Advanced Analog Integrated Circuits

Basic Transistor Amplifiers

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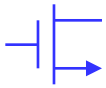
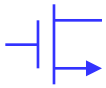
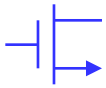


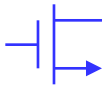
Design Example

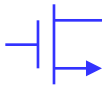


Topology

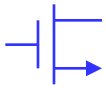


Small signal analysis

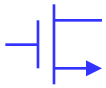




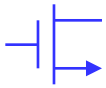
Dynamic Range



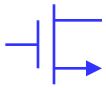
Dynamic Range



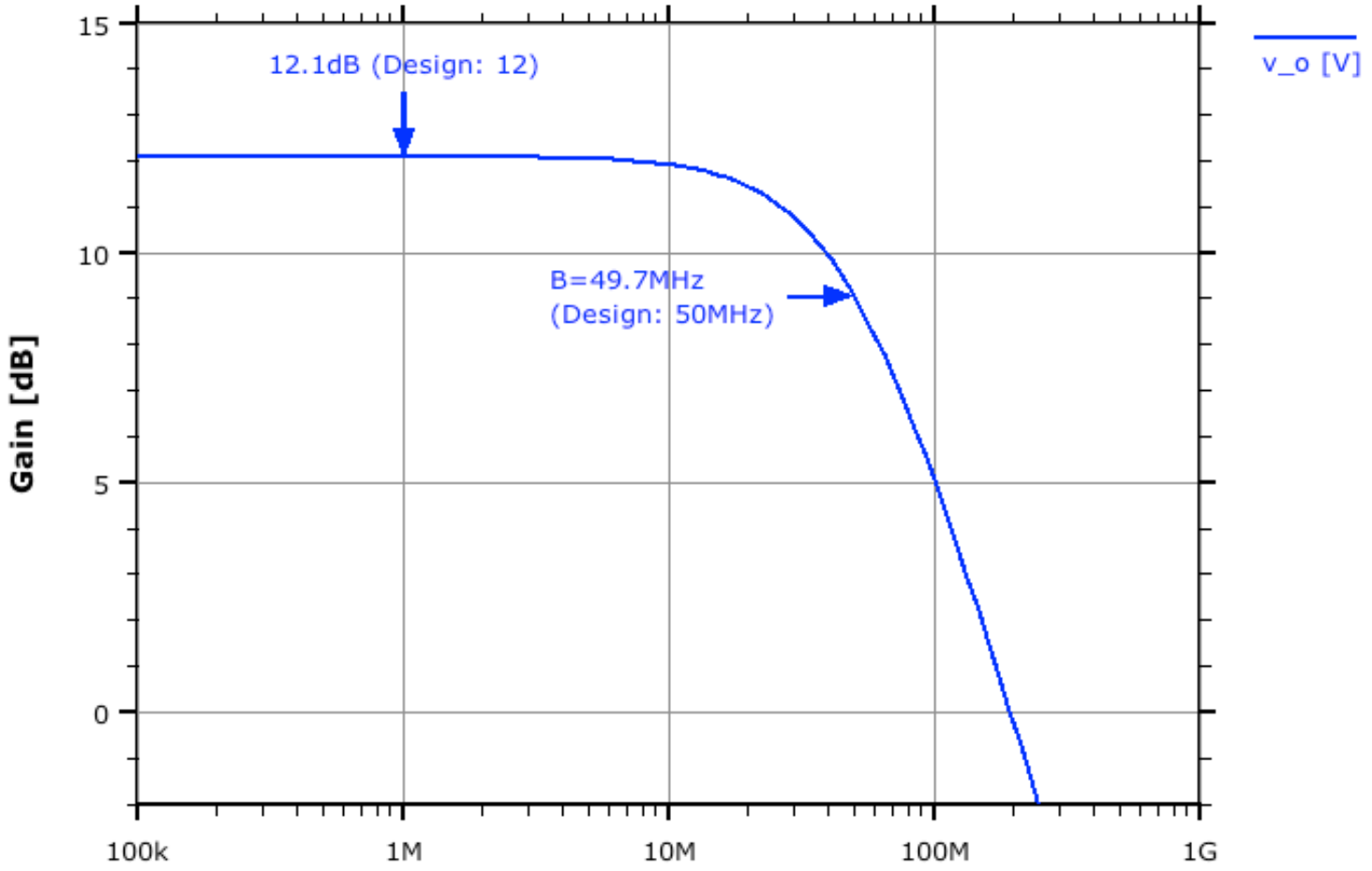
Solve



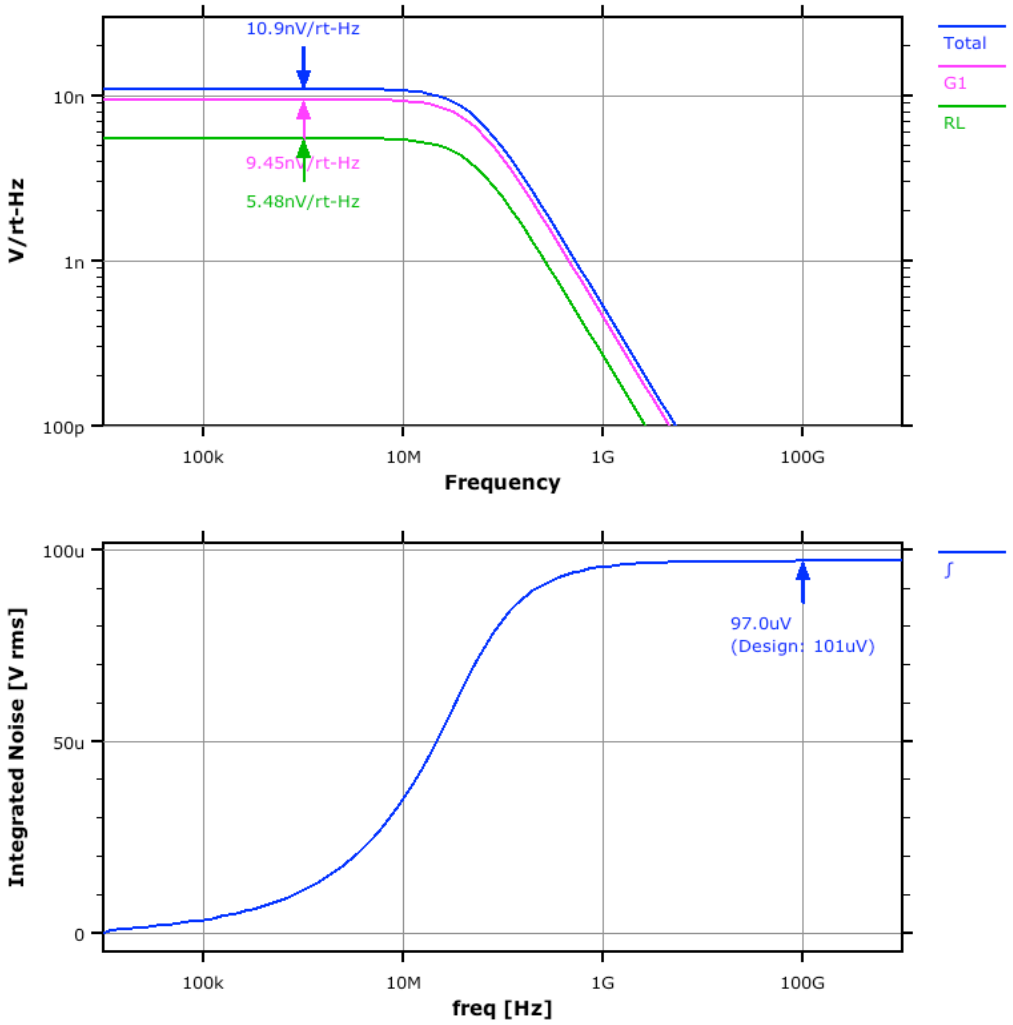
Verify



Gain and Bandwidth



Noise


10.9nV/rt-Hz
9.45nV/rt-Hz
5.48nV/rt-Hz
Total
G1
RL
V/rt-Hz
10n
1n
100p
100k
10M
1G
100G
Frequency
100u
50u
0
Integrated Noise [V rms]
97.0uV
(Design: 101uV)
∫
freq [Hz]

What-If

Common Source

Specifications

Performance: $a_v := 4$ $B := 50MHz$ $DR\_dB := 70$ dB $DR := 10^{\frac{DR\_dB}{10}}$

