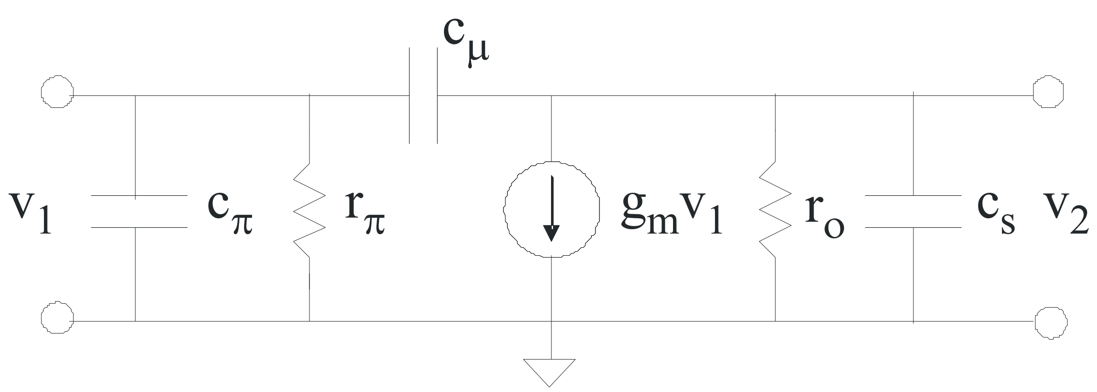
EE4011 RF IC Design Summer 2010
Question 1(a) 14 marks




$$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0} \qquad y_{21} = \left.\frac{i_2}{v_1}\right|_{v_2=0} \qquad y_{12} = \left.\frac{i_1}{v_2}\right|_{v_1=0} \qquad y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$

Applying the y-parameter definitions to the above circuit and performing the circuit analysis under the appropriate conditions gives:

$$y_{11} = \frac{1}{r_\pi} + j\omega\left(c_\pi + c_\mu\right)$$

$$y_{12} = -j\omega c_\mu$$

$$y_{21} = g_m - j\omega c_\mu$$

$$y_{22} = \frac{1}{r_o} + j\omega\left(c_s + c_\mu\right)$$

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Question 1(a) continued

The equations on the previous page have to be manipulated to give the small signal-element values as follows:

$$g_m = \mathbf{Re}(y_{21}) = 0.15S$$

$$r_\pi = \frac{1}{\mathbf{Re}(y_{11})} = 250\Omega$$

$$r_o = \frac{1}{\mathbf{Re}(y_{22})} = 1.5k\Omega$$

$$c_\mu = \frac{-\mathbf{Im}(y_{12})}{2\pi f} = 0.7\,pF$$

$$c_\pi = \frac{\mathbf{Im}(y_{11})}{2\pi f} - c_\mu = 4.5\,pF$$

$$c_s = \frac{\mathbf{Im}(y_{22})}{2\pi f} - c_\mu = 0.3\,pF$$

Question 1(b) 6 marks

$$V_T = \frac{kT}{q} = 25.9mV$$

(i) $I_C = g_m V_T = 3.9mA$

(ii) $V_A = r_o I_C = 5.82V$

(iii) $\beta = g_m r_\pi = 37.5$

(iv) $f_T = \dfrac{g_m}{2\pi(c_\pi + c_\mu)} = 4.59GHz$

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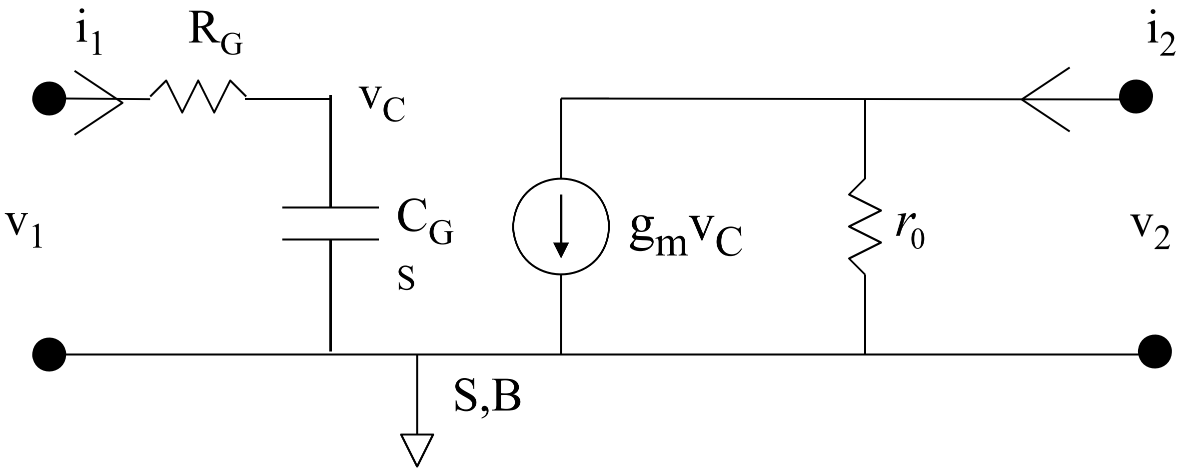
Question 2(a) 8 marks




