OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2006

B. E. (ELECTRICAL)
B.E. (MICROELECTRONIC)
M.ENG.SC. (MICROELECTRONIC)
H.DIP. (MICROELECTRONIC)

RF IC Design
EE4011

Professor Dr. U. Schwalke
Professor P. Murphy
Dr. K. G. McCarthy

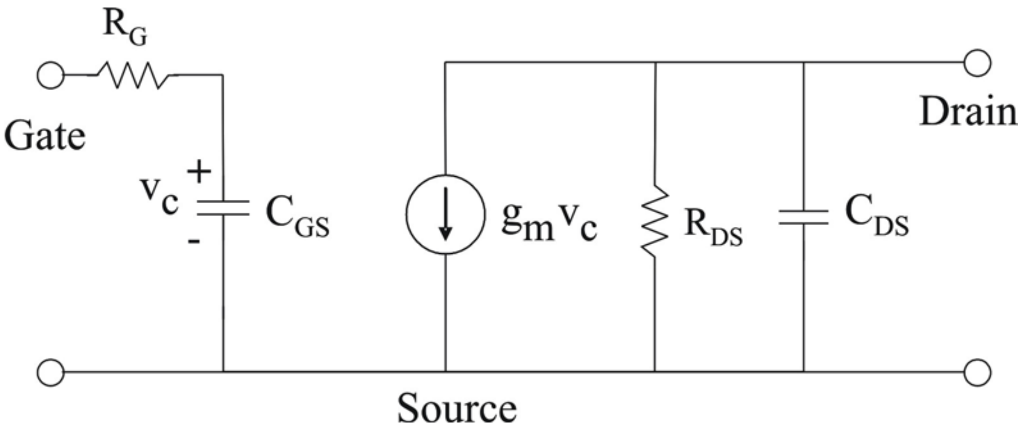
Time allowed: *3 hours*

Answer *five* questions.

All questions carry equal marks.
The use of a Casio fx570w or fx570ms calculator is permitted.
The use of log/statistical tables is allowed.
A Smith chart is appended to this script. Detach and use as required.
Extra copies of the Smith chart are available on request.

The following physical constants may be used as appropriate:
Boltzmann's Constant: $k = 1.38 \times 10^{-23}$ J/K
Elementary Charge: $q = 1.602 \times 10^{-19}$ C

1. (a) The diagram on the next page shows a simplified small-signal model of a GaAs MESFET. If this device is considered to be a two port network with port 1 at the gate, port 2 at the drain and the source grounded, derive expressions for the y-parameters of the device in terms of the circuit elements.



[*10 marks*]

(b) Calculate the y-parameters for the device in (a) at a frequency of 1GHz using the following component values:

R_G = 5Ω, C_{GS} = 0.5pF, g_m = 0.1S, R_{DS} = 100Ω, C_{DS} = 0.2pF

[*4 marks*]

(c) If the MESFET in (a) with component values in (b) is measured at 1GHz in a non-ideal measurement set-up which has stray capacitances from the signal lines to the ground lines at ports 1 and 2 as shown in the diagram below, determine the measured y-parameters for the full setup including stray capacitances.

[*6 marks*]

2. (a) Show a suitable small-signal model for a bipolar transistor and from this derive an expression for the z-parameters of the device assuming that the base is at port 1 and the collector is at port 2 of the two-port network representation. The only capacitive component which needs to be considered is the base-emitter capacitance.

[*12 marks*]

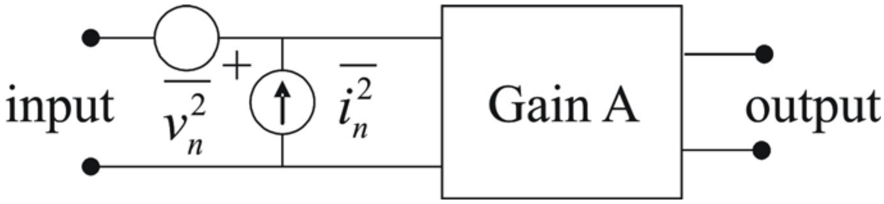
(b) Determine the z-parameters for a bipolar transistor configured as described in (a). The frequency is 2GHz, the operating temperature is 300K and the device bias conditions and parameters are as follows: V_{BE} = 0.75V, V_{CE} = 3.0V, $I_S = 1\text{x}10^{-15}$A, V_A = 10V, β = 100, C_{JE} = 0.3pF, M_{JE} = 0.5, V_{JE} = 1.0V, τ_F = 0.1ns.

