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IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2010

MSc and EEE PART IV: MEng and ACGI

Corrected copy
(Q3)

HIGH PERFORMANCE ANALOGUE ELECTRONICS

Friday, 21 May 10:00 am

Time allowed: 3:00 hours

There are FOUR questions on this paper.

Answer ALL questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : E. Rodriguez-Villegas
Second Marker(s) : C. Papavassiliou

The Questions

1.

(a) Explain briefly the role of the mixer in a superheterodyne receiver.

[4]

(b) Consider a superheterodyne receiver with a local oscillator providing a pure sinusoidal tone at 10 MHz. The incoming RF signal is centered at 9 MHz and has a bandwidth of 400 kHz. What would be the frequency range of the image signal?

[4]

(c) If you had a first order low pass filter with programmable cut-off frequency, how would you use it in the receiver in (b) to reduce the image problem?

[4]

(d) If the cut-off frequency of the filter in (c) was programmed to be at 10 MHz, what would be the attenuation of the image signal? Note: You can just give the value at the centre of the range.

[3]

(e) For the Hartley receiver, shown in Figure 1.1, give two possible values for ϕ_1 and ϕ_2 that would completely eliminate the image signal. Explain your answer.

[5]

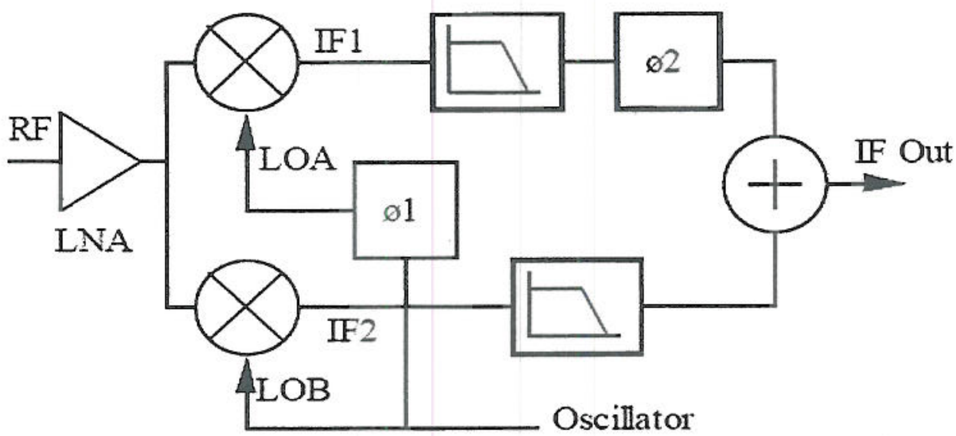

Figure 1.1

2.

(a) Name five specification parameters that need to be considered when designing a filter.

[4]

(b) What is a linear phase filter? Why is linear phase important?

[4]

(c) For the circuits in Figure 2.1 (a) and (b), find the transfer functions $\frac{V_{out}(s)}{V_{in}(s)}$ in the Laplace domain. What kind of systems do these transfer functions correspond to?

[4]

