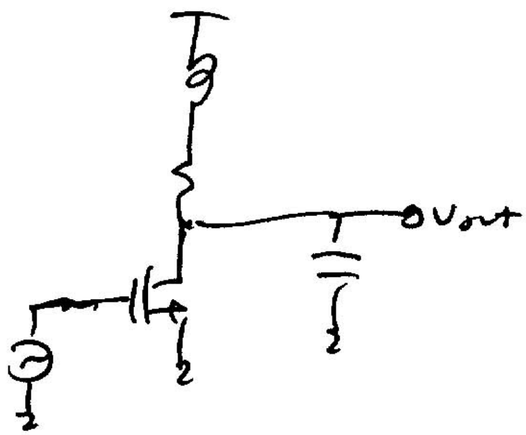
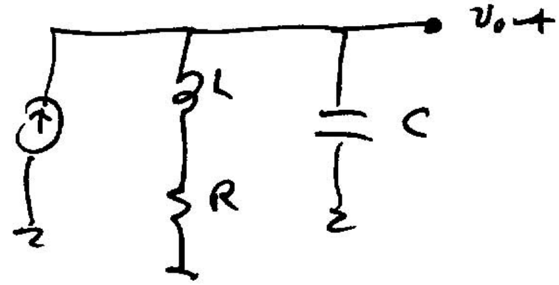
LECTURE 24

SHUNT-PEAKED AMPLIFIER



$\Rightarrow$



$$Z(s) = (sL + R) \parallel \frac{1}{sC} = \frac{R\left(s(L/R) + 1\right)}{s^2 LC + sRC + 1}$$

$$Z(j\omega) = R \sqrt{\frac{(\omega L/R)^2 + 1}{(1 - \omega^2 LC) + (\omega RC)^2}}$$

$$m \equiv \frac{RC}{L/R}$$

$$Z(s) = \frac{R\,(\tau s + 1)}{s^2 \tau^2 m + s\tau m + 1}$$

$$\frac{|Z(j\omega)|}{R} = \sqrt{\frac{(\omega\tau)^2 + 1}{(1 - \omega^2\tau^2 m)^2 + (\omega\tau m)^2}}$$

SOLVE QUADRATIC $= 1/\sqrt{2}$

$$\frac{\omega}{\omega_1} = \sqrt{\left(-\frac{m^2}{2} + m + 1\right) + \sqrt{\left(-\frac{m^2}{2} + m + 1\right)^2 + m^2}}$$

$$\omega = \omega_1$$

$$\omega\tau = 1$$

$$z'(\omega_1) = \sqrt{\frac{2}{(1-m)^2 + m^2}}$$

$$Z(\omega_0) = \frac{1}{\sqrt{2}} Z(0) = \frac{R}{\sqrt{2}}$$

$$\frac{1}{2} = \frac{(\omega\tau)^2 + 1}{(1-\omega^2\tau^2 m)^2 + (\omega\tau m)^2}$$

$$(1-\omega^2\tau^2 m)^2 + (\omega\tau m)^2 = 2(\omega\tau)^2 + 2$$

$$\cancel{1 - 2\omega^4\tau^4 m^2 + \omega}$$

$$0 = 1 - 2\omega^2\tau^2 m + \omega^4\tau^4 m^2 + (\omega\tau m)^2 - 2(\omega\tau)^2 - 2$$

$$x = \omega\tau$$

$$1 - 2x^2 m + x^4 m^2 + x^2 m^2 - 2x^2 - 2 = 0$$

$$x^4 m^2 + x^2(m^2 - 2m - 2) - 1 = 0$$

$$x^2 = \frac{(-m^2 - 2m - 2) \pm \sqrt{(m^2-2m-2)^2 + 4m^2}}{2}$$

MAX BW $m = \sqrt{2} = 1.41$

1.85 X BW ENHANCEMENT!

→ 20% PEAKING

COMPROMISE $\frac{\omega}{\omega_1} = \sqrt{1+\sqrt{5}} = 1.8$

$m = 2$

3% PEAKING

NO PEAKING $m = 1 + \sqrt{2} \simeq 2.41$

LINEAR PHASE DELAY (EQUAL TIME DELAY)