Process: 180nm CMOS $V_{DD} := 1.8V$ $\gamma_{low} := 0.86$

Design Equations

Low frequency gain: $a_v = g_m \cdot R_L$

3-dB Bandwidth: $B = \frac{1}{2 \cdot \pi \cdot R_L \cdot C_L}$

Dynamic Range: $DR = \frac{\frac{1}{2} \cdot \left(\frac{r \cdot V_{DD}}{2}\right)^2}{\frac{k \cdot T}{C_L} \cdot \left(1 + \gamma_n \cdot a_v\right)}$

Transistor specs: $L_1 := 180nm$ $V_{star} := 120mV$ $r := 0.5$

Load capacitance: $C_L := DR \cdot \frac{2 \cdot k_B \cdot T_r \cdot \left(1 + \gamma_n \cdot a_v\right)}{\left(r \cdot \frac{V_{DD}}{2}\right)^2} = 1.76 \cdot pF$

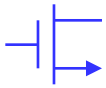
Load resistance: $R_L := \frac{1}{2 \cdot \pi \cdot B} \cdot \frac{1}{C_L} = 1.81 \cdot k\Omega$

Transconductance: $g_m := \frac{a_v}{R_L} = 2.21 \cdot mS$

Bias current: $I_d := \frac{g_m \cdot V_{star}}{2} = 132 \cdot \mu A$ $R_L \cdot I_d = 240 \cdot mV$ $\frac{a_v \cdot V_{star}}{2} = 240 \cdot mV$

Power dissipation: $P_{tot} := V_{DD} \cdot I_d = 238 \cdot \mu W$ How can we reduce this?

Total noise: $v_{oT} := \sqrt{\frac{k_B \cdot T_r}{C_L} \cdot \left(1 + \gamma_n \cdot a_v\right)} = 101 \cdot \mu V$



What-If: Reduce Power Dissipation?

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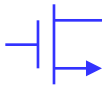

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Transistor specs: $L_1 := 180nm$ $V_{star} := 120mV$ $r := 0.5$

Load capacitance: $C_L := DR \cdot \frac{2 \cdot k_B \cdot T_r \cdot (1 + \gamma_n \cdot a_v)}{\left(r \cdot \frac{V_{DD}}{2}\right)^2} = 1.76 \cdot pF$

Load resistance: $R_L := \frac{1}{2 \cdot \pi \cdot B} \cdot \frac{1}{C_L} = 1.81 \cdot k\Omega$

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Transistor specs: $L_1 := 180nm$ $V_{star} := 120mV$ $r := 0.75$

Load capacitance: $C_L := DR \cdot \frac{2 \cdot k_B \cdot T_r \cdot (1 + \gamma_n \cdot a_v)}{\left(r \cdot \frac{V_{DD}}{2}\right)^2} = 0.78 \cdot pF$

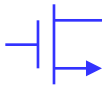
Load resistance: $R_L := \frac{1}{2 \cdot \pi \cdot B} \cdot \frac{1}{C_L} = 4.08 \cdot k\Omega$

Transconductance: $g_m := \frac{a_v}{R_L} = 0.98 \cdot mS$

Bias current: $I_d := \frac{g_m \cdot V_{star}}{2} = 59 \cdot \mu A$ $R_L \cdot I_d = 240 \cdot mV$ $\frac{a_v \cdot V_{star}}{2} = 240 \cdot mV$

Power dissipation: $P_{tot} := V_{DD} \cdot I_d = 106 \cdot \mu W$ How can we reduce this?

Total noise: $v_{oT} := \sqrt{\frac{k_B \cdot T_r}{C_L} \cdot (1 + \gamma_n \cdot a_v)} = 151 \cdot \mu V$



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Check: Verification with “Real” Transistor

