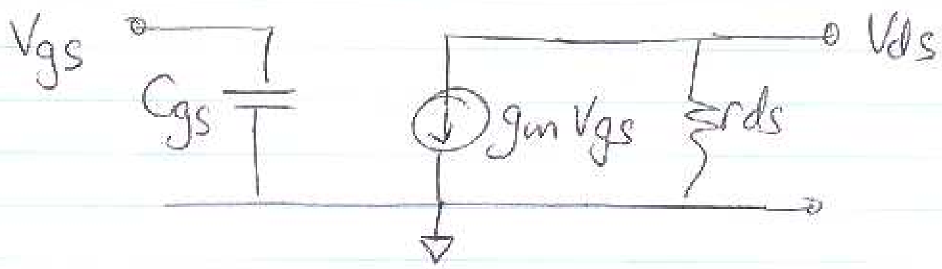
RF IC Design Sample Paper 2004
Sample answers to Kevin McCarthy's section.

Q1

(a) Directly from the notes



$$I_{DS} = \frac{1}{2}\frac{W}{L}\mu C_{ox}(V_{gs}-V_{TH})^2(1+\lambda V_{DS})$$

$$I_{DS} \approx \frac{1}{2}\frac{W}{L}\mu C_{ox}(V_{gs}-V_{TH})^2$$

$$\Rightarrow g_m = \frac{dI_{ds}}{dV_{ds}} = \frac{W}{L}\mu C_{ox}(V_{gs}-V_{TH})$$

$$g_{ds} = \frac{dI_{ds}}{dV_{DS}} = \lambda\frac{1}{2}\frac{W}{L}\mu C_{ox}(V_{gs}-V_{TH})^2 \simeq \lambda I_{DS}$$

$$r_{ds} = \frac{1}{g_{ds}}$$

Cut off frequency (following derivation in notes):

$$f_T = \frac{g_m}{2\pi C_{gs}}$$

Note: Q7 not answered as it's straight out of the notes.

(b) $\mu = 400\ cm^2/Vs = 400 \times 10^{-4} = 0.04\ m^2/Vs$

$$C_{ox} = \frac{\epsilon_{ox}}{T_{ox}} = \frac{(\epsilon_r)_{ox}\,\epsilon_0}{T_{ox}} = \frac{3.9 \times 8.854 \times 10^{-12}}{4 \times 10^{-9}}$$

$$= 0.0086\ F/m^2$$

$V_{GS} - V_{TH} = 2.5 - 0.5 = 2V$

~~I_{DS}~~ Not given V_{DS} so ignore λ factor for I_{DS} calculation

$$I_{DS} = \frac{1}{2}\ \frac{10 \times 10^{-6}}{0.25 \times 10^{-6}} \times 0.04 \times 0.0086 \times 2^2$$

$$= 0.0275\ A$$
$$= 27.5\ mA$$

$$g_m = \frac{10 \times 10^{-6}}{0.25 \times 10^{-6}} \times 0.04 \times 0.0086 \times 2$$

$$= 0.0275\ A/V$$
$$= 27.5\ mA/V$$

(just a coincidence that g_m and I_{DS} worked out the same for this bias voltage).

The total gate oxide capacitance is

$$C_{GS} = C_{ox\,TOTAL} = C_{ox} \cdot WL$$
$$= (0.0086)(10 \times 10^{-6})(0.25 \times 10^{-6})$$
$$= 2.15 \times 10^{-14} F$$
$$= 21.5\ fF$$

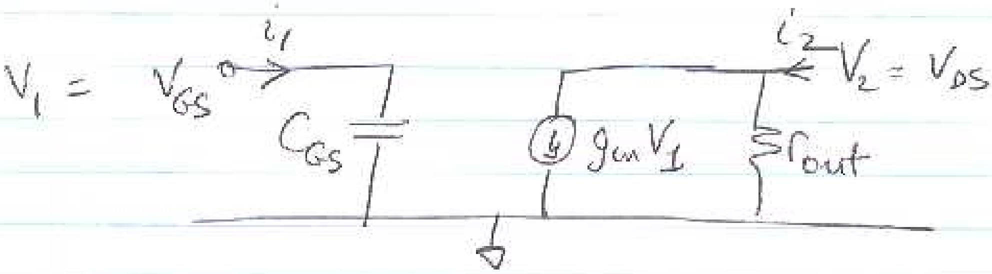
$$f_T = \frac{g_m}{2\pi C_{GS}} = \frac{27.5 \times 10^{-3}}{2\pi \times 21.5 \times 10^{-15}} = 200\,G\text{[illegible]}$$