$$T_D = \frac{-d\phi}{d\omega}$$

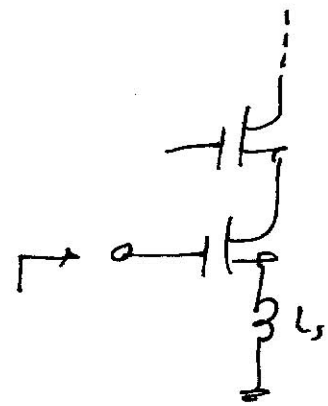
⋮

$$m = 1 + \left(\frac{3+\sqrt{5}}{2}\right)^{1/3} + \left(\frac{3-\sqrt{5}}{2}\right)^{1/3} \approx 3.10$$

ACTIVE FILTER CMOS LNA

CONSIDER THE INPUT IMPEDANCE OF THE INDUCTIVELY DEGENERATED LNA:

IGNORE C_{gd}:



$$Z_1 = \begin{pmatrix} R_G + \frac{1}{j\omega C_{gs}} & 0 \\ \frac{-g_m r_o \| \frac{1}{j\omega C_{ds}}}{j\omega C_{gs}} & r_o \| \frac{1}{j\omega C_{ds}} \end{pmatrix}$$

$$Z_2 = j\omega L_s \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \qquad Z_{11}' = Z_1 + Z_2$$

$$Z_{11}' = j\omega L_s + \frac{1}{j\omega C_{gs}} + R_G$$

$$Z_{in} = j\omega L_s + \frac{1}{j\omega C_{gs}} + R_G - \frac{(j\omega L_s)\left(\frac{-g_m r_o \| \frac{1}{j\omega C_{ds}}}{j\omega C_{gs}}\right)}{r_o \| \frac{1}{j\omega C_{ds}} + R_L}$$

$$\simeq j\omega L_s + \frac{1}{j\omega C_{gs}} + R_G + L_s \left(\frac{g_m}{C_{gs}}\right) \underbrace{\frac{r_o \| \frac{1}{j\omega C_{ds}}}{r_o \| \frac{1}{j\omega C_{ds}} + R_L}}_{\approx 1}$$

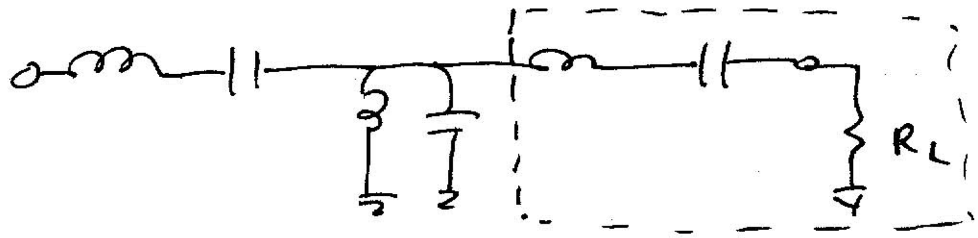
$$Re(Z_{in}) = R_G + \omega_T L_s = R'$$