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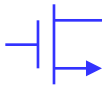
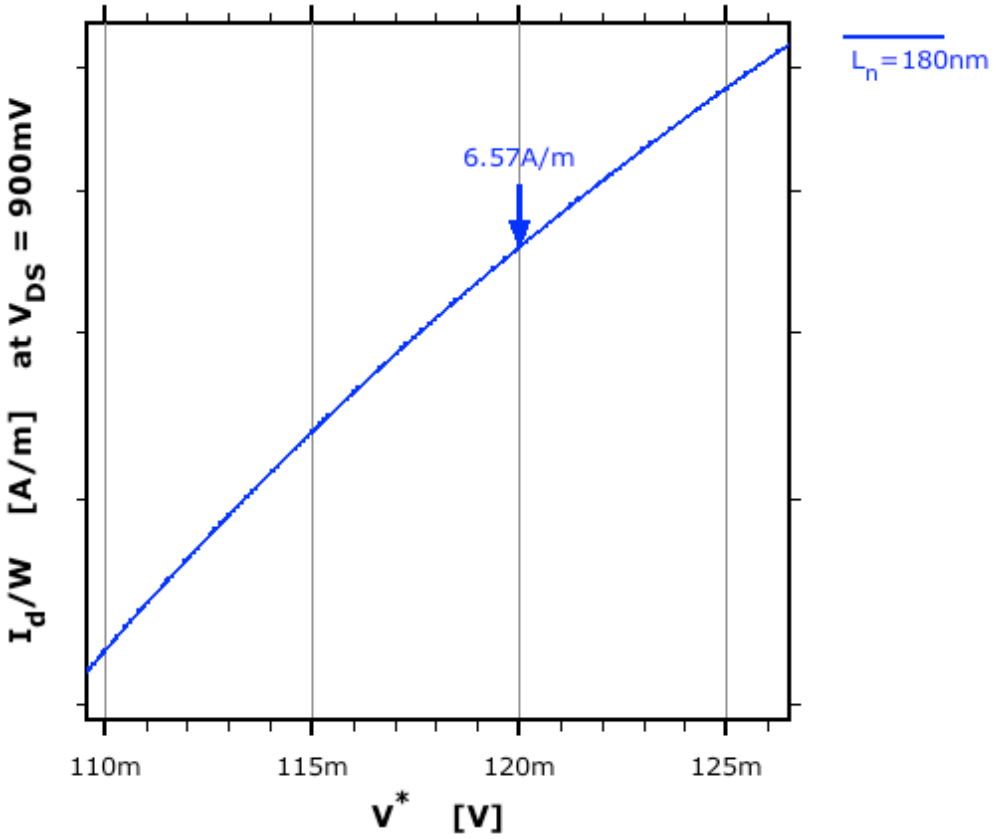
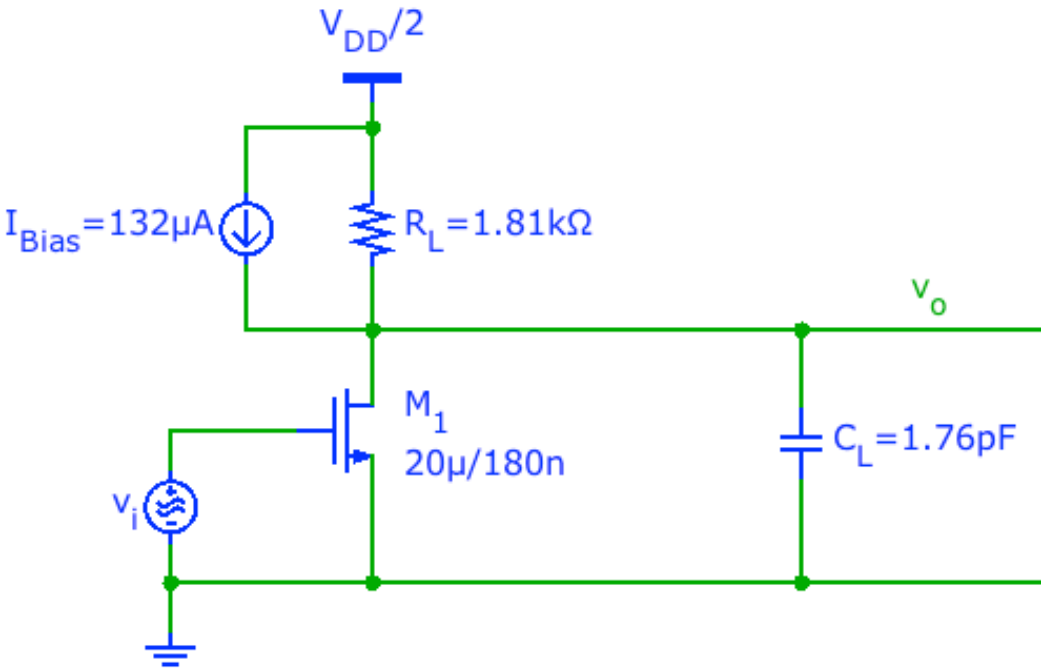