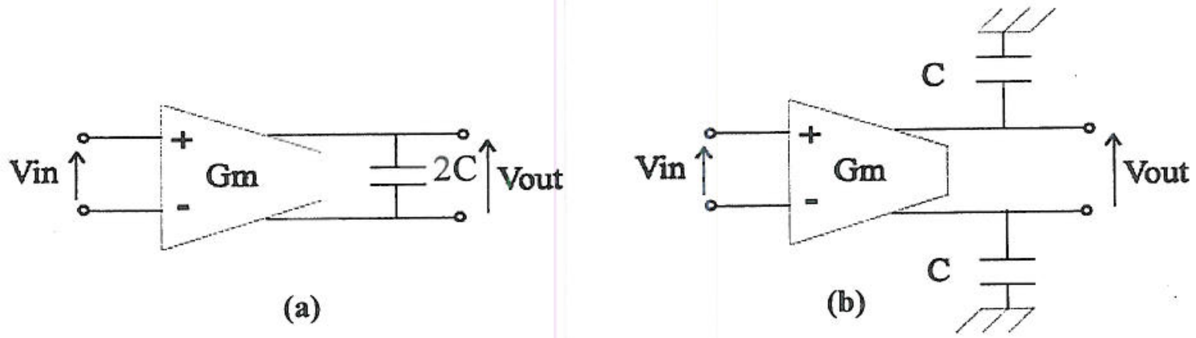

Figure 2.1

(d) For the circuit in Figure 2.2, find the transfer functions $\frac{(V_1 - V_2)}{(U_1 - U_2)}$ and $\frac{(V_3 - V_4)}{(U_1 - U_2)}$ in the Laplace domain. What kind of systems do these transfer functions correspond to?

[4]

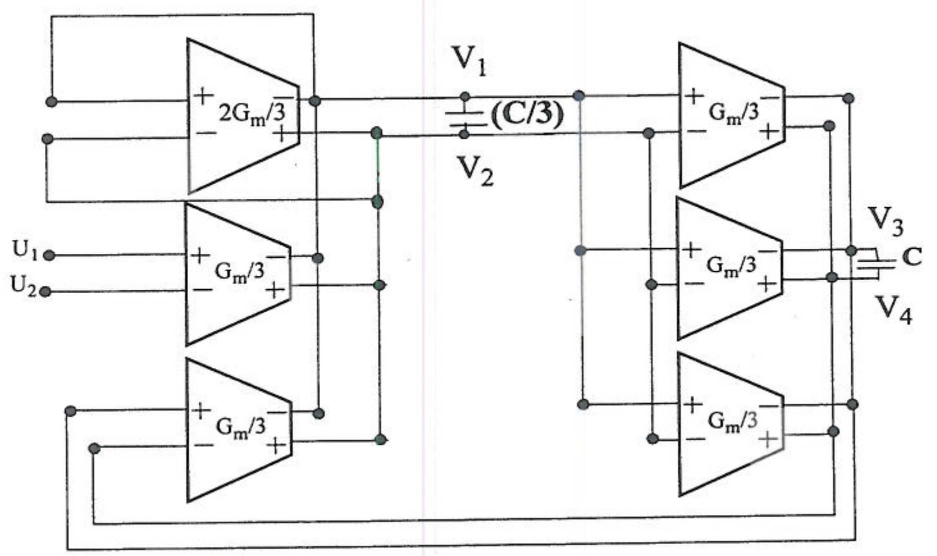

Figure 2.2

(e) If (V_3-V_4) is considered to be the output of the circuit, the cut-off frequency is w_c and the total equivalent noise at the input within a frequency band $[0, (w_c/10)]$ is $10\mu V$, what would be the equivalent output noise in the same band?

[4]

3.

(a) For the circuit in Figure 3.1 give an expression for I_{out} assuming M1 is operating in the strong inversion ohmic region and the amplifier is ideal.

[2]

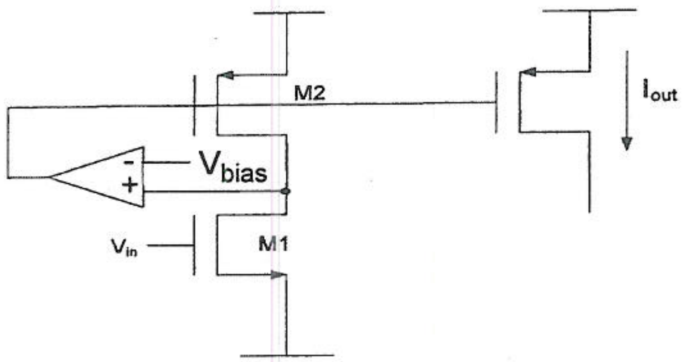

Figure 3.1

(b) What is the value of the transconductance for the circuit in Figure 3.1?

