

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MSc and EEE PART IV: M.Eng. and ACGI

CURRENT-MODE ANALOGUE SIGNAL PROCESSING

Wednesday, 14 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

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

Examiners responsible	First Marker(s) :	E. Drakakis
	Second Marker(s) :	C. Papavassiliou

Special Information for Invigilators: none

Information for candidates

Some notation

$\frac{W}{L}$ denotes the width over the length of a MOS transistor

The symbol “//” means “in parallel with”; for example $R_1 // R_2$ means “ R_1 in parallel with R_2 ”

The Questions

1. (a) Explain the reasons why the switched-current circuit design technique constitutes an attractive alternative compared to the conventional switched-capacitor technique. [7]

- (b) Figure 1.1 illustrates a switched-current circuit. Show that its z-domain current transfer function corresponds to an inverting lossy integrator and derive an expression for its time-constant when $\omega T \ll 1$ (T denotes the clock period). You may assume that the switches are ideal and that the transistors' sizing are as follows: $\left(\frac{W}{L}\right)_{M_1} = \left(\frac{W}{L}\right)_{M_2}$, $\left(\frac{W}{L}\right)_{M_4} = b_4 \left(\frac{W}{L}\right)_{M_1}$ and $\left(\frac{W}{L}\right)_{M_3} = b_3 \left(\frac{W}{L}\right)_{M_1}$. [13]