Applying the z-parameter definitions to the above circuit and performing the circuit analysis under the appropriate conditions gives:

$$z_{11} = \left.\frac{v_1}{i_1}\right|_{i_2=0} = R_G + \frac{1}{j\varpi c_{GS}}$$

$$z_{21} = \left.\frac{v_2}{i_1}\right|_{i_2=0} = -\frac{g_m r_o}{j\varpi c_{GS}}$$

$$z_{12} = \left.\frac{v_1}{i_2}\right|_{i_1=0} = 0$$

$$z_{22} = \left.\frac{v_2}{i_2}\right|_{i_1=0} = r_o$$

Question 2(b) 8 marks

$$C'_{OX} = \frac{\varepsilon_{OX}}{T_{OX}} \qquad V_{DS} > \left(V_{GS} - V_{TH}\right) \text{ so MOSFET in saturation}$$

For a MOSFET in saturation:

$$I_{DS} = \frac{1}{2}\frac{W}{L}\mu C'_{OX}\left(V_{GS} - V_{TH}\right)^2\left(1 + \lambda V_{DS}\right)$$

$$g_m = \frac{W}{L}\mu C'_{OX}\left(V_{GS} - V_{TH}\right) = \sqrt{2\frac{W}{L}\mu C'_{OX} I_{DS}}$$

$$g_{ds} = \frac{1}{r_O} \frac{1}{2}\frac{W}{L}\mu C'_{OX}\left(V_{GS} - V_{TH}\right)^2 \lambda$$

$$C_{GS} = \frac{2}{3} WLC'_{OX}$$

Doing the calculations and inserting these values into the previous formulas for the z-parameters at 1GHz gives:

$z_{11} = 987.7 \angle -89.4°$ $z_{12} = 0$ $z_{21} = 13929 \angle 90°$ $z_{22} = 100 \angle 0°$

(c) 4 marks

Gate resistance with parallel layout and gate contacted at both sides.

$$R_{Geff} = \frac{R_G}{4N^2} = \frac{10}{4 \times 25} = 0.1\Omega$$

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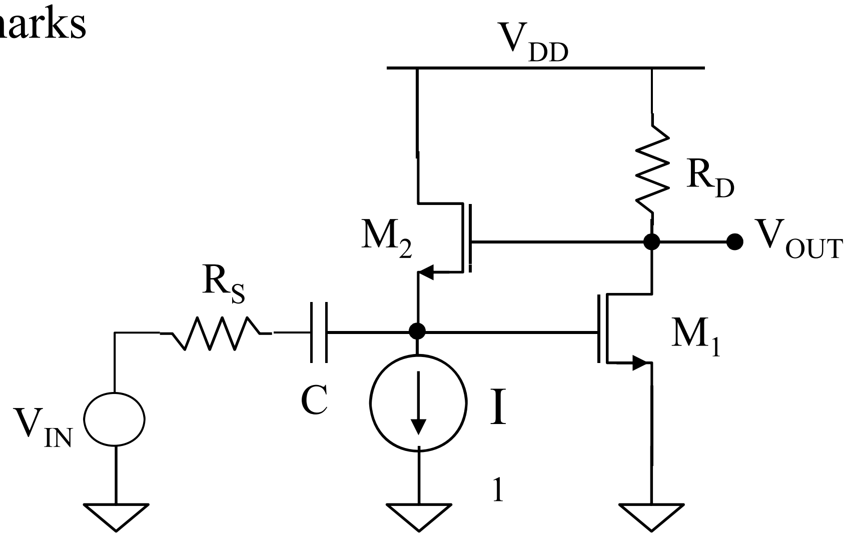
Question 3

