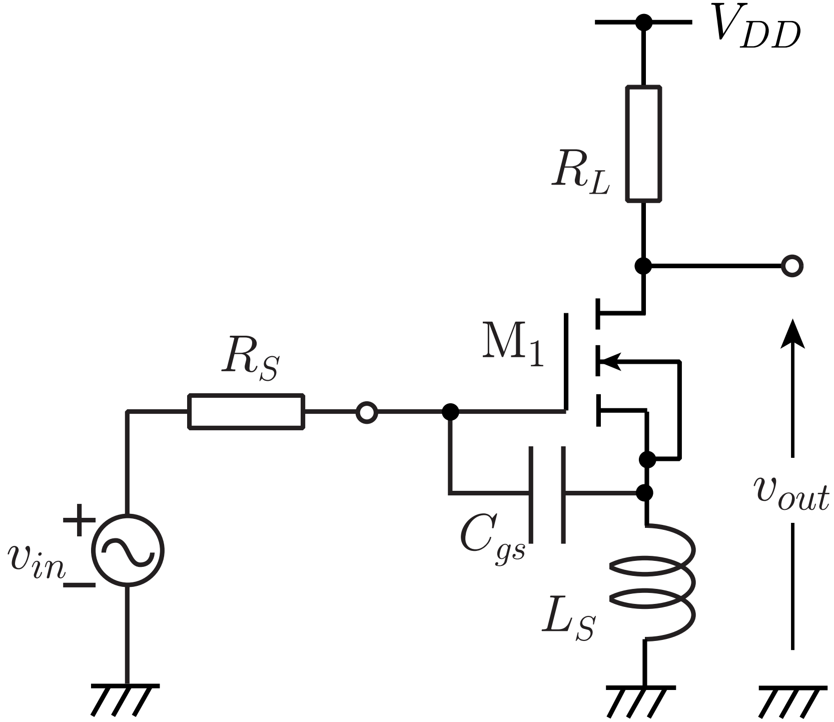
通信機器用低雑音増幅回路

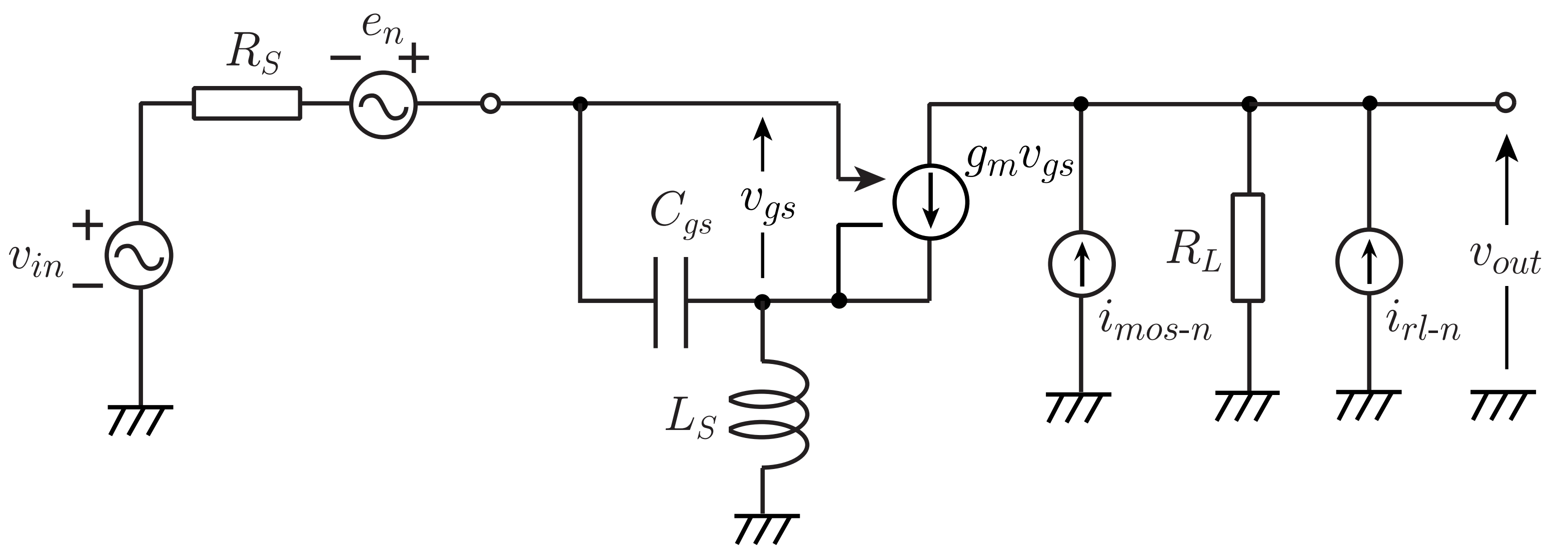
高周波(数GHz)

狭帯域

LC共振特性の応用

LC共振特性の応用





$$\overline{v_N{}^2} = R_L{}^2\left(\overline{i_{rl\text{-}n}{}^2} + \overline{i_{mos\text{-}n}{}^2}\right)$$

$$A = \frac{-g_m R_L}{1 + sL_S(g_m + sC_{gs})}$$

$$Z_T = \frac{g_m}{sC_{gs}} R_L$$

$$\overline{v_N^{\ 2}} = R_L^{\ 2}\left(\overline{i_{rl\text{-}n}^{\ 2}} + \overline{i_{mos\text{-}n}^{\ 2}}\right)$$

$$A = \frac{-g_m R_L}{1 + sL_S(g_m + sC_{gs})} \qquad\qquad Z_T = \frac{g_m}{sC_{gs}} R_L$$