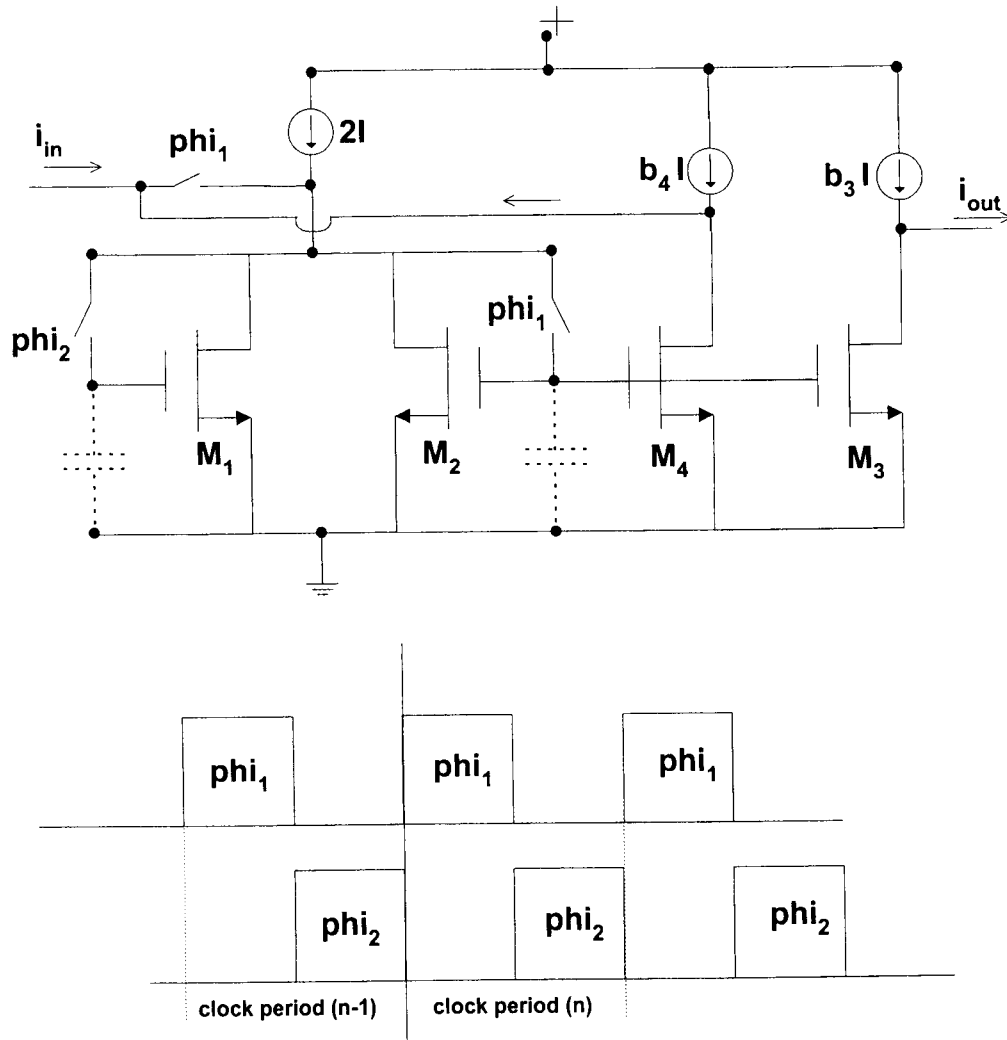


Figure 1.1

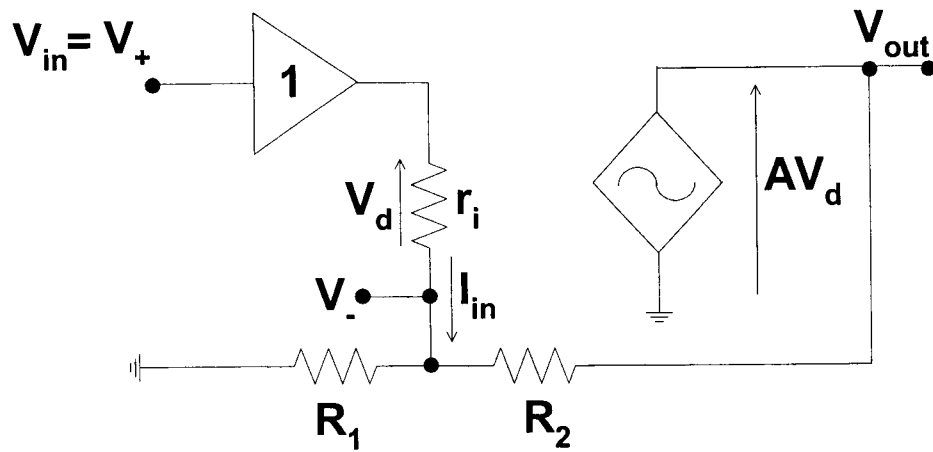


Figure 2.1

2. (a) Figure 2.1 above illustrates the equivalent circuit of a current-feedback operational amplifier (CFOA) connected in a non-inverting amplifier configuration. By means of analytical calculations show that the closed-loop bandwidth can be set independently of the closed-loop gain when

$$A = A_0 / \left(1 + j \frac{f}{f_0} \right). \text{ You may assume that } 1 + \frac{R_2}{R_1} = G. \quad [12]$$

- (b) With respect to figure 2.1 show how the closed-loop transfer function V_{out} / V_{in} can be expressed in terms of an open-loop transimpedance gain Z_t and calculate the closed-loop bandwidth when

$$Z_t = R_0 // \frac{1}{j C_0 \omega}. \quad [4]$$

- (c) Figure 2.2 illustrates a typical CFOA. Draw a new CFOA with an input buffer stage of reduced offset voltage. Explain how the offset voltage is reduced and briefly discuss relevant design trade-offs. [4]