3(a) 3 marks

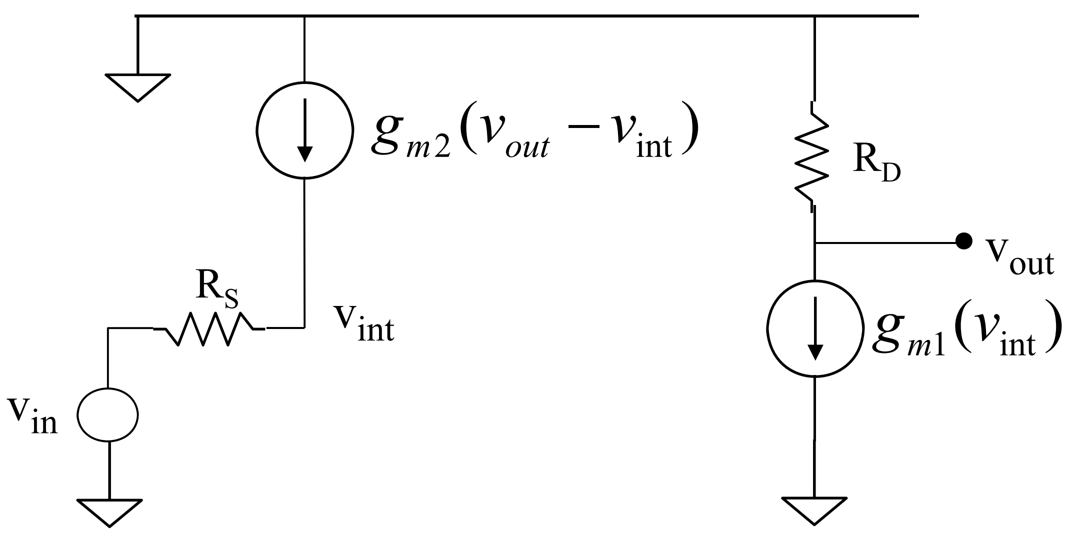
$$\text{Noise Figure, NF} = 10\log_{10}\left(\frac{SNR_{in}}{SNR_{out}}\right) \quad (\text{in dB}, \geq 0)$$

$SNR_{in}$ = (signal power in)/(noise power in)
$SNR_{out}$ = (signal power out)/(noise power out)

3(b) 7 marks




Using all the assumptions stated in the question, the circuit to calculate the small-signal gain is as follows:



Question 3(b) continued

Going through the small-signal analysis of the circuit on the previous page will produce the formulas for output voltage and circuit gain:

$$v_{out} = -R_D g_{m1} \frac{v_{in}}{1 + R_S g_{m2}(1 + R_D g_{m1})}$$

$$v_{out} = -R_D g_{m1} \frac{v_{in}}{1 + R_S g_{m2}(1 + R_D g_{m1})}$$

$$A = \frac{v_{out}}{v_{in}} = -\frac{R_D g_{m1}}{1 + R_S g_{m2}(1 + R_D g_{m1})}$$

3(c)

The noise contributed by is the source resistance $R_S$ is

$$v^2{}_{n,in} = 4kTR_S \qquad v^2 / Hz$$

The signal to noise ratio at the input in then:

$$SNR_{in} \frac{v^2{}_{in}}{v^2{}_{n,in}} = \frac{v^2{}_{in}}{4kTR_S}$$

To calculate the SNR at the output, the total noise at the output from both $R_S$ and $R_D$ have to be calculated. The output noise from the source resistance can be calculated just assuming the source resistance is a normal input voltage source i.e.

