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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2006

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

RF IC Design
EE4011

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Professor P. Murphy
Dr. K. G. McCarthy

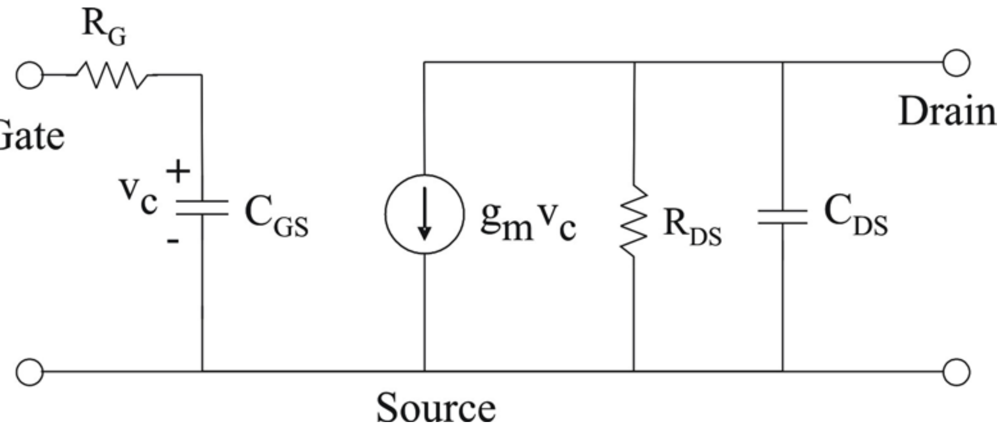
Time allowed: *3 hours*

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.
Smith charts are appended to this paper. Detach and use as required.

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 1(a) at a frequency of 1.5GHz using the following component values:

R_G = 6Ω, C_{GS} = 0.8pF, g_m = 0.15S, R_{DS} = 50Ω, C_{DS} = 0.3pF

[*4 marks*]

Note: Express the calculated y-parameters in polar (magnitude and phase) form.

(c) If the MESFET in 1(a) with component values in 1(b) is measured at 1.5GHz 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 small-signal model of a MOS transistor suitable for first-order analysis and from this derive an expression for the cut-off frequency of a MOS transistor. Assume the transistor is biased in saturation and that the current can be approximated by:

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

where the symbols have their usual meaning. Also assume that the only capacitance to be considered is the gate-source capacitance.

[*10 marks*]

(b) An NMOS transistor is biased in saturation and configured as a common-source two-port amplifier with the input applied to the gate (port 1) and the output taken from the drain (port 2) with the following bias conditions and device parameters:

W=10μm, L=0.25μm, T_{ox}=4nm, μ=400cm^2/Vs, V_{GS}=2.5V, V_{DS}=2V, V_{TH}=0.5V, λ=0.1 V^{-1}.

Determine:

(i) The cut-off frequency

[2 *marks*]

(ii) The 4 two-port y-parameters at a frequency of 1GHz.

[8 *marks*]

3. (a) Determine an expression for the 1dB compression point (P1dB) of an amplifier whose output y(t) can be described by the following equation:

$$y(t) = \alpha_1 x(t) + \alpha_3 x^3(t)$$

where the input x(t) is given by:

$$x(t) = A\cos(\omega t)$$

A is the amplitude of the input waveform and ω is the frequency in radians/s. Assume that $\alpha_1 > 0$ and $\alpha_3 < 0$.

[*10 marks*]

(b) For the amplifier described in 3(a), determine the input amplitude corresponding to the 1dB compression point if $\alpha_1 = 10$ and $\alpha_3 = -0.1$.

[*5 marks*]

(c) An RF amplifier is supplied with an input signal power of 0dBm. The output power at the fundamental frequency is 20dBm and the output power at the third harmonic is –10dBm. Determine by graphical means, or otherwise, the input third-order intercept point (input IP3).

[*5 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*]

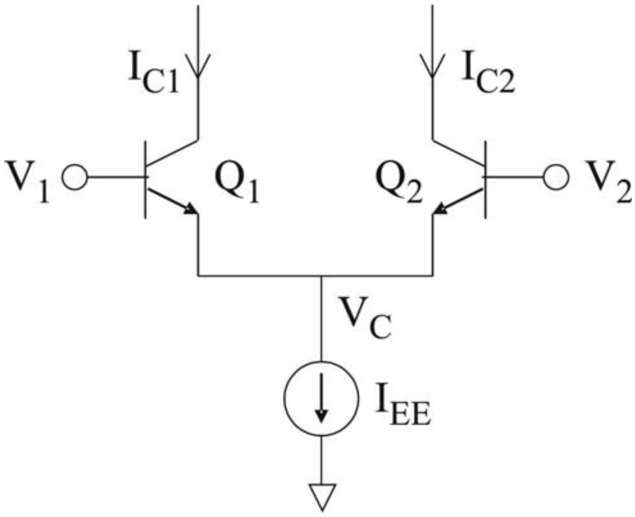
5. (a) Outline the meaning and importance of the "unilateral figure of merit" of a high-frequency amplifier.

[*8 marks*]

(b) Discuss the issue of "image frequencies" in RFIC transceiver design and the resulting effects on choice of topology.

[*12 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 6(a).

[*4 marks*]

(c) Illustrate, using a circuit diagram, how emitter coupled pairs such as shown in 6(a) can be combined to form a Gilbert-cell double-balanced mixer for RF applications.

[*4 marks*]

7. (a) Illustrate a Type II Phase Locked Loop (PLL) based on the Phase-Frequency-Detector/Charge-Pump concept. Assume that the PLL has an integer divider in the feedback path and has an added zero for stability.

[*4 marks*]

(b) For the PLL in 7(a) derive expressions for

(i) the open-loop response

[6 *marks*]

(ii) the closed-loop response

[4 *marks*]

Notes:

1. The "average current" method can be used to determine the transfer function of the PFD/CP combination.

2. The denominator of a second-order system is conveniently written in the following form where the symbols have their usual meaning:

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

(c) A Type II PLL has the following parameters:

I_P=1mA, C_P=100pF, R_P=10kΩ, K_{VCO}=100MHz/V, M=1000

Determine:

(i) The natural frequency

[2 *marks*]

(ii) The damping factor

[2 *marks*]

(iii) The loop time constant

[2 *marks*]

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