$$Im(Z_{in}) = j\omega L_s + \frac{1}{j\omega C_{gs}}$$

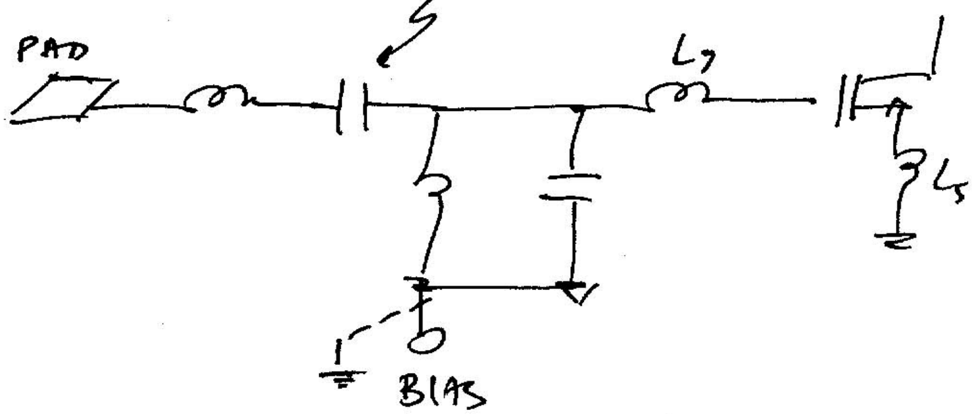
EQ CIRCUIT IS A SERIES RLC CIRCUIT

BUT INPUT RESONANCE IS NOT AT FREQ ω_0.
THE Q L_s ALSO NOT UNDER OUR CONTROL ...

OBSERVATION: A FILTER (BANDPASS) LOOKS LIKE



WE CAN ABSORB THE AMPLIFIER INPUT INTO THE FILTER



CHEBYCHEV FILTER: RIPPLE GIVEN BY ρ_p

$$|\Gamma|^2 = 1 - \frac{1}{\rho_p}$$

CHOOSE RIPPLE SMALL ENOUGH TO MEET INPUT SPECS

$$|\Gamma| < -10\,dB \Rightarrow \rho_p < 0.46\,dB$$

GAIN

$$\frac{v_o}{v_{in}} = -\frac{g_m W(s)}{s C_{gs} R_s} \times Z_L(s)$$

$$Z_{in} = \frac{R_s}{W(s)}$$

W(s) CHEBYCHEV FILTER TRANSFER FUNC

$|W(s)| \approx 1$ IN BAND

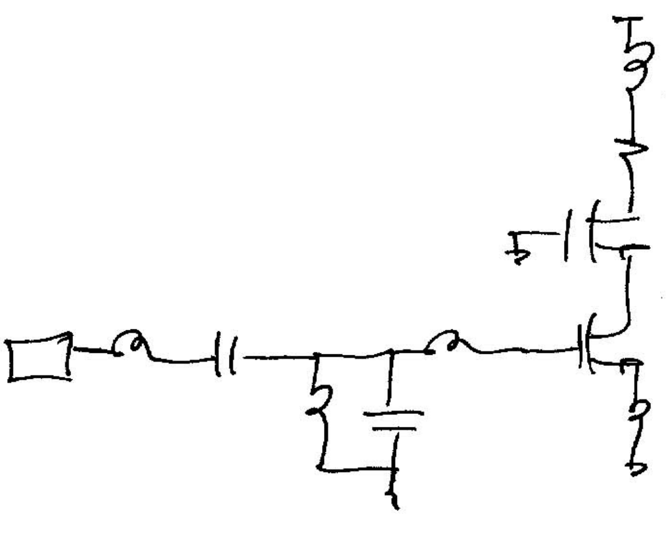
$|W(s)| \approx 0$ OUT OF BAND

$$i_{in} = \frac{v_{in} W(s)}{R_s}$$

$$\beta = \frac{g_m}{s C_{gs}}$$ (CURRENT GAIN)

USE A SHUNT-PEAKED LOAD TO EXTEND BW & COMPENSATE FOR CURRENT GAIN ROLL-OFF

$$Z_L(s) = \frac{R_L(1 + sL_L/R_L)}{1 + s R_L C_{out} + s^2 L_L C_{out}}$$



SHUNT-PEAKED LOAD

NOISE ANALYSIS

EQUIV INPUT GENERATORS: $i_n = i_{ng} + \frac{j\omega C_{gs}}{g_m} i_{nd}$

$$e_n = j\omega L_s i_{ng} + \left(1 - \omega^2 C_{gs} L_s\right) \frac{i_{nd}}{g_m}$$

$$\simeq \frac{i_{nd}}{g_m} + j\omega L_s i_{ng}$$

$$\overline{i_{ng}^2} = 4kT\delta \frac{\omega^2 C_{gs}^2}{5 g_{do}} \qquad \overline{i_{nd}^2} = 4kT\gamma g_{do}$$

$\Rightarrow$ STANDARD ANALYSIS ...