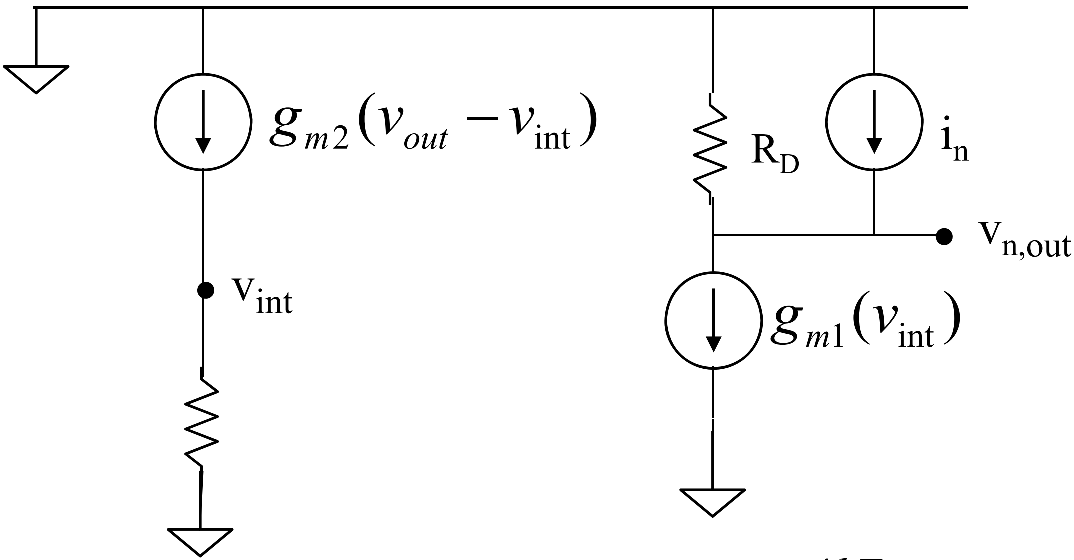
$$\left(v^2{}_{n,out}\right)_{RS} = A^2 4kTR_S$$

Similarly the signal power at the output can be calculated from the gain of the circuit:

$$v^2{}_{out} = A^2 v^2{}_{in}$$

Question 3(c) continued

To calculate the noise contributed at the output from $R_D$, a new circuit analysis has to be performed assuming the noise current from $R_D$ is the only signal supplied in the circuit.




$$i^2_{n,RD} = \frac{4kT}{R_D} \quad \text{A}^2/\text{Hz}$$

Working through the small-signal analysis of this circuit gives the Output voltage noise caused by $R_D$ as:

$$\left(v^2_{n,out}\right)_{RD} = \frac{4kT / R_D}{\left(\dfrac{1}{R_D} + \dfrac{g_{m1} R_S g_{m2}}{1 + R_S g_{m2}}\right)}$$

The total o/p noise is then

$$v^2_{n,out} = \left(v^2_{n,out}\right)_{RS} + \left(v^2_{n,out}\right)_{RD} = A^2 4kTR_S + \frac{4kT / R_D}{\left(\dfrac{1}{R_D} + \dfrac{g_{m1} R_S g_{m2}}{1 + R_S g_{m2}}\right)}$$

$$SNR_{out} = \frac{v^2 out}{v^2_{n,out}} \qquad F = \frac{SNR_{in}}{SNR_{out}}$$

As the expressions which include output noise are cumbersome the final three expressions with those on the previous page will be accepted as the answer.

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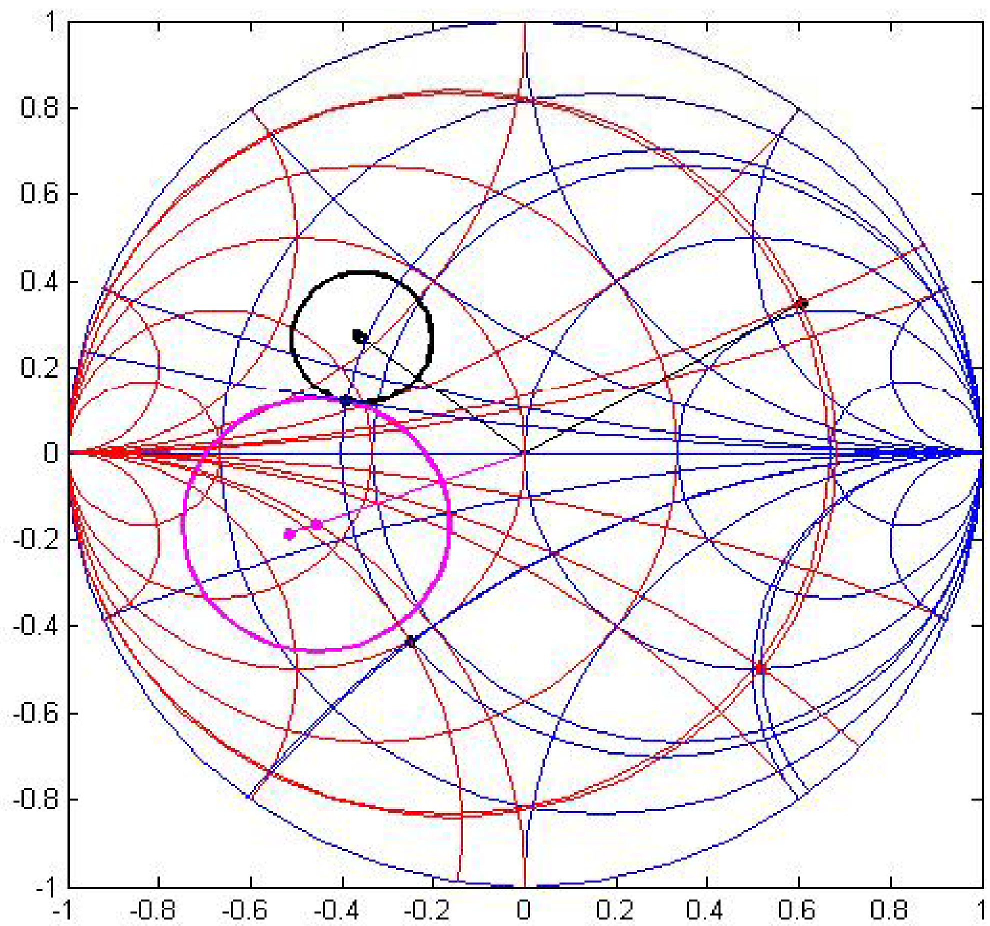
Question 4