(~~bit~~ very unrealistic for this dimension)

Q1(b) Continued

$$g_{ds} = \lambda I_{DS}$$
$$= 0.1 \times 0.0275$$
$$= 0.00275$$
$$= 2.75 \text{ mA/V}$$

$$r_{ds} = \frac{1}{g_{ds}} = 364\ \Omega$$



Y-parameters

$$y_{11} = \frac{i_1}{V_1}\bigg|_{V_2=0} = \frac{j\omega C_{GS} V_1}{V_1} = j\omega C_{GS}$$

$$y_{12} = \frac{i_1}{v_2}\bigg|_{v_1=0} = \frac{0}{V_2} = 0$$

$$y_{21} = \frac{i_2}{v_1}\bigg|_{v_2=0} = \frac{g_m v_1}{v_1} = g_m = 0.0275$$

$$y_{22} = \frac{i_2}{v_2}\bigg|_{v_1=0} = \frac{v_2 / r_{out}}{v_2} = \frac{1}{r_{out}} = g_{ds}$$
$$= 0.00275$$

The only frequency-dependent term is y_{11}

At 1 GHz, $y_{11} = j\omega C_{GS} = j\, 2\pi \times 10^9 \times 2.15 \times 10^{-14}$

$$= j\, 1.35 \times 10^{-4}$$

$$|y_{11}| = 1.35 \times 10^{-4} \text{ A/V}.$$

Question 2

2(a) Derivation from notes i.e. full derivation is expected leading to:

$$f = 1 + \frac{\overline{(v_n + R_s\, i_n)^2}}{4kTR_s}$$

$\Delta f =$ for 1 Hz

2(b) Use the "normal" small signal circuit to calculate the small signal quantities and the formulas given to calculate v_n and i_n and then do the calculation for the 3 source impedances given.

$$g_m = \frac{q}{kT} I_C = 0.0387 \quad A/V$$

$\beta = 100$ given

Using given T, r_b, β for a 1 Hz bandwidth

$v_n = 1.02 \times 10^{-9}$

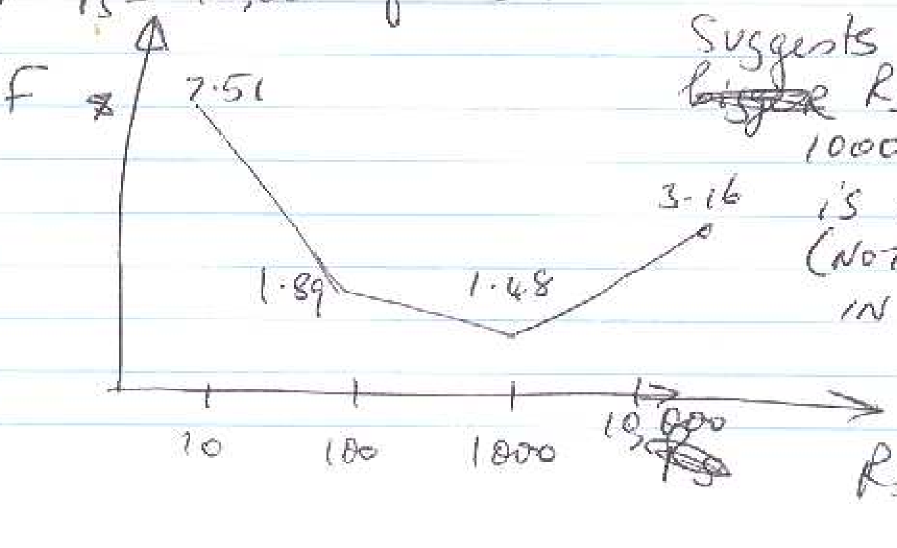
$i_n = 1.79 \times 10^{-12}$

(i) $r_s = 10$, $f = 7.51$

(ii) $r_s = 100$, $f = 1.89$

(iii) $r_s = 1000$, $f =$ ~~[illegible]~~ 1.48

(iv) $r_s = 10{,}000$ $f = 3.16$



Suggests that the ~~bigger~~ Rs between 1000 and 10000 Ω is optimum. (NOT VERY LIKELY IN PRACTICE!)

