# EE240B HW 2

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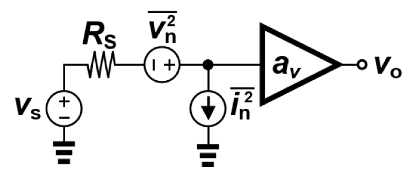
## 1 Electronic Noise




| Noise source | Amplifier A | Amplifier B |
|---|---|---|
| $\sqrt{\frac{\overline{v_n^2}}{\Delta f}}$ | $1\frac{\text{nV}}{\sqrt{\text{Hz}}}$ | $10\frac{\text{nV}}{\sqrt{\text{Hz}}}$ |
| $\sqrt{\frac{\overline{i_n^2}}{\Delta f}}$ | $1\frac{\text{pA}}{\sqrt{\text{Hz}}}$ | $1\frac{\text{fA}}{\sqrt{\text{Hz}}}$ |

(a) Calculate the input referred noise in $V/\sqrt{\text{Hz}}$ achieved with the two amplifiers for $R_S = 50\Omega, 5\text{M}\Omega$. Only consider the amplifier noise. Assume the amplifier voltage and current sources are uncorrelated.

| $R_s$ | Amplifier A | Amplifier B |
|---|---|---|
| 50 $\Omega$ | $1.05\frac{\text{nV}}{\sqrt{\text{Hz}}}$ | $10\frac{\text{nV}}{\sqrt{\text{Hz}}}$ |
| 5 M$\Omega$ | $5000\frac{\text{nV}}{\sqrt{\text{Hz}}}$ | $15\frac{\text{nV}}{\sqrt{\text{Hz}}}$ |

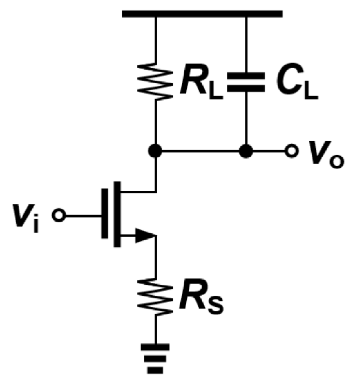
(b) Significance of the result?

If the input voltage source's resistance is low, an amplifier with low voltage noise should be chosen (since the amplifier's current noise won't see a large resistance). Use a BJT op-amp.

If the input voltage source's resistance is high, an amplifier with low current noise should be chosen. This is usually a FET op-amp.

## 2 Amplifier Noise

Derive analytical expressions as a function of $g_m, \gamma, f_T, R_L, R_S$, and $C_L$. Consider only thermal noise from $R_S, R_L$, and transistor shot noise. Ignore flicker noise, $r_o$, and body effect. $C_L$ is fixed and $C_{gs}$ is expressed in terms of $f_T$.




(a) The voltage gain $a_v(s) = v_o/v_i$

This is a standard source-degenerated common-source amplifier with a complex load. We need to consider $C_{gs}$ which will give a 2nd-order transfer function and makes the algebra complicated. I'm using the sympy CAS to do the algebra. I'll provide the source and the derived solution.

```
from sympy import *
def ll(a, b): # Put impedances a and b in parallel symbolically
    return (a*b) / (a + b)
s, RL, CL, ZL, Cgs, Rs, gm = symbols("s R_L C_L Z_L C_{gs} R_s g_m")
igate, isource, idrain = symbols("i_g i_s i_d")
vs, vd, vi = symbols("v_s v_d v_i")
sol = nonlinsolve([
    igate - ((vi - vs) / (1 / (s*Cgs))),
    isource - (vs / Rs),
    idrain - gm*(vi - vs),
    -vd - idrain*ZL,
    isource - igate - idrain
], [igate, isource, idrain, vd, vs])
vd_sol = sol.args[0][3]
gain = vd_sol / vi
ZL_sol = ll(CL, RL)
ZL_sol = ZL_sol.subs(CL, (1 / (s*CL))).simplify()
display(gain.subs(ZL, ZL_sol).simplify())
```

$$a_v(s) = -\frac{R_L g_m}{\left(C_L R_L s + 1\right)\left(C_{gs} R_s s + R_s g_m + 1\right)}$$

(b) The PSD of the noise in $\frac{\mathrm{V}}{\sqrt{\mathrm{Hz}}}$ at node $v_o$

(c) The total noise integrated over all frequencies at node $v_o$

(d) The dynamic range of the circuit as a function of the peak-to-peak voltage range $V_{o,pp}$ at node $v_o$

(e) The minimum detectable signal in $\frac{\text{nV}}{\sqrt{\text{Hz}}}$ at low frequency at $\mu V_{rms}$ based on the total noise at the output of the amplifier

(f) Comment on the effect of $R_S$ on the dynamic range and minimum detectable signal of the circuit