The Smith Chart for parts (a) and (b) is shown below:



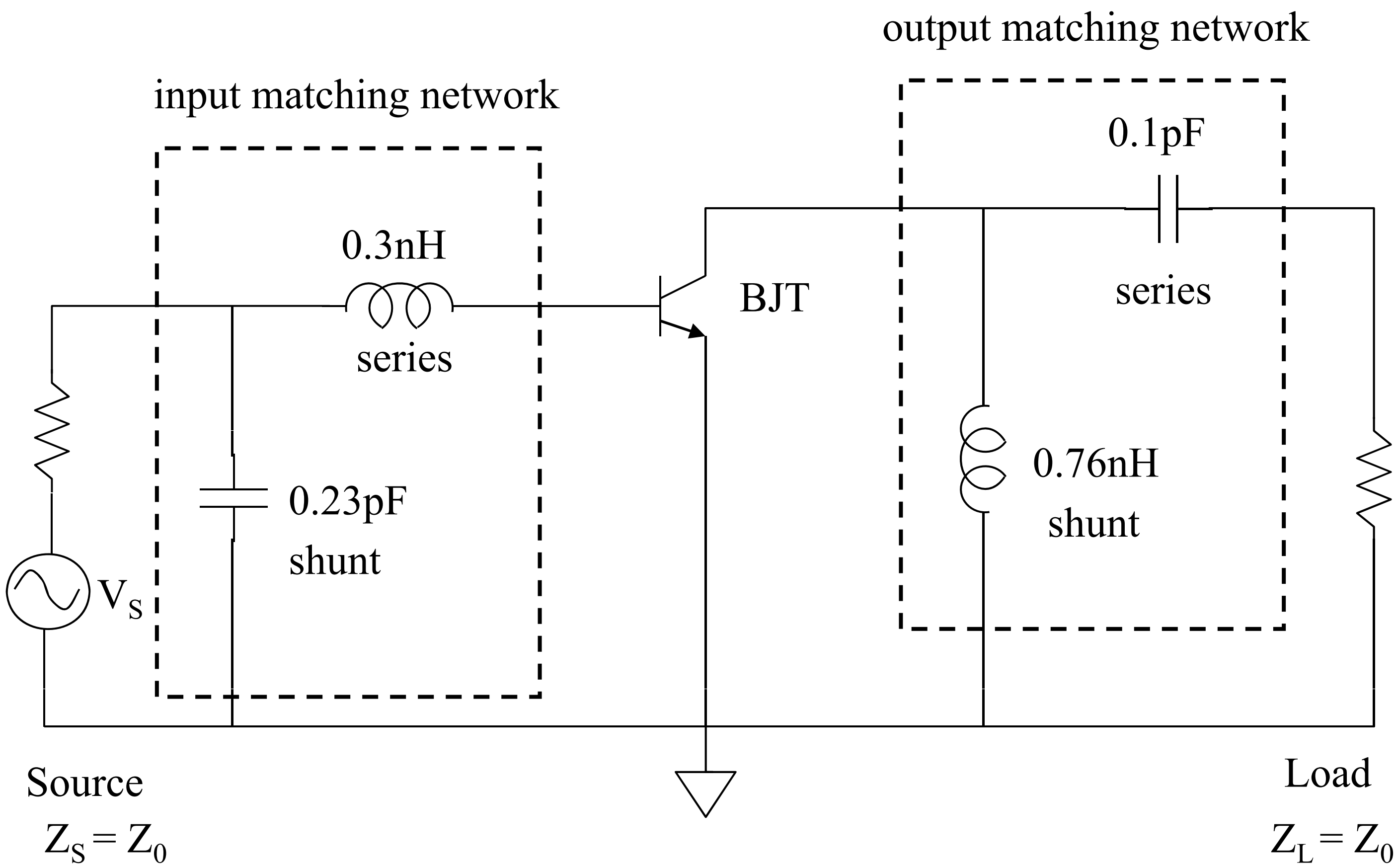

Calculations for D and k show that the transistor will make a stable amplifier. (3 marks)

The noise circle is the larger circle shown (3 marks)

Drawing one or two sample source gain circles shows that the largest gain that can be achieved to meet the noise criterion is 8.4dB

The matching transformations and calculations give the matching network shown on the next page (15 marks)

Question 4(b) continued

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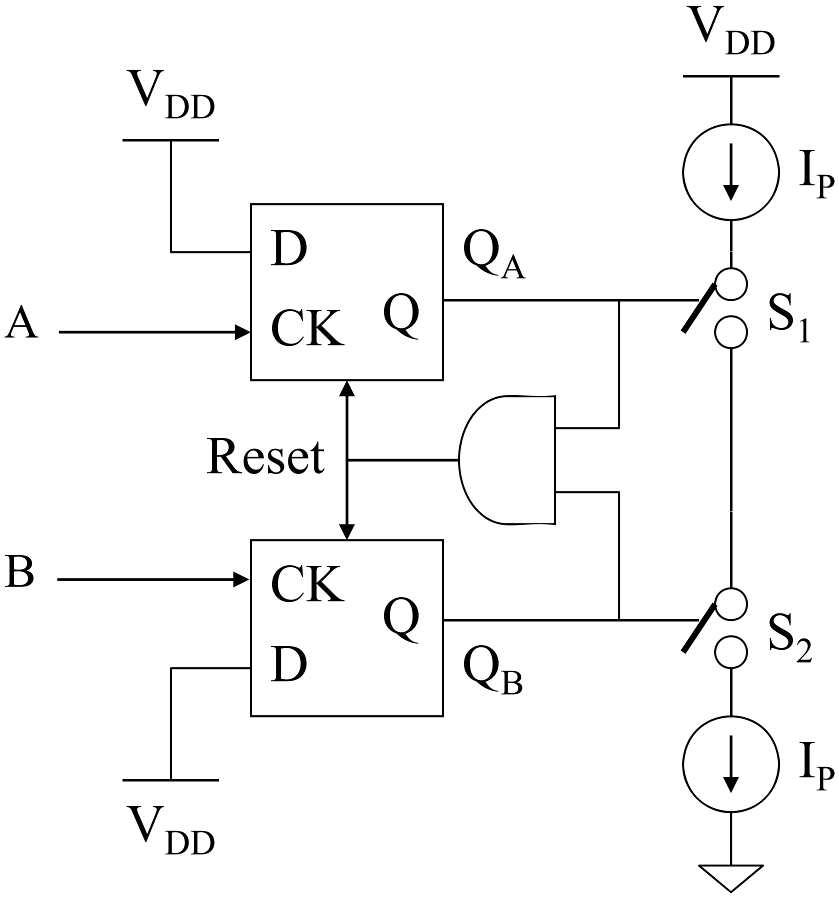
Question 5 concerns derivations from the notes

Question 6

6(a) 5 marks

Suitable PD with transfer function




$$I(s) = \frac{I_P}{2\pi} \Delta \varphi(s)$$

(b) The control voltage is given by:

$$V_C(s) = \frac{I_P}{2\pi}\left(\frac{R_P C_P s + 1}{\left(R_P C_P C_2 s + C_P + C_2\right)s}\right)\Delta \varphi(s)$$

The transfer function is found from this through a closed loop analysis.

Q6(c) concerns production of clock phases from the notes

Q7 This is an essay type question based on a continuous assessment assignment.