[3]

(c) For the circuit in Figure 3.2 give an expression for I_{out} assuming that:

- M_1 and M_{1r} are the same size and are biased in the strong inversion ohmic region;
- The amplifiers are ideal;
- M_2, M_{2r}, M_3 and M_{3r}, M_{a3}, M_{a3r} are the same size;
- M_4, M_{4r}, M_{a1}, M_{a1r} are the same size.

[3]

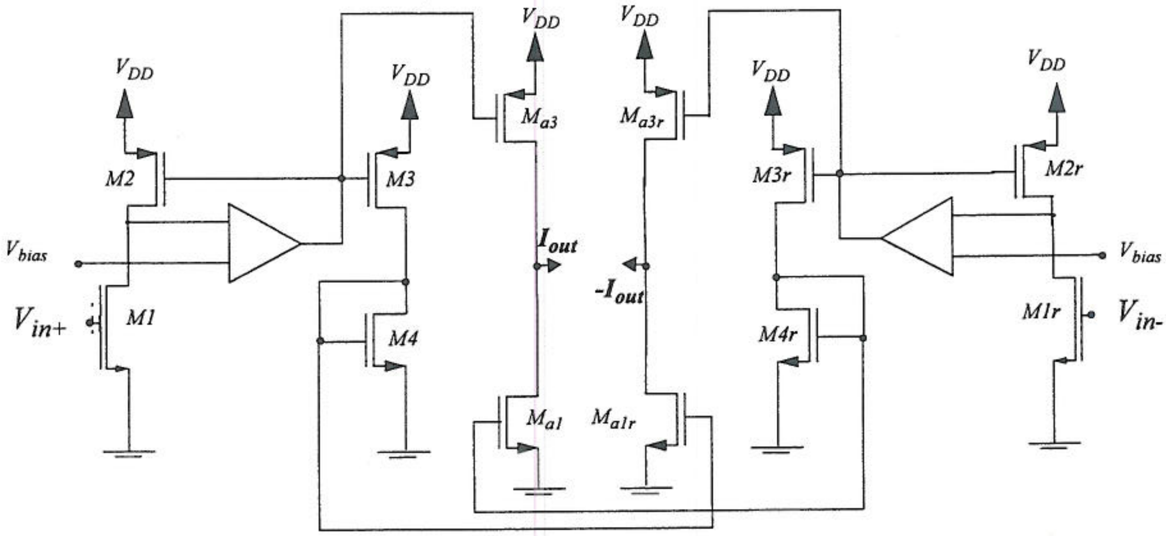

Figure 3.2

(d) What is the value of the transconductance for the circuit in Figure 3.2.

[3]

(e) How would you use the circuit in Figure 3.2 to build an integrator?

[2]

(f) Mention an advantage of (a) versus (b).

[2]

(g) Mention a disadvantage of (a) versus (b).

[2]

(h) For the circuit in Figure 3.3 give an expression for I_{out} assuming M1 is operating in the strong inversion ohmic region and the amplifier is ideal.

[3]

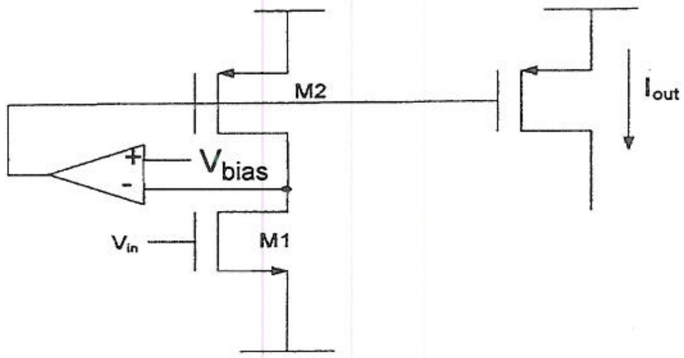

Figure 3.3

4.

(a) Name all the noise sources in an p-channel MOS transistor assuming perfect gate insulation. Write expressions for the power spectral density of each noise source assuming the FET is in the strong inversion saturation region.