Question 3

(a) From notes (except easier because can set $\alpha_0 = 0$, $\alpha_2 = 0$ from beginning)
i.e. have to go through derivation similar to the notes leading to the final formula

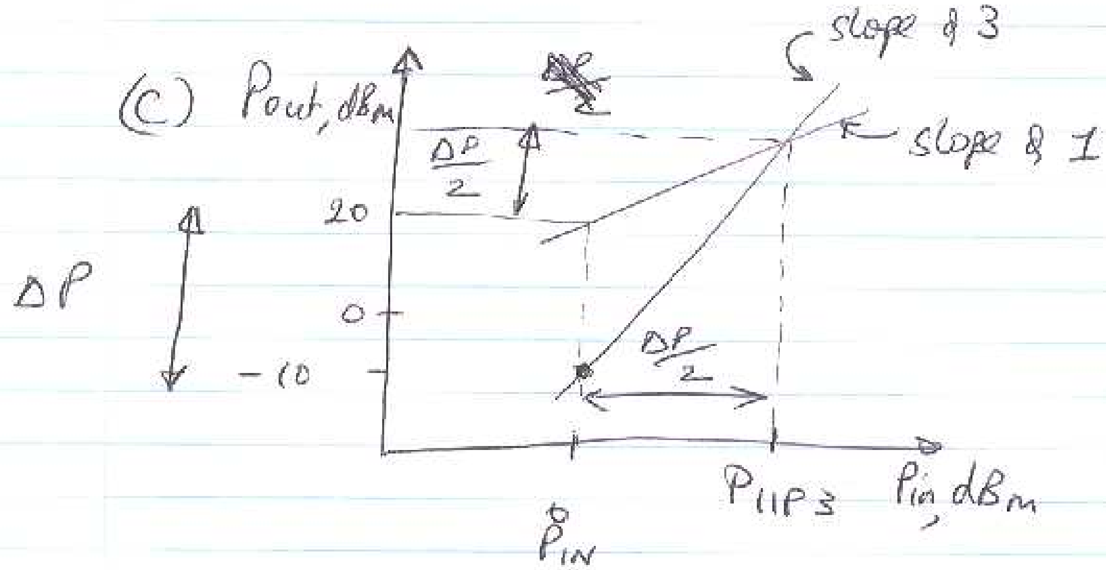
~~P_{1dB} =~~

$$A_{1dB} = \sqrt{0.145 \left| \frac{\alpha_1}{\alpha_3} \right|}$$

(b)

$$A_{1dB} = 3.81 \quad V$$

(c)



$$\Delta P = 30\,dBm \Rightarrow$$

$$P_{IIP3} = P_{IN} + \frac{\Delta P}{2} = 0 + \frac{30}{2} = 15\,dBm$$

(mainly a test of remembering the graphical rule)

Slight typo in question - "third harmonics" should have read "third order IM products".

Q6(c) – Derivation from notes and "picture" of hyperabrupt diode

Question 6

6(a) Pick a topology from the notes and draw the circuit diagram.

(b) $$f = \frac{1}{2\pi\sqrt{LC}} \Rightarrow C = \frac{1}{L} \cdot \frac{1}{(2\pi f)^2}$$

$L = 1\,nH$

$f = 1.8\,GHz \Rightarrow C = 2.6\,pF$

$f = 2.0\,GHz \Rightarrow C = 2.11\,pF$

This is the total capacitance ie.

$$C = C_{Diode} + C_{PAR} \Rightarrow C_{DIODE} = C - C_{PAR}$$

$f = 1.8\,GHz \therefore C_{Diode} = 2.6 - 1 = 1.6\,pF$

$f = 2\,GHz \therefore C_{DIODE} = 2.11 - 1 = 1.11\,pF$

$\therefore$ Zero biasd capacitance $C_{JO} = 1.6\,pF$

With reverse bias:

$$C = \frac{C_{JO}}{\left(1 - \frac{V_D}{V_J}\right)^m}$$

here $M_J = 0.5$, $V_J = 0.8$

$$C = \frac{C_{JO}}{\sqrt{1 - \frac{V_D}{0.8}}} \Rightarrow \left(\frac{C}{C_{JO}}\right)^2 = \frac{1}{\left(1 - \frac{V_D}{0.8}\right)}$$

$$\Rightarrow 1 - \frac{V_D}{0.8} = \left(\frac{C_{JO}}{C}\right)^2 \Rightarrow V_D = 0.8\left(1 - \left(\frac{C_{JO}}{C}\right)^2\right)$$

$$V_D = 0.8\left(1 - \left(\frac{1.6}{1.11}\right)^2\right) = -0.86\,V.$$