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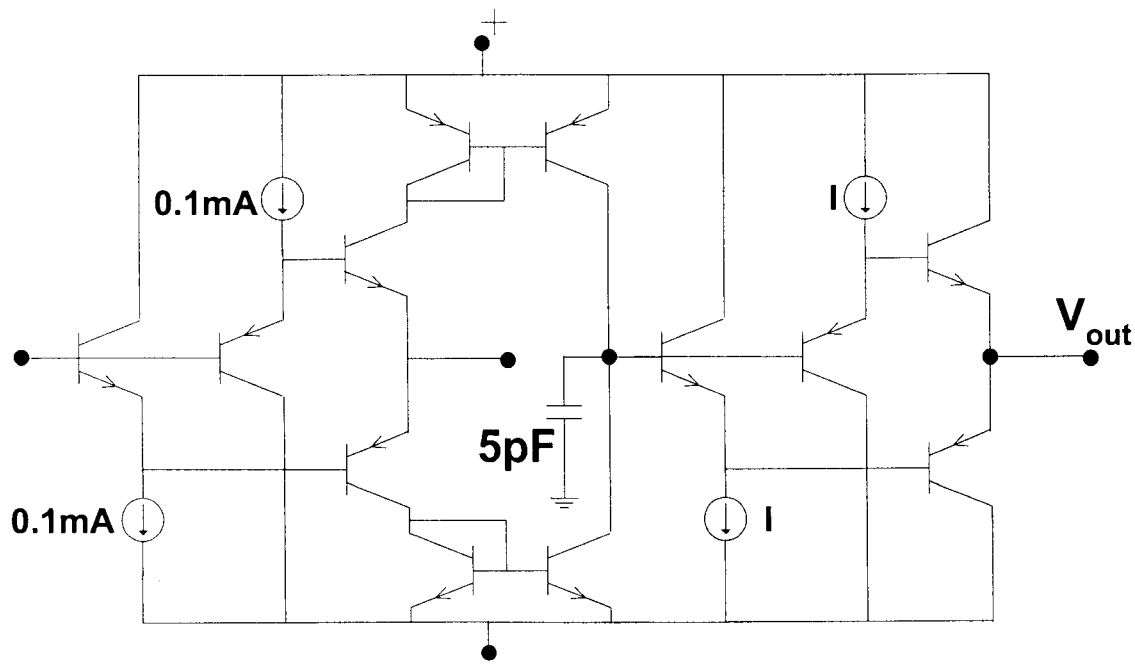


Figure 2.2

3. (a) Figure 3.1 illustrates a single op-amp-based amplifier.

- (i) Show that the output voltage can be expressed as $V_{out} = K_2 V_2 - K_1 V_1$ with the quantities K_2 and K_1 dependent upon R_1, R_2, R_3 and R_4 and find the appropriate condition so that the op-amp realises a difference amplifier. [5]
- (ii) Express the CMRR in terms of the resistors R_1, R_2, R_3 and R_4 and discuss the limitations caused by finite resistor tolerances. [5]

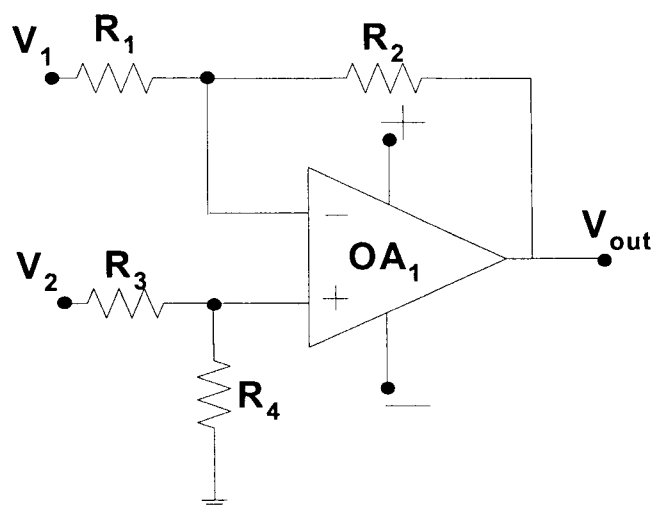


Figure 3.1

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- (b) Figure 3.2 illustrates a current-mode instrumentation amplifier. Discuss the operation of the circuit for both differential and common-mode inputs. What is the main advantage of the circuit when compared to the 3-op-amp instrumentation amplifier? What limits its accuracy and its CMRR performance? [10]