[5]

(b) For the circuit in Figure 4.1, give expressions for the equivalent power spectral density of noise in V_2, as a function of frequency, when $H_2(s) = 2$ and $H_1(s) = 4$.

[5]

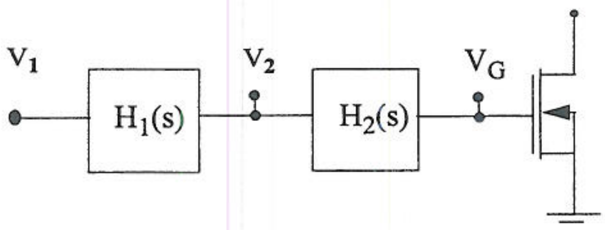

Figure 4.1

(c) For the circuit in Figure 4.1, give an expression for the total input (V_1) noise within a [100 Hz, 1 kHz] bandwidth. Note: $H_2(s) = 2$ and $H_1(s) = 4$.

[5]

(d) For the circuit in Figure 4.1, give an expression for the total power spectral density of noise at the input, as a function of frequency, if H_1 and H_2 are the blocks shown in Figure 4.2 (a) and Figure 4.2 (b) respectively.

[5]

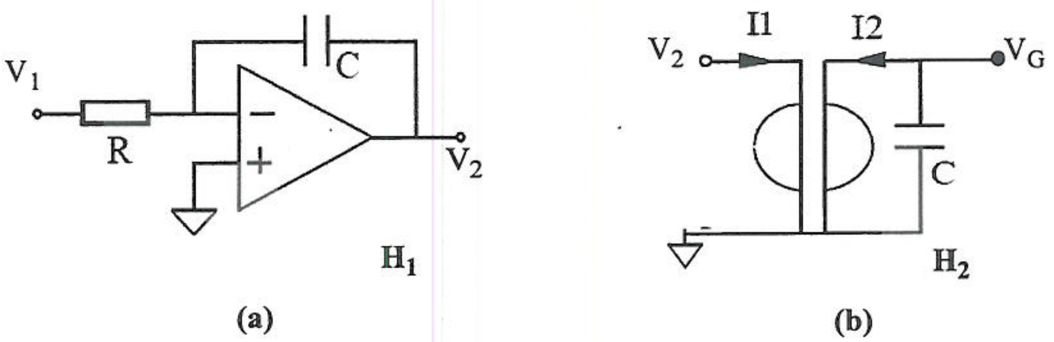

Figure 4.2

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1.

(a) (Theory)

If we are trying to select one particular frequency channel from the complete RF spectrum, then we need a bandpass filter to reject any unwanted frequencies. Generally this filter has to be narrowband, and high Q filters are difficult to design at high frequencies. This problem is compounded if the input signal frequency is variable (i.e. the signal is transmitted in one of a number of possible channels, each with the same bandwidth). A tuneable, high Q bandpass filter with constant bandwidth is now required.

The solution is to use a superhet receiver (supersonic heterodyne). This system downconverts the input signal to an intermediate frequency (IF), and a bandpass IF filter is then used to select the wanted signal. The design of the bandpass IF filter is eased since it doesn't have to be tuneable, and the IF centre frequency is much lower than the input RF signal. The downconversion is performed by 'mixing' (multiplying) the RF input signal (fRF) with a local oscillator signal (fLO), such that the resulting output is at the required IF frequency (fIF). The oscillator frequency fLO is often tuneable to ensure that a range of input RF frequencies can be selected.

(b) (New computed example)

[10.8 MHz, 11.2 MHz]

(c) (Application of theory)

Placing it before of the mixer and programming the cut-off frequency so that it doesn't filter the incoming RF signal but at the same time is as far as possible from the image.

(d) (Application of theory)

$$(-3)\text{dB} + 20\log\left(\frac{f_{\text{cutoff}}}{f_{\text{Image}}}\right) = -3.83\text{dB}$$

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(e) (Theory)

To avoid signal distortion, we require $\cos(\phi 1 + \phi 2)/2 = 1$ i.e. $(\phi 1 + \phi 2)/2 = 2n\pi$

To ensure image rejection, we require $\cos(\phi 1 - \phi 2)/2 = 0$ i.e. $(\phi 1 - \phi 2)/2 = (2n+1)\pi/2$

e.g. $\phi 1 = 90$ $\phi 2 = -90$

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2.

