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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

**SUMMER EXAMINATIONS, 2010**

**B. E. (ELECTRICAL AND ELECTRONIC)**
**M.ENG.SC. (MICROELECTRONICS)**
**VSEU (VISITING EUROPEAN)**

RF IC Design
EE4011


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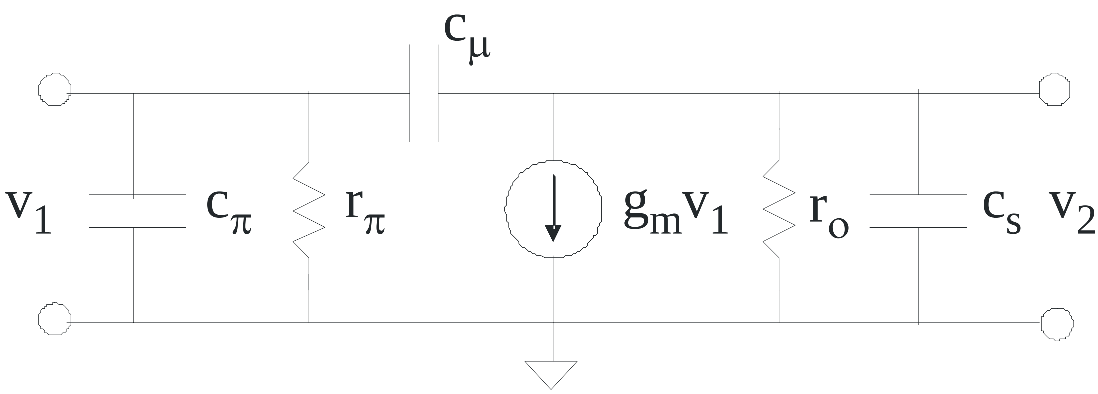
Answer *five* questions.

All questions carry equal marks.
The use of departmental approved non-programmable calculators is permitted.
The use of mathematical/statistical tables is permitted.
Smith Charts are appended to this paper. Detach and use as required. Write your examination number on any charts you use and return them with your examination script.

The following physical constants may be used if necessary:
Boltzmann's Constant: $k = 1.381 \times 10^{-23}$ J/K
Elementary Charge: $q = 1.602 \times 10^{-19}$ C
Vacuum Permittivity: $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Time allowed: *3 hours*

**1.** (a) A bipolar transistor with the following equivalent circuit has been measured.



The measurements have been taken at a frequency of 1.5 GHz using a y-parameter set-up with port 1 corresponding to the input, $v_1$, and port 2 corresponding to the output, $v_2$. The measured y-parameters are:

$$y_{11} = 0.0492 \angle 85.33°$$
$$y_{12} = 0.0066 \angle -90°$$
$$y_{21} = 0.1501 \angle -2.52°$$
$$y_{22} = 0.0094 \angle 85.95°$$

From these measurements, determine the values of the elements of the small-signal equivalent circuit for the device at 1.5GHz.

[*14 marks*]

(b) The measurements in part (a) have been performed at a temperature of 300K with the device biased in its forward active region. Use the small-signal values found in part (a) to determine the following:

(i) The collector current, $I_C$.

(ii) The Early voltage, $V_A$.

(iii) The low-frequency current-gain, $\beta$.

(iv) The cut-off frequency, $f_T$.

[*6 marks*]

**2.** (a) Draw a small-signal transistor model which is suitable for either a MOSFET or a MESFET at high frequency and derive an expression for the z-parameters of the device, assuming the gate is port 1 and the drain is port 2. Include gate resistance in your model. Also include the gate-to-source capacitance, but ignore all other capacitances.

[*8 marks*]

(b) Determine the z-parameters for a MOSFET at a frequency of 1GHz and at a temperature of 300K if it is configured for 2-port measurements with the gate connected to port 1 and the drain connected to port 2. The device bias conditions and parameters are as follows, where the symbols have their usual meanings:

$W = 200\mu m$, $L = 0.35\mu m$, $T_{ox} = 5nm$, $\mu = 400cm^2/Vs$, $V_{GS} = 2V$, $V_{DS} = 2.5V$, $V_{TH} = 0.7V$, $\lambda = 0.15\ V^{-1}$, $\varepsilon_r = 3.9$ (dielectric constant of oxide), $R_G = 10\Omega$.