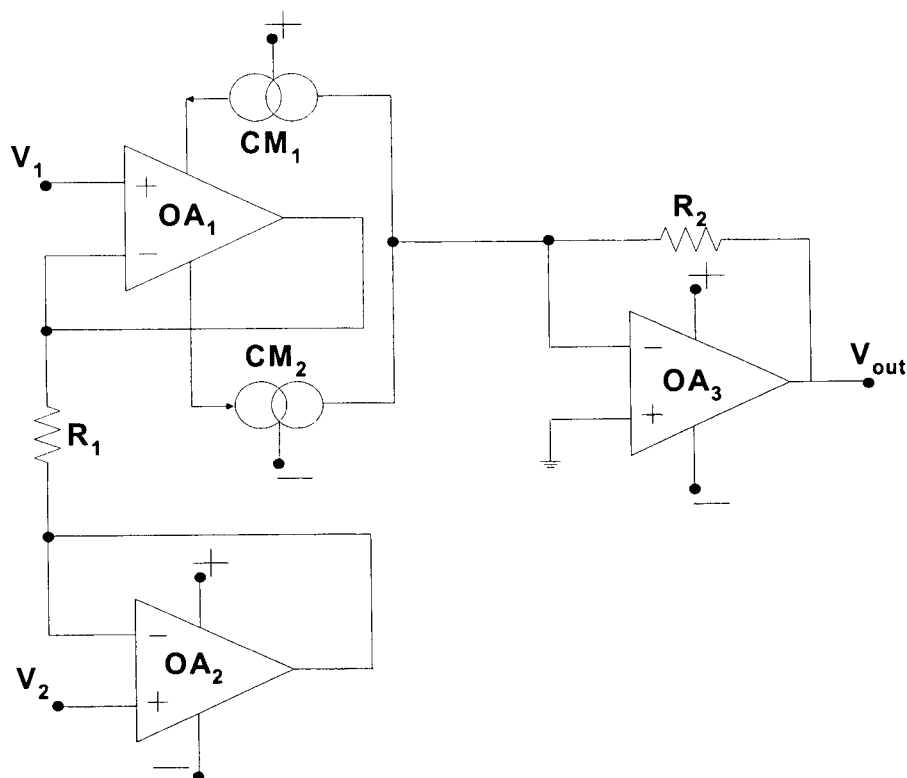


Figure 3.2

4. (a) Derive the bipolar translinear principle with reference to a loop containing 2m base-emitter junctions. State all the assumptions that you make and list the conditions which must be satisfied in order for this principle to be valid. [5]

Question continued on the next page...

(b) Figure 4.1 illustrates a translinear circuit whose differential current output realises a trigonometric approximation.

(i) Express the currents I_3 and I_4 in terms of I and I_x . [3]

(ii) Next, express the differential output $I_2 - I_1$ in terms of I and I_x and

show that when $I_x = yI$ holds: $I_2 - I_1 = I \frac{y - y^3}{1 + y^2}$. You may assume

that the transistors' beta value is large. [4]

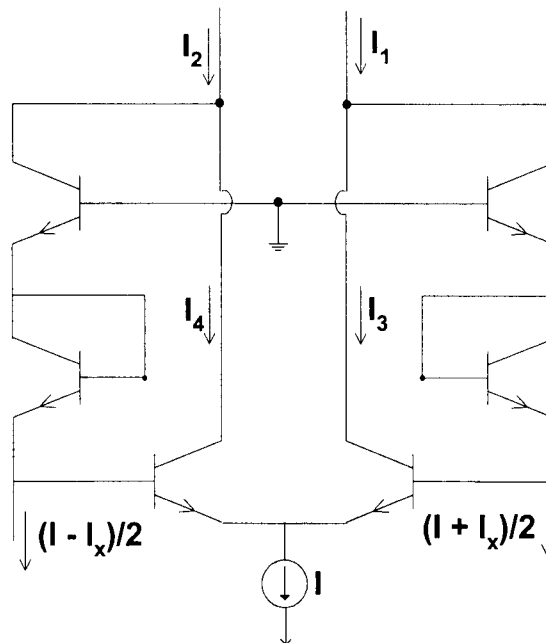


Figure 4.1

(c) Figure 4.2 illustrates a translinear circuit whose output current I_z can implement a variety of trigonometric approximations.

(i) Express the current I_2 in terms of I, I_x and the output current I_z . [2]

(ii) Next, express the output current I_z in terms of I, I_x and the emitter area A . [3]

(iii) Determine the emitter area A so that $I_z = 1.54 I_x - 0.54 \frac{I_x^3}{I^2}$. [3]