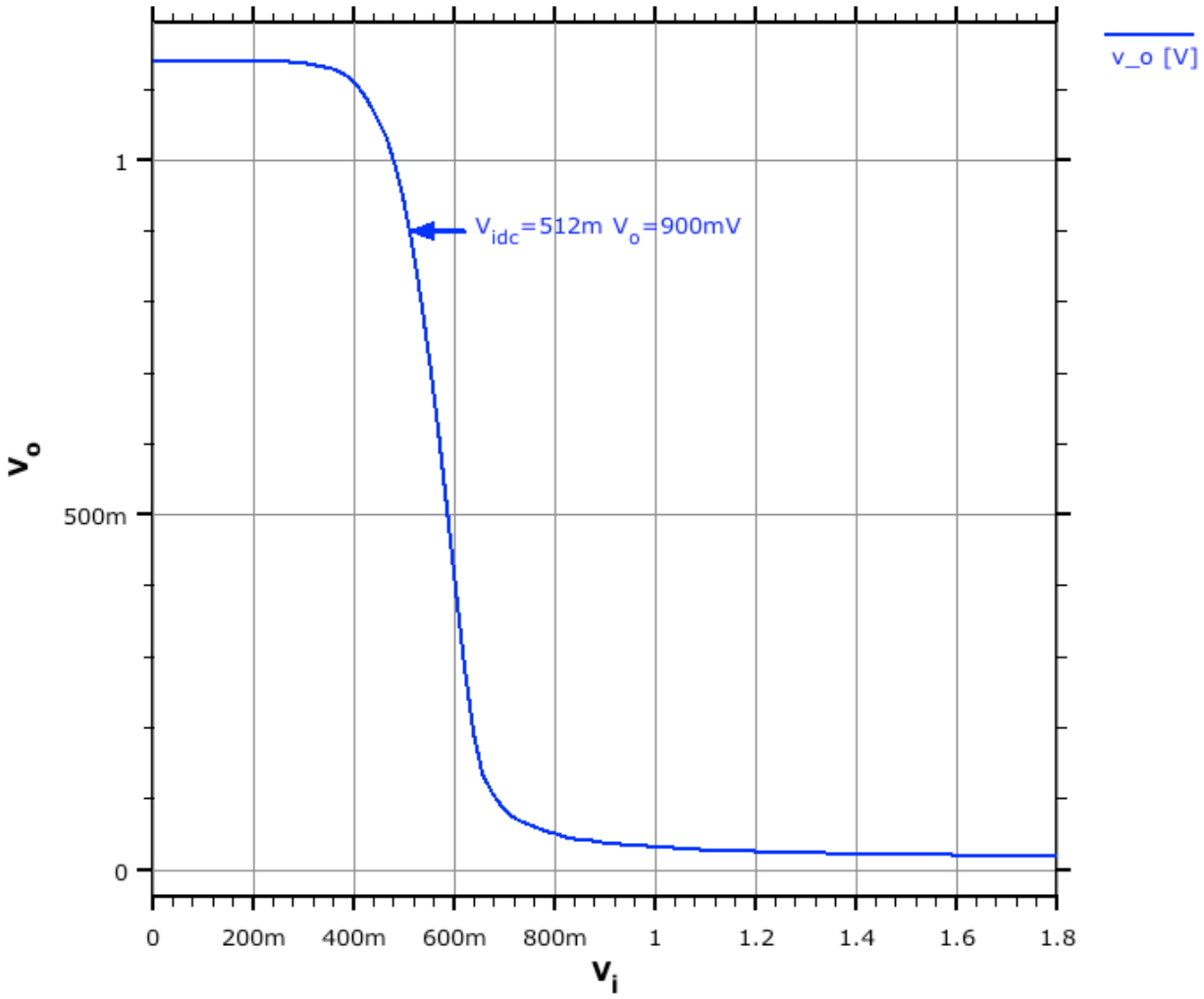
But … what about a “real” transistor?



