Version SS/3

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 30 April 2019 9.30 to 11.10

Module 4B21

ANALOGUE INTEGRATED CIRCUITS

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 4B21 Formula sheet (1 page).
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) Briefly explain any two advantages and two disadvantages of the cascode voltage amplifier architecture. [20%]

(b) Consider the voltage amplifier shown in Fig. 1. The circuit is driven by a DC power supply voltage, V_{DD}. Although the DC bias to all transistors is not shown, they are biased in saturation mode operation. The transconductance of all n-channel metal oxide semiconductor field effect transistors (MOSFETs) is g_{mn} and the transconductance of the p-channel MOSFETs is g_{mp}. Channel length modulation can be ignored in all transistors. The small signal input and output voltages are v_{in} and v_{out}, respectively. Find the expression for the

(i) small signal, low frequency voltage gain. [25%]

(ii) small signal, low frequency output impedance. [25%]

(c) (i) Consider a diode connected n-channel MOSFET with a channel length modulation resistance of r_0 and transconductance g_m. Prove that the diode connected configuration can be equivalently represented by a resistor. Also identify the resistance of this resistor. [15%]

(ii) An n-channel MOSFET is biased in saturation mode operation with the gate overdrive voltage being 2 V and the current through the MOSFET being 1 mA. What is the transconductance of the MOSFET at this operation point? [15%]

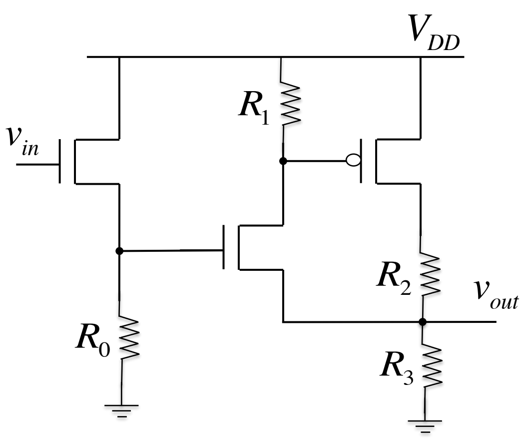

Fig. 1

2 (a) (i) Define the term 'transit frequency' in relation to a metal oxide semiconductor field effect transistor (MOSFET). [10%]

(ii) The transit frequency of a MOSFET in saturation is f_0. If the channel width is doubled, the channel length halved and the MOSFET is retained in saturation with the same gate-source voltage, the transit frequency would become αf_0. Find the value of α. Ignore channel length modulation. [10%]

(b) The transfer function of an operational amplifier (OPAMP) in Laplace domain is

$$T(s) = \frac{v_{out}}{v_{in}} = \frac{A}{[1 + (s/\omega_p)]^3}$$

with v_{out} the small signal output voltage, v_{in} the small signal input voltage, ω_p the angular frequency defining the location of the pole and $A >> 1$ the DC gain.

(i) With the help of an approximately drawn Bode gain and phase plot for the OPAMP in open loop configuration, briefly remark on the stability of the OPAMP when it is used in closed loop configuration. [25%]

(ii) With the help of an approximately drawn Bode gain and phase plot, explain how the technique of dominant pole compensation helps improve stability. [25%]

(c) Consider the voltage amplifier circuit shown in Fig. 2. The DC power supply voltage is V_{DD}, the small signal input voltage is v_{in} and the small signal output voltage is v_{out}. The n-channel MOSFET is in saturation with transconductance g_m. It has negligible overlap capacitance and negligible channel length modulation.

(i) Identify the high frequency small signal voltage gain v_{out}/v_{in} in the Miller equivalent circuit. [15%]

(ii) If the time constant of the input series resistor-capacitor circuit (R-C circuit) of the Miller equivalent circuit is 10 times the time constant of the output R-C circuit, find the DC gain of the amplfier. [15%]

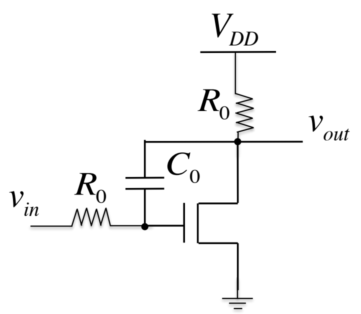

Fig. 2

3 (a) (i) In a 2-transistor current mirror circuit using metal oxide semiconductor field effect transistors (MOSFETs), explain the consequence of significant channel length modulation. [10%]

(ii) Explain the advantage of complementary metal oxide semiconductor (CMOS) technology in the context of designing voltage amplifiers. [10%]

(b) In the circuit of Fig. 3, MOSFETs M3, M4 and M6 are in saturation mode operation. The channel length modulation in all MOSFETs can be ignored. The aspect ratio of all MOSFETs is defined within brackets in Fig. 3 with W being the channel width and L being the channel length. All n-channel MOSFETs have a threshold voltage of 1 V and are identical from the point of device properties. The DC power supply voltage is V_{DD} and the DC output voltage is V_{out}. Find

(i) V_{out} when V_{DD} = 10 V [25%]

(ii) V_{out} when V_{DD} = 15 V [25%]

(c) Consider a current amplifier with gain A. Prove that adding negative feedback F to this amplifier

(i) decreases the input impedance of the amplifier [15%]

(ii) increases the output impedance of the amplifier [15%]