$$R_{opt} = \sqrt{\frac{R_u}{G_n} + R_c^2} = \sqrt{\frac{R_u}{G_n}}$$

$$= \frac{p\alpha\chi\sqrt{1-|c|^2}}{\omega C_{gs}\left(1 + 2|c|p\alpha\chi + p^2\alpha^2\chi^2\right)}$$

$$X_{opt} = -X_c$$

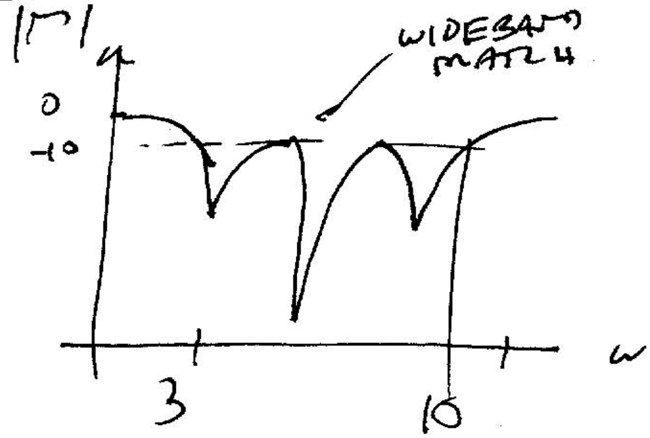
$$Z_c = jX_c = \frac{1 - \omega^2 L_s C_{gs} \frac{1 + 2|c|p\alpha\chi + p^2\alpha^2\chi^2}{1 + |c|p\alpha\chi}}{j\omega C_{gs} \frac{1 + 2|c|p\alpha\chi + p^2\alpha^2\chi^2}{1 + |c|p\alpha\chi}}$$

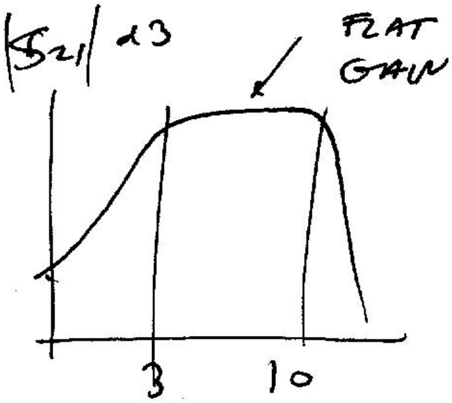
$$p = \frac{C_{gs}}{C_t} \qquad p = 1 \text{ IN THIS CASE}$$

$$\chi = \sqrt{\delta/5\gamma} \qquad c = \frac{\langle i_{ng}, i_{nd} \rangle}{\sqrt{\overline{i_{ng}^2}\ \overline{i_{nd}^2}}} \approx 0.4j$$

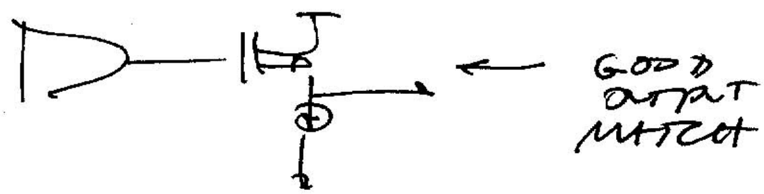
$$\alpha = \frac{g_m}{g_{do}}$$

DESIGN EXAMPLE 3–10 GHz LNA



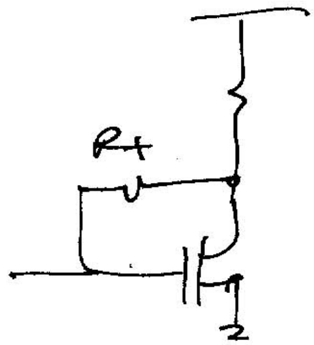


COMPLETE AMP CAN DRIVE MIXER INPUT DIRECTLY OR A REAL LOAD THRU A BUFFER



CAN SHOW THAT NEARLY OPTIMUM NOISE PERF CAN BE ACHIEVED WITH A POWER MATCH.