[*8 marks*]

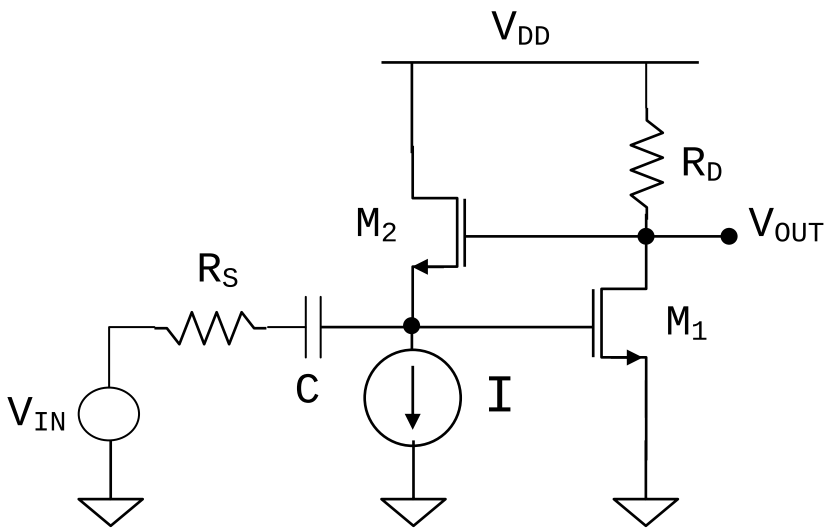
(c) The device in part (b) was originally laid out as a long thin stripe with the gate contacted at only one side. If the MOSFET was redrawn as 5 parallel transistors, but keeping the same overall width, W, and the gates were contacted at both sizes, determine the gate resistance, $R_G$, of the new layout.

[*4 marks*]

**3.** (a) Give a formula for the noise figure, NF, of an amplifier circuit and explain all the terms in the formula.

[*3 marks*]

(b) The schematic below shows an RF CMOS input amplifier:




Determine an expression for the small-signal voltage gain of the circuit. For the analysis, you can make the following assumptions: (i) the current source, I, is ideal; (ii) the impedance of the capacitor, C, is negligible (very small); and (iii) the MOSFETs can be represented by ideal transconductances with infinite output resistance and negligible parasitic capacitances.

[*7 marks*]

(c) For the circuit in part (b), if the only components producing noise are the resistors, $R_S$ and $R_D$, determine an expression for the mean square output noise voltage and the noise figure, NF, of the amplifier.

[*10 marks*]

**4.** (a) A MESFET has the following S-parameters and noise parameters (with $Z_0$=50Ω) at 14GHz:

$$s_{11} = 0.46\angle -143° \quad s_{12} = 0.01\angle 98° \quad s_{21} = 1.70\angle 59° \quad s_{22} = 0.70\angle -30°$$

$$F_{\min} = 2.5\, dB \quad \Gamma_{opt} = 0.55\angle -160° \quad R_N = 5.5\,\Omega$$

(i) State the conditions necessary to ensure that the device will be stable in an amplifier configuration and determine if the device satisfies these conditions.

[*3 marks*]

(ii) On a Smith-Chart, draw the 3 *dB* noise circle associated with this device.

Note: The following equations specify the noise circles where the symbols have their usual meanings:

$$N_i = \frac{F_i - F_{\min}}{4R_N / Z_0}\left|1+\Gamma_{opt}\right|^2 \quad C_{Fi} = \frac{\Gamma_{opt}}{N_i + 1} \quad R_{Fi} = \frac{\sqrt{N_i\left(N_i + 1 - \left|\Gamma_{opt}\right|^2\right)}}{\left(N_i + 1\right)}$$

[*2 marks*]

(b) Using Smith-Chart procedures, determine the largest unilateral transducer gain which can be achieved (to the nearest 0.1 *dB*) if the MESFET in part (a) is used for a low-noise amplifier at 14GHz, without exceeding a noise figure of 3 *dB,* and determine values for the 2-element input and output matching networks needed to achieve this gain (in a 50Ω system).

Note: The following equations specify the source gain circles where the symbols have their usual meanings:

$$\left|C_S\right| = \frac{g_s\left|s_{11}\right|}{1-\left|s_{11}\right|^2\left(1-g_s\right)} \qquad R_S = \frac{\sqrt{1-g_s}\left(1-\left|s_{11}\right|^2\right)}{1-\left|s_{11}\right|^2\left(1-g_s\right)}$$

[*15 marks*]

**5.** (a) Draw a schematic of a double-balanced mixer for RF applications based on transconductances, switches and resistors, showing clearly all the connections in the circuit including the RF, LO, and output signals.

[4 *marks*]

(b) For a double-balanced mixer, such as the one drawn in part (a), determine an expression for the output voltage of the mixer, clearly identifying the different frequency components in the output signal. Assume the input RF signal has the form $V_{RF}\cos(\omega_{RF}t)$ and the LO signal is a square wave with frequency $\omega_{LO}$ rad/s.