Biasing …



DC Operating Point



Transistor Operating Point Check

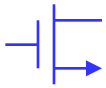
```
M1: bsim3v3
  d : V(root.v_o) = 899.066 mV
  g : V(root.vgs) = 512 mV
  s : val(0) = 0
  b : val(0) = 0
       type = n
     region = subth
   reversed = no
        ids = 132.516 uA
      isub = 42.2913 pA
        vgs = 512 mV
        vds = 899.066 mV
        vbs = 0 V
        vgb = 512 mV
        vdb = 899.066 mV
        vgd = -387.066 mV
        vth = 514.279 mV
     vdsat = 69.4368 mV
    vfbeff = -1.09875 V
         gm = 2.24692 mS
        gds = 50.2374 uS
       gmbs = 644.535 uS
    betaeff = 65.1953 mA/V^2
        cjd = 10.2586 fF
        cjs = 11.7154 fF
         qb = -18.5858 fCoul
         qg = 19.9153 fCoul
         qg = 19.9153 fCoul
         qd = 2.86107 fCoul
        qbd = -10.6792 fCoul
        qbs = -105.569e-21 Coul
        cgg = 29.5591 fF
        cgd = -7.34957 fF
        cgs = -15.5588 fF
        cgb = -6.65065 fF
        cdg = -7.39886 fF
        cdd = 17.6518 fF
        cds = 7.46008 aF
        cdb = -10.2604 fF
        csg = -15.9526 fF
        csd = -25.7075 aF
        css = 30.1804 fF
        csb = -14.2021 fF
        cbg = -6.20759 fF
        cbd = -10.2765 fF
        cbs = -14.629 fF
        cbb = 31.1131 fF
        ron = 6.78457 kOhm
         id = 132.516 uA
         is = -132.516 uA
      ibulk = -42.2919 pA
        ibs = -41.3032 aA
        ibd = -42.2919 pA
        pwr = 119.141 uW
  gmoverid = 16.9558 1/V
    cgsovl = 7.3926 fF
    cgdovl = 7.3926 fF
   cgbovl = 26.5891 aF
        i1 = 132.516 uA
        i3 = -132.516 uA
        i4 = -42.2919 pA
       gbd = 776.844 pS
       gbs = 4.58359 pS
   vgsteff = 36.6265 mV
      qinv = 2.08789 mCoul
       igd = 0 A
       igs = 0 A
       igb = 0 A
       qgi = 18.9781 fCoul
       qsi = -405.587 aCoul
       qdi = -289.142e-21 Coul
       qbi = -18.5722 fCoul
    cddbi = 611.498e-21 F
    cssbi = 11.0724 fF
    cggbi = 14.7473 fF
    cgsbi = -8.16625 fF
    cgdbi = 43.0261 aF
    cbdbi = -17.93 aF
    cbsbi = -2.91363 fF
    qsrco = -4.19053 fCoul
```