NOISE IN SHUNT FB AMP



$$Y_{FET} \cong \begin{pmatrix} j\omega C_{gs} & 0 \\ g_m & j\omega C_{ds} \end{pmatrix}$$

$$Y_f = \begin{pmatrix} G_f & -G_f \\ -G_f & G_f \end{pmatrix}$$

$$Y_{in} = Y_{11} - \frac{Y_{12} Y_{21}}{Y_{22} + Y_L}$$

$$= G_f + j\omega C_{gs} - \frac{-G_f \cdot (g_m - G_f)}{j\omega C_{ds} + G_f + G_L}$$

$$= G_f + j\omega C_{gs} + \frac{G_f (g_m - G_f)}{j\omega C_{ds} + G_f + G_L}$$

$$\mathrm{Re}\{Y_{in}(\text{LOW FREQ})\} = G_f + \frac{G_f (g_m - G_f)}{G_f + G_L}$$

$$\approx \cancel{G_f} + \frac{\cancel{G_f}\, g_m}{\cancel{G_f}} - \frac{\cancel{G_f^2}}{\cancel{G_f}} \approx g_m$$

→ LOW FREQ

→ HIGH LOAD IMPEDANCE (BUFFER)

WANT $|G_f + G_L| \gg |j\omega C'_{ds}| = \omega(C_{ds} + C_L)$

$$\omega < \frac{G_f + G_L}{C_{ds} + C_L} \cong \frac{1}{R_f(C_{ds} + C_L)}$$

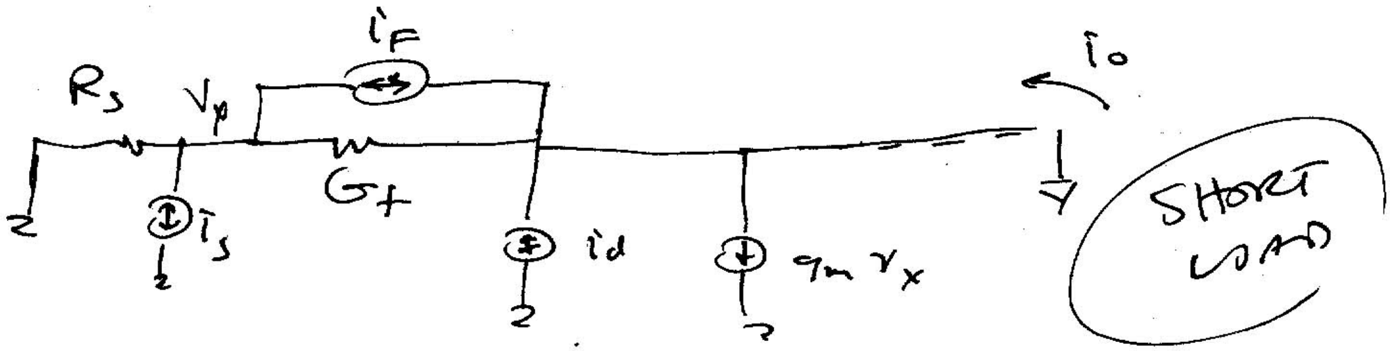
SAY $\omega_0 = 10\,GHz \cdot 2\pi \Rightarrow R_f < \frac{1}{\omega_0\, 50f}$

$C_{ds} + C_L \simeq 50f$

$$R_f < \frac{1}{2\pi \times 10 \times 10^9 \times 50 \times 10^{-15}}$$

$$= \frac{1}{\cancel{2}\pi \cdot 10^{\cancel{11}} \cdot 10^{-15} \cdot \cancel{5}} \simeq \frac{10^3}{\pi} \simeq 300\Omega$$

