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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

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**SUMMER EXAMINATIONS, 2004**

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

RF IC Design
EE4011

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Time allowed: *3 hours*

Answer *five* questions .

All questions carry equal marks.
The use of a Casio fx570w or fx570ms calculator is permitted.
Smith Charts are available on request.

The following physical constants may be used as appropriate:
Boltzmann's Constant: k = 1.38 x $10^{-23}$ J/K
Elementary Charge: q = 1.602 x $10^{-19}$ C
Vacuum Permittivity: $\varepsilon_0$ = 8.854 x $10^{-12}$ F/m
Relative Permittivity of Oxide: $\varepsilon_r$ = 3.9

**1.** (a) Show a small-signal model of a bipolar junction transistor (BJT) suitable for first-order analysis and from this derive an expression for the cut-off frequency of the transistor in a common-emitter configuration. Assume the transistor is biased in the forward active region with currents given by

$$I_C = I_S e^{\frac{qV_{BE}}{kT}}\left(1+\frac{V_{CE}}{V_A}\right) \quad , \quad I_B = \frac{I_C}{\beta}$$

where the symbols have their usual meaning. Only consider capacitances associated with the base-emitter circuit.

[*10 marks*]

**1.** (b) A BJT is configured as a common-emitter two-port amplifier with the input applied to the base (port 1) and the output taken from the collector (port 2). Determine:

(i) The cut-off frequency.

[*2 marks*]

(ii) The 4 two-port y-parameters.

[*8 marks*]

Use the following bias conditions and parameters:

$V_{BE}$=0.75 V, $V_{CE}$=3.0 V, T=300 K

$I_S=10^{-15}$ A, $\beta$=100, $V_A$=10V, $C_{JE}=10^{-12}$ F, $V_{JE}$=1 V, $M_{JE}$=0.5, $\tau_F=10^{-10}$ s.

**2.** (a) Derive an expression for the noise figure of a two-port network driven by a source with impedance $R_S$. Assume that the two-port can be represented by a noiseless two-port with equivalent input-referred noise voltage and current sources.

[*14 marks*]

(b) The equivalent input-referred noise voltage and current sources of a bipolar transistor at moderate frequencies are given by:

$$\overline{v^2} = 4kT\left(r_b + \frac{1}{2g_m}\right)\Delta f \quad \overline{i^2} = 2q\frac{I_C}{\beta_f}\Delta f$$

where the symbols have their usual meaning and $r_b$ is the parasitic base resistance.

A BJT is biased in the forward active region with a collector current, $I_C$=1mA at 300 K. It has a forward active current gain of 100 and a parasitic base resistance of 50Ω. Determine the noise figure for a bandwidth of 1Hz if it is driven by a source with the following impedances:

(i) 10Ω

[*3 marks*]

(ii) 100Ω

[*3 marks*]

**3.** (a) Show a graphical means by which the input-referred third-order intercept point ($P_{IIP3}$) of an amplifier can be determined by measuring the fundamental output power and the IM3 output power of an amplifier for just one input power level. Clearly identify all important parts of your diagram.

[*7 marks*]

(b) Starting with the definition of the noise factor for an amplifier, develop an expression for the sensitivity of the amplifier which specifies the minimum input power that is required to give an acceptable minimum signal-to-noise ratio, $SNR_{min}$, at the output. Assume the amplifier has bandwidth B, and also assume that the amplifier input forms a conjugate match to the source so that the noise power delivered from the source is given by

$$P_{RS} = kT \quad W/Hz$$

From the expression you derive, identify the noise floor of the system.

[*7 marks*]

(c) Illustrate the concept of spurious free dynamic range (SFDR) using a suitable diagram and calculate the SFDR for a receiver system that requires a minimum SNR of 12dB at the output. The system characteristics are as follows:

NF=9 dB, $P_{IIP3}$= -15 dBm, B=200kHz, T=300K

[*6 marks*]

**4.** In the context of RFIC amplifiers, distinguish between "transducer power gain", "available power gain" and "operating power gain".

[*8 marks*]

A high-frequency transistor has the following characteristics (at 4GHz with 50 ohm reference);

$$S_{11} = 0.863 \angle -79.1°$$
$$S_{12} = 0.072 \angle 36.5°$$
$$S_{21} = 3.434 \angle 106.2°$$
$$S_{22} = 0.627 \angle -58.3°$$

Sketch the input and output stability circles and the 5dB source gain circle.

[*12 marks*]

**5.** (a) What do you understand by the "unilateral figure of merit" of a high-frequency amplifier?

[*8 marks*]

(b) Discuss the factors which led to the development of "Direct Conversion" RFIC transceivers and identify the advantages and disadvantages of the direct conversion architecture.

[12 *marks*]

**6.** (a) Illustrate a MOSFET VCO topology based on the "negative-$g_m$" concept and which uses a single current source connected to the negative supply.

[*5 marks*]

(b) By using a suitable small-signal analysis, derive the equivalent input resistance of the cross-coupled MOSFET pair in (a) and specify the necessary condition for oscillation.

[*10 marks*]

(c) If the inductors in the topology of (a) have a parasitic resistance of 10Ω and a bias current of 10mA is used, determine the width (W) of the MOSFETs which is required to sustain oscillation assuming both MOSFETs have L=0.25μm. The following MOSFET parameters should be used:
$T_{OX}$=5nm, $\mu$=400cm$^2$/Vs

[*5 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.

[*5 marks*]

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

(i) the open-loop response

*[7 marks]*

(ii) the closed-loop response

*[3 marks]*

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

(c) For the PLL in (a) determine the natural frequency, the damping factor and the loop time constant for the following PLL parameters:

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

*[5 marks]*

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

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