(a) (Theory)

Kind of filter, i.e. low-pass, high-pass, bandpass etc; Passband gain and ripple; Stopband attenuation; Cut-off frequency ; Stopband frequency; Transition band; Phase response; Noise; Distortion; Dynamic range; Size; Cost ; Time response

(b) (Theory)

It is a filter whose phase response varies linearly with frequency.
For an input sinewave, a time delay between input and output is equivalent to a phase shift.
For an input signal which is a mixture of frequencies (e.g. a square wave), if we want the same time delay for each individual frequency to preserve the 'shape' of the input signal the phase response must be linear with frequency.

(c) (Application of theory)

$\frac{G_m}{2Cs}$ for (a) and $\frac{2G_m}{Cs}$ for (b). Integrators

(d) (Application of theory)

$$(C/3)\dot{x}_1 = -(2G_m/3)x_1 - (G_m/3)x_2 + (G_m/3)u$$

$$C\dot{x}_2 = 3(G_m/3)x_1$$

where $x_1 = (V_1 - V_2)$, $x_2 = (V_3 - V_4)$, and $u = (U_1 - U_2)$. Applying Laplace transform to the state space equations.

$$X_2(s) = \frac{k_o^2}{s^2 + 2k_o s + k_o^2} U(s) \text{ Lowpass filter}$$

$$X_1(s) = \frac{sk_o}{s^2 + 2k_o s + k_o^2} U(s) \text{ Bandpass filter}$$

where $k_o = G_m/C$.

(e) (Application of theory)

Since the noise is computed within the passband of a lowpass filter and the gain in the passband is 1, the total output noise will be the same as in the input, i.e. $10\mu V$

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3.

(a) (New theory)

$$I_{out} = 2\beta\left[(V_{in} - V_{th})V_{bias} - \frac{V_{bias}^2}{2}\right]$$

(b) (New theory)

$$G_m = 2\beta V_{bias}$$

(c) (New theory)

$$I_{out} = 2\beta[(V_{in+} - V_{in-})V_{bias}]$$

(d) (Application of theory)

$$G_m = 2\beta V_{bias}$$

(e) (Application of theory)

Connecting a capacitor between the two output nodes,

(f) (Application of theory)

Area

(g) (Application of theory)

Even order distortion resulting from non-idealities in the current law.

(h) (New theory)

0. It's positive feedback.

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4.

(a) (Theory)

Thermal noise due to the resistance of the channel:

$$ind^2 = \frac{8kTgm\Delta f}{3} \ A^2$$

This noise source can also be represented by an equivalent channel resistance rd = 3/2gm.

Flicker (1/f) noise in series with the gate:

$$vng^2 = \frac{k_f \Delta f}{CoxWLf} \ V^2$$

kf is a flicker noise coefficient which is process dependent.

(b) (Application of theory

T

$$\frac{\left(\frac{8kT}{3g_m} + \frac{k_f}{WLC_{ox}f}\right)}{4} (V^2/Hz)$$

(c) (Application of theory)

$$\int_{100}^{1000} \frac{\left(\frac{8kT}{3g_m} + \frac{k_f}{WLC_{ox}f}\right)}{16 \cdot 4} df = \left(\frac{8kT}{3g_m} \cdot \frac{900}{64} + \frac{k_f}{64WLC_{ox}} \ln(10)\right) V^2$$

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(d) (Application of theory)

$$\frac{\left(\frac{8kT}{3g_m} + \frac{k_f}{WLC_{ox}f}\right)}{|H_1|^2|H_2|^2}$$

where $|H_1|^2 = \left(\frac{1}{2\pi RCf}\right)^2$ and $|H_2|^2 = \left(\frac{G}{2\pi Cf}\right)^2$.