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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2005

B.E. (ELECTRICAL)
B.E. (MICROELECTRONIC)
M.Eng.Sc. (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.

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

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.

[*8 marks*]

(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). The cut-off frequency has been measured at a temperature of 300K for two values of collector current as follows:

For I_C = 1mA, f_T = 1.26 GHz
For I_C = 5mA, f_T = 1.51 GHz

For this device, estimate (i) the forward base transit time and (ii) the base-emitter junction capacitance (the bias dependence of the base-emitter junction capacitance may be ignored for this calculation).

[*8 marks*]

(c) For a typical BJT illustrate the variation of (i) the current gain and (ii) the cut-off frequency, as a function of collector current.

[*4 marks*]

2. (a) Show a small-signal model of a GaAs MESFET suitable for small-signal analysis and derive expressions for the four y-parameters of the device, assuming that port 1 of the network is at the gate/source and port 2 is at the drain/source. The gate-to-drain capacitance may be ignored.
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[*10 marks*]

(b) The y-parameters of a GaAs MESFET in a common-source amplifier configuration have been measured at 3GHz with the following results:

$y_{11} = 0.018 \angle 85.7°$
$y_{12} = 0$
$y_{21} = 0.249 \angle -4.31°$
$y_{22} = 0.020 \angle 8.05°$

From these measurements, determine the values of the elements of the small-signal equivalent circuit for the device at 3GHz and also the cut-off frequency of the device.

[*10 marks*]

3. (a) The input of a balanced (differential) RF amplifier consists of two cosinusioidal waveforms with amplitudes A_1 and A_2 (V) and frequencies ω_1 and ω_2 (rad/s) respectively. The output waveform is as follows:

$$
\begin{aligned}
y(t) = &\left[\alpha_1 A_1 + \frac{3}{4}\alpha_3 A_1^3 + \frac{3}{2}\alpha_3 A_1 A_2^2\right]\cos(\varpi_1 t) \\
&+ \left[\alpha_1 A_2 + \frac{3}{4}\alpha_3 A_2^3 + \frac{3}{2}\alpha_3 A_1^2 A_2\right]\cos(\varpi_2 t) \\
&+ \frac{1}{4}\alpha_3 A_1^3 \cos 3\varpi_1 t + \frac{1}{4}\alpha_3 A_2^3 \cos 3\varpi_2 t \\
&+ \frac{3}{4}\alpha_3 A_1^2 A_2 \cos(2\varpi_1 + \varpi_2)t + \frac{3}{4}\alpha_3 A_1^2 A_2 \cos(2\varpi_1 - \varpi_2)t \\
&+ \frac{3}{4}\alpha_3 A_1 A_2^2 \cos(2\varpi_2 + \varpi_1)t + \frac{3}{4}\alpha_3 A_1 A_2^2 \cos(2\varpi_2 - \varpi_1)t
\end{aligned}
$$

Using the formula for y(t) as a starting point and assuming that α_1 and α_3 have opposite signs, define and derive expressions for the following:

(i) The 1dB gain compression point (P1dB)

[5 *marks*]

(ii) The input-referred 3rd-order intermodulation intercept point (IIP3)

[5 *marks*]

(b) An amplifier such as the one described in part (a) has a single-frequency input with amplitude 1mV_{rms}. The output at the fundamental is measured as 100mV_{rms} and the 3rd-harmonic output is measured as 1nV_{rms}. Determine the 1dB compression-point of the amplifier.

[*5 marks*]

(c) Based on the expression for y(t) outlined in part (a) discuss two other undesired effects resulting from amplifier non-linearity in addition to those already considered in part (a).

[*5 marks*]

4. (a) Outline the design procedure used when designing a microwave amplifier for maximum gain.

[*5 marks*]

(b) A microwave junction transistor has the following characteristics (at 5 GHz with 50 ohm reference);

$S_{11} = 0.5 \angle -135°$
$S_{12} = 0.05 \angle 30°$
$S_{21} = 2.65 \angle 195°$
$S_{22} = 0.5 \angle -45°$

Check the stability of the device and design input and output matching networks for maximum power gain.

[*15 marks*]

5. (a) Discuss, using illustrative diagrams, the importance of the *image frequency* in a standard super-hetrodyne transceiver architecture.

[*8 marks*]

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

[*6 marks*]

(c) Identify and discuss the sources of low-frequency errors in direct conversion receivers.

[*6 marks*]

6. (a) Draw a block diagram of a Type-I PLL with an integer feedback divider, clearly illustrating the blocks and connections.

[*5 marks*]

(b) For the PLL in part (a) derive an expression for the closed-loop response. Arrange your result so that the denominator is in the form of a typical 2nd-order system:

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

[*8 marks*]

(c) A mobile telephone uses a PLL for frequency synthesis. The low pass filter of the PLL has a cut-off frequency of 20kHz. If the set frequency is changed from 900MHz to 900.2MHz, illustrate the resulting output frequency as a function of time, assuming that the PLL system is under-damped. Also, determine how long the PLL takes to settle to within 100Hz of the new set frequency.

[*7 marks*]

7. (a) Illustrate a simple RF mixer based on a switch. From the illustration derive an expression for the frequency components in the output waveform and the voltage conversion gain of the mixer.

[*10 marks*]

Note that a square wave of frequency ω rad/s which toggles between 0 and 1V can be represented by the Fourier expansion:

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

(b) Draw a circuit diagram of a Gilbert multiplier made with bipolar transistors and describe the three common operating modes (and functions) of the circuit.

[10 *marks*].