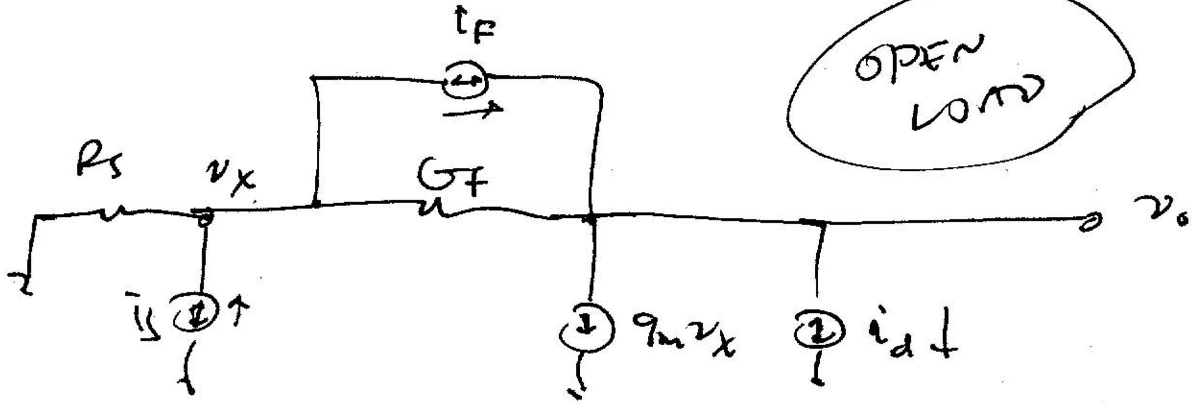
WHAT ABOUT NOISE? CONSIDER ONLY DRAIN NOISE



$$i_o = g_m v_x + i_d + i_F + i_s \frac{G_f}{G_f + G_s}$$

$$\cancel{v_x = i_s \frac{G_s}{G_s + G_f} R_s}$$

$$\frac{v_x}{R_s} + i_s + i_F + \frac{v_x}{R_F} = 0$$



$$(v_o - v_x)G_f + g_m v_x + i_d + i_F = 0$$

$$\underline{v_x G_s} + i_F + (v_x - v_o)G_f - i_s = 0$$

$$v_x(G_s + G_f) = v_o G_f + i_s - i_F$$

$$v_o G_f + (g_m - G_f)\, v_x = i_F - i_d$$

$$v_o G_f + \frac{(g_m - G_f)}{G_s + G_f}\left(v_o G_f + i_s - i_F\right) = i_F - i_d$$

$$v_o G_f\left(1 + \frac{g_m - G_f}{G_s + G_f}\right) = i_F\left(1 + \frac{g_m - G_f}{G_s + G_f}\right) - i_d - i_s\frac{(g_m - G_f)}{G_s + G_f}$$

$$v_o G_f(G_s + g_m) = i_F(g_m + G_s) - i_s(g_m - G_f) - i_d(G_s + G_f)$$

$$v_0 = i_F R_F - i_s R_F \frac{g_m - G_f}{g_m + G_s} - i_d R_F \frac{(G_s + G_f)}{G_s + g_m}$$

$$\overline{v_0^2} = R_F^2 \, \overline{i_F^2} + R_F^2 \frac{(g_m - G_f)^2}{(g_m + G_s)^2} \, \overline{i_s^2} + R_F^2 \left(\frac{G_s + G_f}{G_s + g_m}\right)^2 \overline{i_d^2}$$

$$F = 1 + \cancel{4} \frac{G_F}{G_S} \left(\frac{g_m + G_s}{g_m - G_f}\right)^2 + \frac{\gamma g_{d0}}{G_s} \left(\frac{G_s + G_f}{g_m - G_f}\right)^2$$

$$\cong 1 + \frac{R_s}{R_F} \frac{4 g_m^2}{g_m^2} + \frac{\gamma}{\alpha} \left(\cancel{g_m R_s}^{\,1}\right) \frac{g_m^2}{g_m^2}$$