[*8 marks*]

3. (a) Define the noise factor, NF, of a two-port network.

[4 *marks*]

(b) An amplifier with voltage gain A can be represented as a noiseless gain stage in combination with correlated input noise voltage and current sources as shown below. Develop an expression for the noise factor, NF, of such an amplifier if the input signal to the amplifier comes from a source with resistance R_S.



[*16 marks*]

4. (a) Describe the principles of operation of a high-frequency balanced amplifier.

[*5 marks*]

(b) A high-frequency FET has the following S-parameters (at 12 GHz with 50Ω reference);

$S_{11} = 0.601 \angle 178.5°$
$S_{12} = 2.245 \angle -5.7°$
$S_{21} = 0.076 \angle -15.9°$
$S_{22} = 0.587 \angle -146.4°$

Check the stability of the device and plot the output 1dB constant gain circle.

[*15 marks*]

5. (a) Discuss, using illustrative diagrams, the concept of *image rejection* in a standard super-heterodyne receiver.

[*8 marks*]

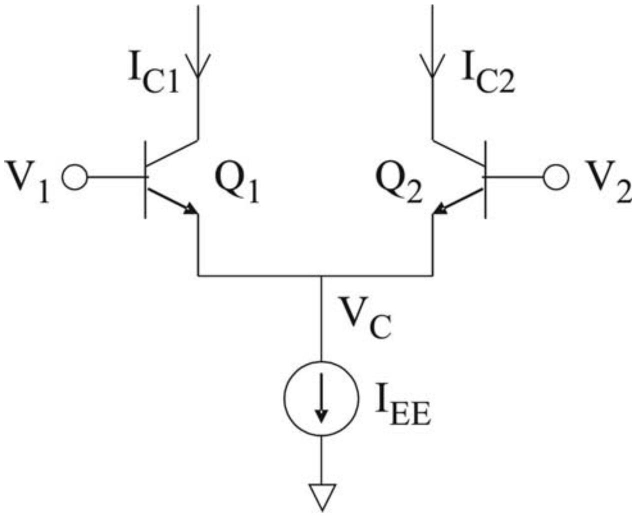
(b) Describe briefly what you understand by each of the following terms; (i) *sensitivity* (ii) *selectivity* (iii) *dynamic range.*

[*6 marks*]

(c) Discuss the issue of *receiver non-linearity* in super-heterodyne and direct conversion architectures.

[*6 marks*]

6. (a) The circuit below shows a bipolar common-emitter pair formed using identical transistors Q_1 and Q_2 and a current source I_{EE}.



Determine an expression for the difference between the collector currents ($\Delta_{IC} = I_{C1} - I_{C2}$) as a function of the differential input voltage ($\Delta V = V_1 - V_2$).

[*12 marks*]

(b) Describe two techniques which can be used to increase the dynamic range of emitter-coupled pairs such as illustrated in (a).

[*4 marks*]

(c) Illustrate, using a circuit diagram, how emitter coupled pairs such as shown in (a) can be combined to form a Gilbert-cell double-balanced mixer for RF applications.

[*4 marks*]

7. (a) Illustrate a Type 1 Phase Locked Loop (PLL) using an integer feedback divider.

[*4 marks*]

(b) Determine the closed-loop transfer function of the PLL in (a) making sure that the denominator follows the form of a standard second-order system where the symbols have their usual meaning:

$$s^2 + 2\varsigma\omega_n s + \omega_n^2$$

[8 *marks*]

(c) A Type 1 PLL using an integer feedback divider is to be used as a frequency synthesizer to generate frequencies from 890MHz to 915MHz in steps of 200kHz.

(i) Determine the appropriate input reference frequency.

[2 *marks*]

(ii) Determine the range of divider values to give the desired frequency range.

[2 *marks*]

(iii) Determine the cut-off frequency of the low pass filter using an appropriate rule of thumb. [2 *marks*]

(iv) Determine the PLL gain constant ($K_{PD}K_{VCO}$) to give a damping factor of 0.707 i.e. a critically damped configuration. [2 *marks*]