132uA

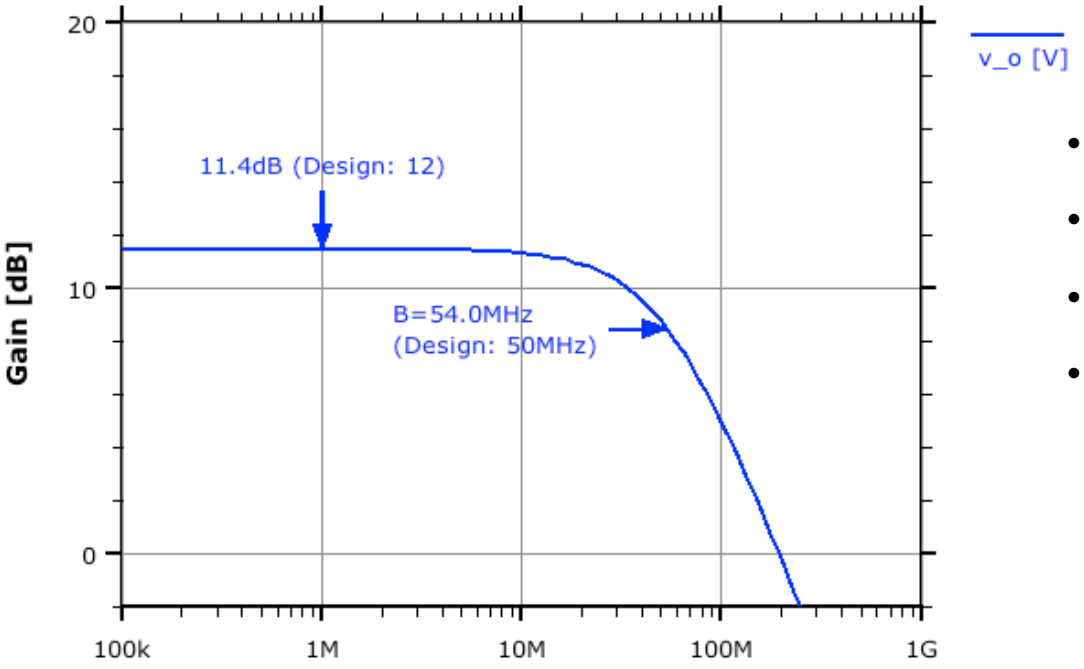
900mV

2.21mS

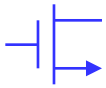
16.7 /V



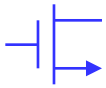
Gain and Bandwidth



- Gain below spec
- 11.4dB = 3.7 < 4
- Why?
- Transistor a_{vo}
  - From operating point analysis: $g_m/g_{ds} = 44.8$
  - ~10% error on gain of 4
- Note: only @ operating point, amplifier is quite nonlinear and the output range limited by R_L



Conclusions



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Common Gate Stage

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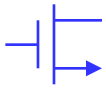

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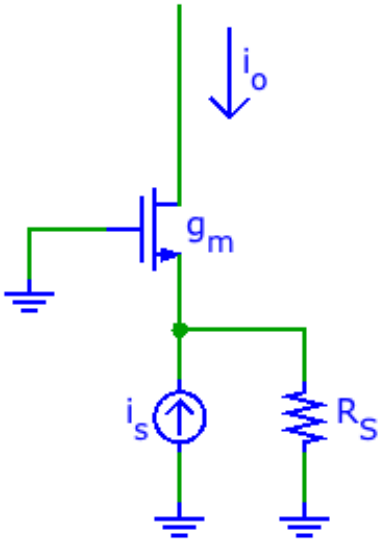
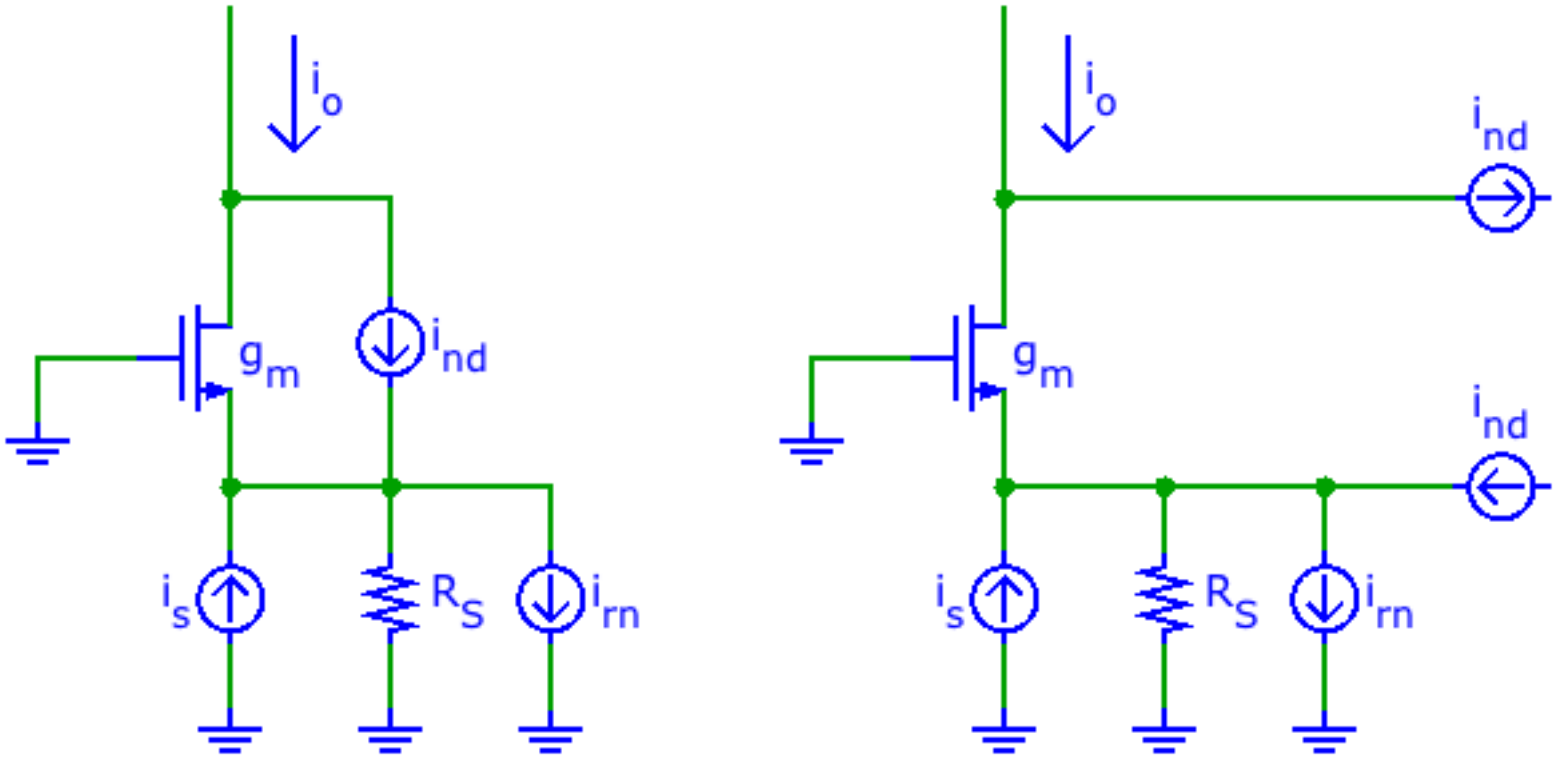
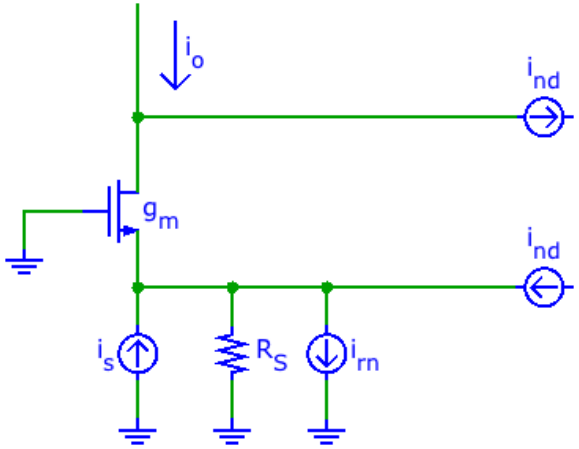