Note: A square wave which toggles between 0 and 1V at a frequency of ω radians/s has a Fourier expansion as follows:

$$s(t) = \frac{1}{2} + \frac{2}{\pi}\left[\sin(\varpi t) + \frac{1}{3}\sin(3\varpi t) + \frac{1}{5}\sin(5\varpi t) + \cdots\right]$$

[12 *marks*]

(c) Draw the circuit diagram of a double-balanced mixer (Gilbert cell) implemented with MOSFETs, clearly showing all connections and labeling all the signals.

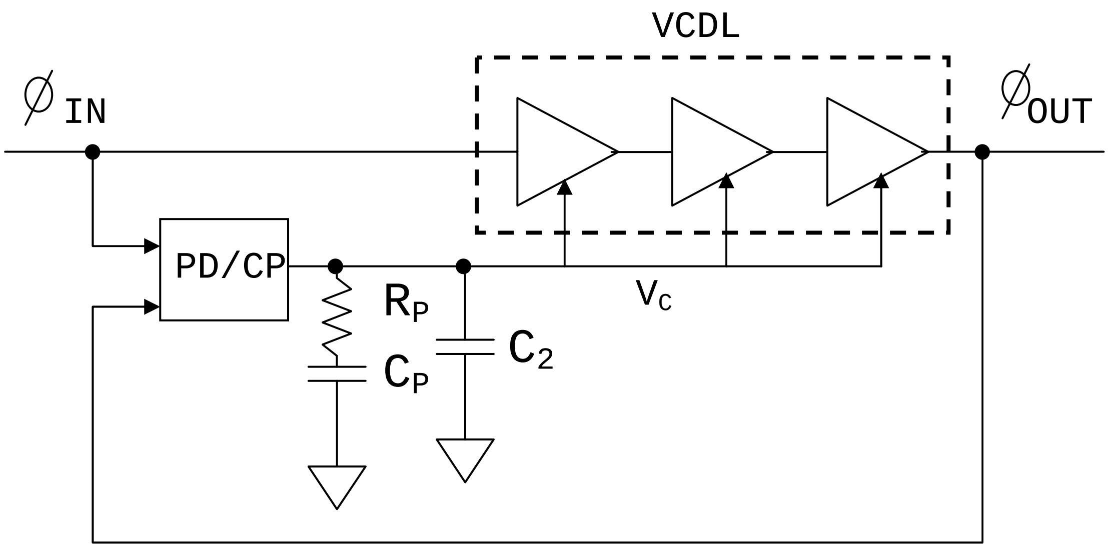
[4 *marks*]

**6.** (a) Draw the schematic of a phase-detector/charge-pump based on D flip-flops that is suitable for use in Type II Phase Locked Loops (PLLs). Illustrate the operation of the circuit using timing diagrams and develop an expression for the output of the circuit as a function of the phase difference, $\Delta\phi$, of the input signals.

[*5 marks*]

(b) The schematic below shows a design for a Delay Locked Loop (DLL). It is based on a phase-detector/charge-pump block and a low-pass filter similar to those used in Type II PLLs. It also uses a Voltage Controlled Delay Line. The VCDL has a delay which depends on the control voltage $V_C$ and its transfer function can be represented as:

$$\frac{\varphi_{OUT}(s)}{V_C(s)} = K_{VCDL}$$




Determine an expression for the closed-loop transfer function of the DLL.

[*10 marks*]

(c) Describe how a DLL similar to that shown in part (b) could be used to generate 5 clock phases with equal delay between the phases and show sample waveform illustrating the operation.

[5 *marks*]

Question 7 is shown on the next page

**7.** (a) Draw a detailed block-level architecture of a single-chip CMOS GPS receiver and outline the functions of the main blocks in the IC providing detail of frequencies, bandwidth, gain, noise levels and data rates as appropriate.

[*10 marks*]

(b) For the single-chip GPS receiver outlined in (a), provide a detailed discussion of **ONE** of the following topics:

(i) Operation of the GPS System, or

(ii) Radio Architectures for GPS receivers, or

(iii) LC Voltage Controlled Oscillators, or

(iv) PLL Frequency Synthesizers, or

(v) Mixers (for frequency conversion), or

(vi) Low Noise Amplifiers (LNAs), or

(vii) IF Filters, or

(viii) Electrostatic Discharge (ESD) Protection, or

(ix) Signal Integrity/Isolation for RFICs.

[*10 marks*]