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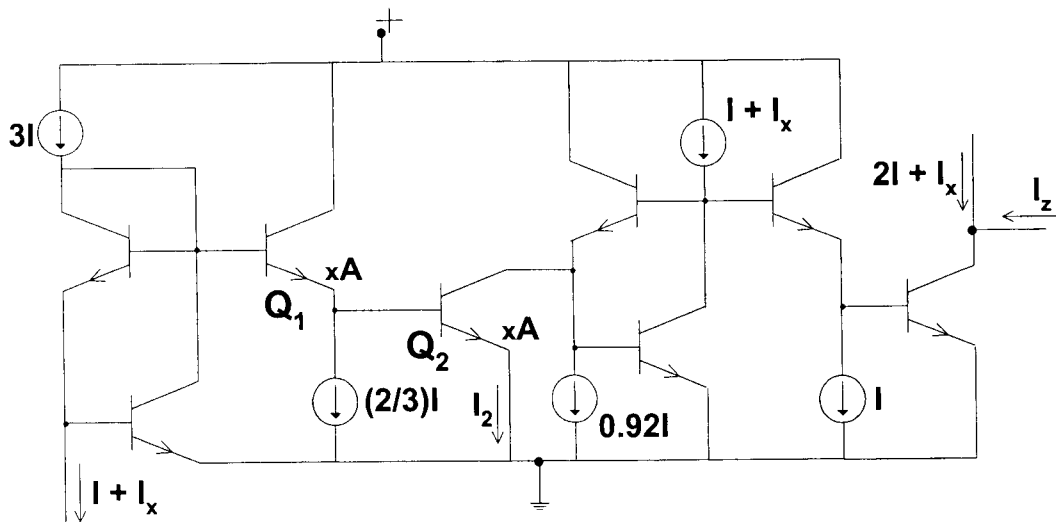


Figure 4.2

5. The transfer function for a second order topology has been decomposed into the following state-space equations:

$$\begin{aligned}\dot{x}_1 &= -\left(\frac{\omega_0}{Q}\right)x_1 + \omega_0 x_2 \\ \dot{x}_2 &= -\omega_0 x_1 + \omega_0 u \\ y_1 &= x_1 \\ y_2 &= x_2\end{aligned}$$

where y_1 and y_2 are outputs, x_1 and x_2 are state-variables and u is the input (a dot above a variable denotes time-differentiation).

- (a) Show that the output y_1 can be used to implement a second order lowpass transfer function whereas the output y_2 can be used for the implementation of a “two-pole one-zero” second order transfer function. [4]

Question continued on the next page...

(b) Using the exponential mappings $x_j = I_0 \exp\left(\frac{V_j}{V_T}\right)$ ($j = 1, 2$) and

$$u = I_S \exp\left(\frac{V_u}{V_T}\right)$$

show that the above linear state-space equations can be transformed into non-linear log-domain design equations. [7]

(c) From these design equations sketch a transistor-level implementation of a log-domain topology which realises the two transfer functions (the lowpass and the “two-pole one-zero” ones). Assuming that all capacitors are equal to 20pF determine the dc current bias values I_0 so that $\omega_0 = 4\text{MHz}$. You may assume that $V_T \cong 26\text{mV}$. [9]

6. (a) State the relation which must be satisfied by two N-port networks, if these two networks are to be considered adjoint networks. Exploiting this relation derive the adjoint network of a resistor, a nullor and an open-loop “ideal” voltage amplifier. [4]

(b) Figure 6.1 illustrates a voltage-mode Tow-Thomas biquad implemented by means of voltage op-amps. Derive its current-mode equivalent. [3]