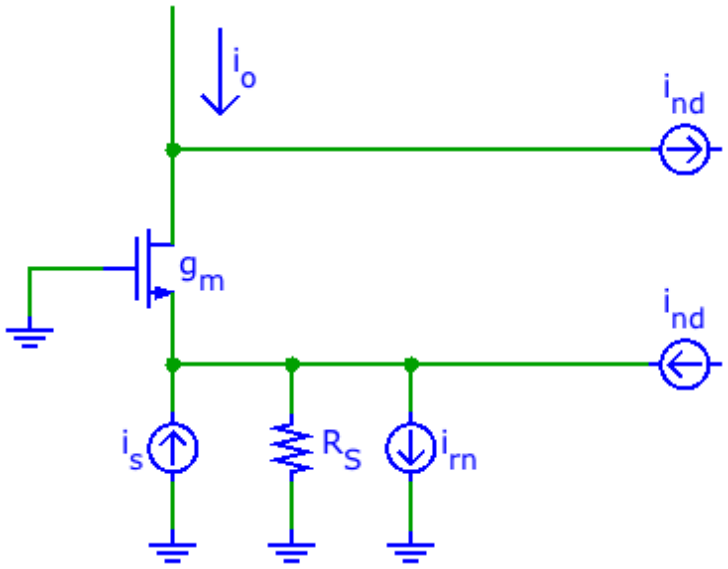
CG Noise Sources



CG Noise Analysis



CG Noise at High Frequency



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Source Follower

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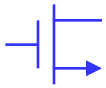

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