$g_m R_s = 1$

$G_s >> G_f$

$$F = 1 + \frac{\gamma}{\alpha} + \frac{R_S}{R_F} \times 4$$

$$= 1 + \frac{\gamma}{\alpha} + \frac{1}{g_m R_F} \times 4$$

$g_m R_F = 4$

$F = 2 + \gamma/\alpha$

HIGH

BAD

$g_m R_F >> 1$

OK

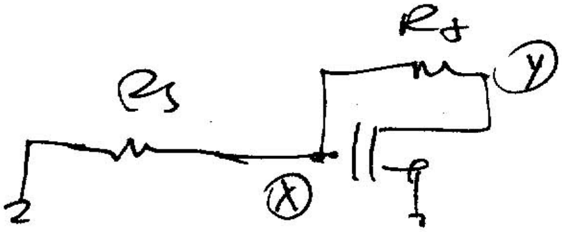
BIPOLAR AMP: $g_m = \frac{I_C}{V_T}$ $\quad \frac{1}{g_m} = 25\,\Omega/(mA)$

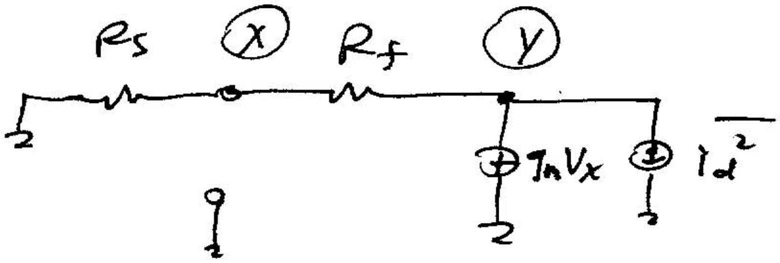
$I_C = 10\,mA$ $\quad \frac{1}{g_m} = 2.5\,\Omega$

$R_F = 250\,\Omega$

NOISE IN BROADBAND SHUNT FEEDBACK AMP

CONSIDER DRAIN NOISE:





IGNORE ALL CAPS

$$v_x = v_y \frac{R_s}{R_s + R_f}$$

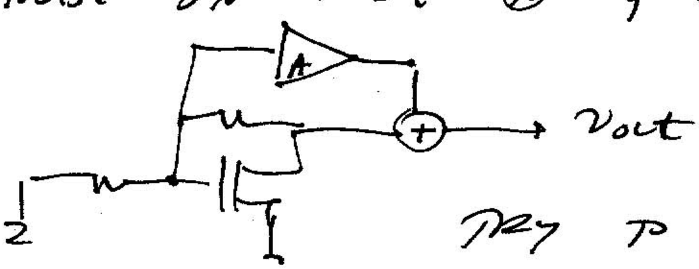
KCL AT Y: $\pm i_d + g_m v_x + \frac{v_y}{R_s + R_f} = 0$

OR $i_d = g_m v_x + \frac{1}{R_s} v_x$

$$v_x = \frac{R_s}{1 + g_m R_s} i_d$$

$$v_y = \frac{R_s + R_f}{1 + g_m R_s} i_d$$

THE NOISE ON NODE X & Y IS CORRELATED!



TRY TO CANCEL NOISE OUT!

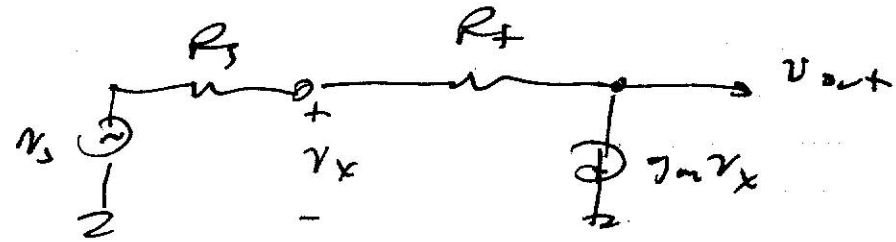
$$-A v_x = v_y \quad \Rightarrow \quad -R_s A = R_s + R_f$$

$$\boxed{A = -\ 1 + \frac{R_f}{R_s}}$$

WHAT ABOUT SIGNAL? DRAIN VOLTAGE IS 180° OUT OF PHASE SO SIGNALS ADD

$$v_y^{SIG} = v_x(\underbrace{A_1}_{\text{ORIG AMP}} + A)$$

ORIG AMP:



$$g_m v_x + \frac{v_{out} - v_s}{R_s + R_f} = 0$$

MATCH $v_x = \frac{1}{2} v_s$

$$\frac{g_m}{2} v_s + \frac{V_{out} - V_s}{R_s + R_f} = 0$$

$$V_{out} - V_s + \frac{g_m}{2}(R_s + R_f) V_s = 0$$

$$\frac{V_{out}}{V_s} = 1 \cancel{+} - \frac{g_m}{2}(R_s + R_f)$$

GENERAL CASE:

$$\frac{v_x - v_s}{R_s} + \frac{v_x - v_{out}}{R_f} = 0$$

$$(v_x - v_s) R_f + (v_x - v_{out}) R_s = 0$$

$$v_x (R_f + R_s) = v_s R_f + v_{out} R_s$$

$$v_x = v_s \frac{R_f}{R_f + R_s} + v_{out} \frac{R_s}{R_s + R_f}$$

$$g_m v_s \frac{R_f}{\cancel{R_s + R_f}} + g_m v_{out} \frac{R_s}{\cancel{R_s + R_f}} + \frac{v_{out} - v_s}{\cancel{R_s + R_f}} = 0$$

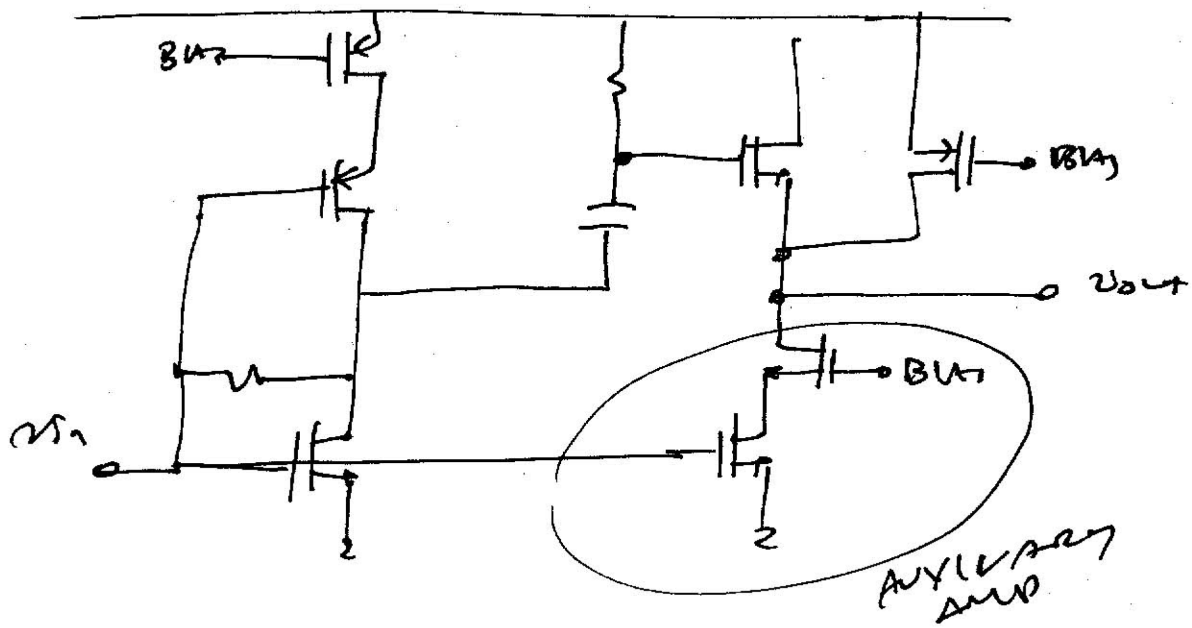
$$(g_m R_f - 1) v_s = -(1 + g_m R_s) v_{out}$$

$$\frac{v_{out}}{v_s} = -\frac{g_m R_f - 1}{1 + g_m R_s} = \frac{1 - g_m R_f}{1 + g_m R_s}$$

$$g_m R_s = 1$$

$$\frac{v_{out}}{v_s} = \frac{1 - g_m R_f}{2}$$

COMPLETE AMP



DESIGN AUX AMP FOR LOW NOISE
DESIGN MAIN AMP FOR MATCH