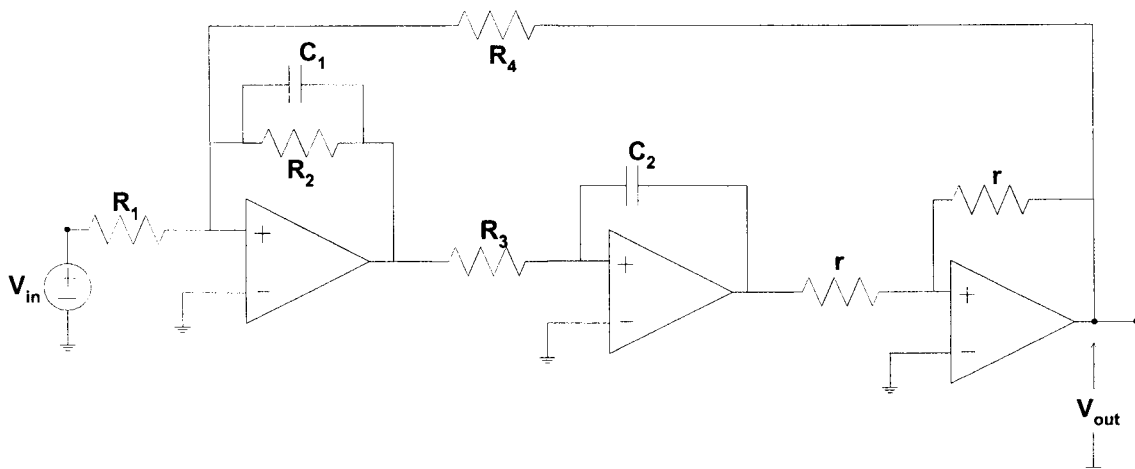


Figure 6.1

Question continued on the next page...

(c) You are asked to implement an I-I converter. What kind of amplifier would you choose to use if :

- (i) high-gain ideal amplifiers of any of the four kinds were available to you. **[1]**
- (ii) only practical amplifiers were available to you. **[1]**
- (iii) if high-performance current-followers and voltage-followers were available to you. **[1]**

(d) Figure 6.2 shows a log-domain filter.

- (i) Express the capacitor current in terms of I_{outI} and its derivatives.
- (ii) Express the current u in terms of I_{outI} and known circuit parameters.
- (iii) Exploiting the translinear principle determine the s -domain transfer

function $\frac{I_{out2}(s)}{I_{in}(s)}$. When $I_d = 10 \mu\text{A}$ determine the dc biasing current

I_0 and the capacitor value C so that the filter has a low-frequency gain of 1 and a pole frequency of 1MHz. You may assume that $V_T \cong 26\text{mV}$ and that beta-induced errors are negligible. [10]

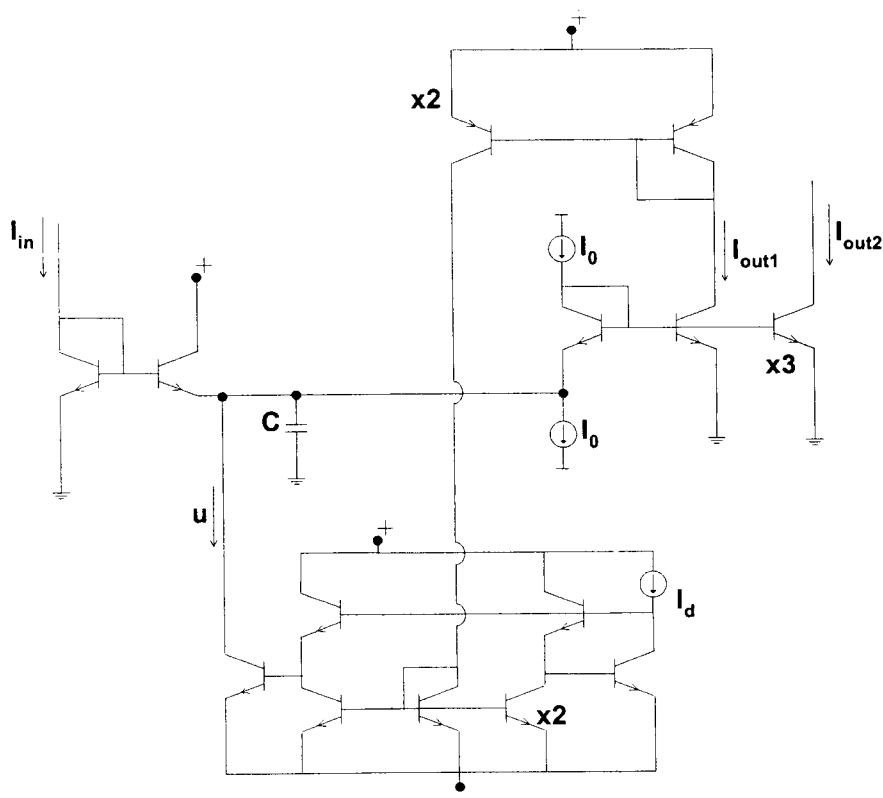


Figure 6.2