$$\overline{v_n^{\ 2}} = \left|\frac{1 + sL_S(g_m + sC_{gs})}{g_m}\right|^2 \left(\overline{i_{rl\text{-}n}^{\ 2}} + \overline{i_{mos\text{-}n}^{\ 2}}\right)$$

$$\overline{i_n^{\ 2}} = \left|\frac{sC_{gs}}{g_m}\right|^2 \left(\overline{i_{rl\text{-}n}^{\ 2}} + \overline{i_{mos\text{-}n}^{\ 2}}\right)$$

$$\overline{v_n^2}=\left|\frac{1+sL_S(g_m+sC_{gs})}{g_m}\right|^2(\overline{i_{rl\text{-}n}^2}+\overline{i_{mos\text{-}n}^2})$$

$$\overline{i_n^2}=\left|\frac{sC_{gs}}{g_m}\right|^2(\overline{i_{rl\text{-}n}^2}+\overline{i_{mos\text{-}n}^2})$$

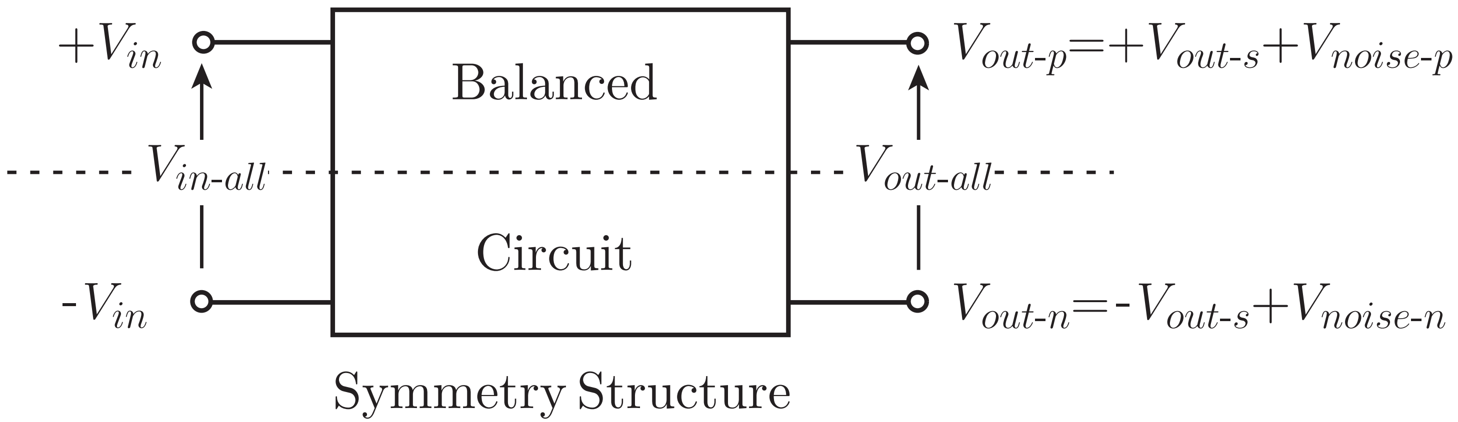
$$\sqrt{\frac{\overline{v_n^2}}{\overline{i_n^2}}}=\left|\frac{1+sL_S(g_m+sC_{gs})}{sC_{gs}}\right|$$

$$\left|\frac{1+sL_S(g_m+sC_{gs})}{sC_{gs}}\right|=R_S$$

↑

$f=\frac{1}{2\pi}\sqrt{\frac{1}{L_SC_{gs}}}$のとき$\frac{L_Sg_m}{C_{gs}}$の純抵抗

平衡型構成による雑音の低減？



$$V_{noise\text{-}d}=\frac{V_{noise\text{-}p}-V_{noise\text{-}n}}{2}$$

$$V_{noise\text{-}p}=+V_{noise\text{-}d}+V_{noise\text{-}c}$$

$$V_{noise\text{-}c}=\frac{V_{noise\text{-}p}+V_{noise\text{-}n}}{2}$$

$$V_{noise\text{-}n}=-V_{noise\text{-}d}+V_{noise\text{-}c}$$

$$V_{out\text{-}all}=V_{out\text{-}p}-V_{out\text{-}n}=2V_{out\text{-}s}+2V_{noise\text{-}d}$$

不平衡型回路のSNR

$$V_{out} = V_{out\text{-}s} + V_{noise}$$

$$\lim_{T \to \infty} \frac{1}{T} \int_0^T V_{out\text{-}s}{}^2 dt = \overline{V_{out\text{-}s}}^2 \qquad \lim_{T \to \infty} \frac{1}{T} \int_0^T V_{noise}{}^2 dt = \overline{V_{noise}}^2$$

$$SNR_{imbal} = \frac{\overline{V_{out\text{-}s}}^2}{\overline{V_{noise}}^2}$$

平衡型回路のSNR

$$V_{out\text{-}all}=V_{out\text{-}p}-V_{out\text{-}n}=2(V_{out\text{-}s}+V_{noise\text{-}d})$$

$$\lim_{T\to\infty}\frac{1}{T}\int_0^T V_{out\text{-}s}{}^2 dt=\overline{V_{out\text{-}s}}^2$$

$$\overline{V_{noise\text{-}d}}^2=\lim_{T\to\infty}\frac{1}{T}\int_0^T V_{noise\text{-}d}{}^2 dt=\lim_{T\to\infty}\frac{1}{T}\int_0^T V_{noise\text{-}c}{}^2 dt=\frac{1}{2}\overline{V_{noise}}^2$$

SNRの改善： $SNR_{bal}=\dfrac{\overline{V_{out\text{-}s}}^2}{\overline{V_{noise\text{-}d}}^2}=2\dfrac{\overline{V_{out\text{-}s}}^2}{\overline{V_{noise}}^2}$

ただし，回路規模は2倍