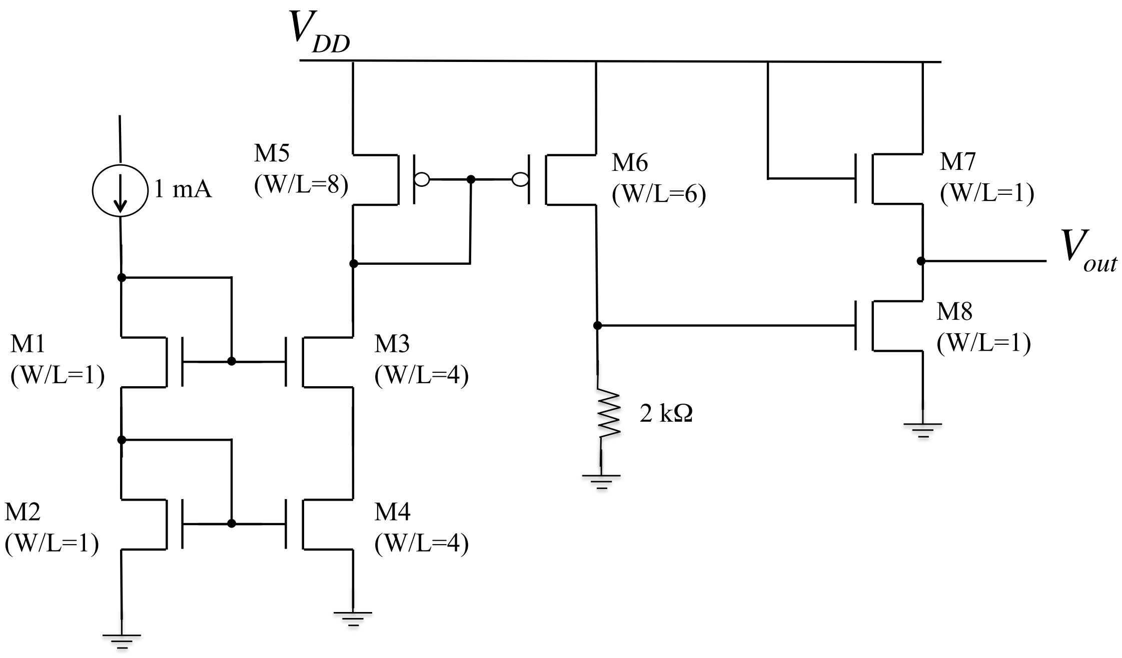

Fig. 3

4 (a) In a metal oxide semiconductor field effect transistor (MOSFET)-capacitor based switched capacitor circuit, the MOSFET switch is used to control the reading and writing of data on the capacitor. In this context

(i) Explain parasitic errors due to clock feedthrough [10%]

(ii) Explain parasitic errors due to charge injection [10%]

(b) Consider the gain boosted differential amplifier shown in Fig. 4 with the gain boosting voltage amplifier having gain A. All MOSFETs are in saturation and have equal transconductance g_m. All MOSFETs have channel length modulation with the equivalent channel length modulation resistance being r_0. The DC power supply voltage is V_{DD} and the DC reference voltage is V_{REF}. The small signal input voltages are v_1 and v_2 and the corresponding small signal output voltages are v_{01} and v_{02}. If the amplifier receives a equal and oppositely varying signal $v_1 = v_{in}$ and $v_2 = -v_{in}$ at the inputs, identify

(i) The differential gain [25%]

(ii) The common mode rejection ratio [25%]

(c) (i) What is meant by the term 'corner frequency' of a MOSFET. [15%]

(ii) The corner frequency of the MOSFET biased in saturation is f_c. If the channel width is doubled, the channel length halved and the MOSFET is retained in saturation with the same drain-source current through it, the corner frequency would become αf_c. Find the value of α. Ignore channel length modulation. [15%]

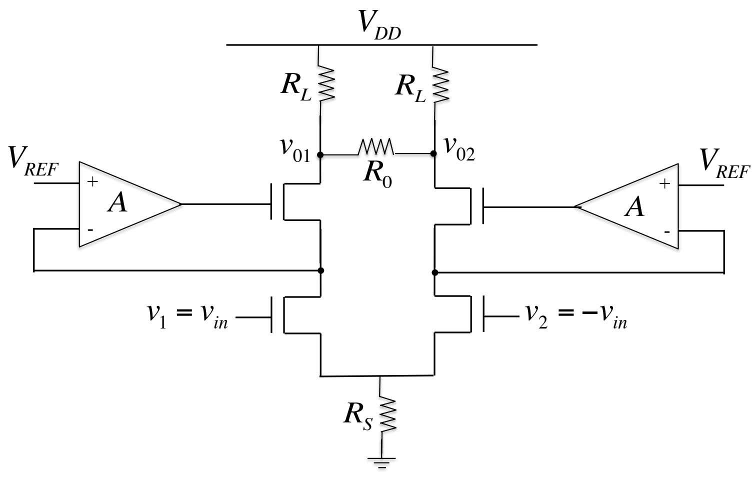

Fig. 4

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Solution to Numerical Questions

4B21 2019

Q1c (ii) $1x10^{-3}$ A/V

Q2a (ii) 4

Q2c (ii) -10

Q3b (i) 4.085 V

(ii) 9 V

Q4c (ii) 2

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4B21 FORMULA SHEET

MOSFET Device Parameters

If μ is the mobility, C_{ox} the oxide/insulator capacitance per unit area, W the channel width, L the channel length, $\beta = \mu C_{ox}(W/L)$.

MOSFET Current Voltage Characteristics

I_{ds} is the drain-source current, V_{gs} the gate-source voltage, V_T the threshold voltage, V_{ds} the drain-source voltage.
MOSFET in Linear Operation (i.e. when $V_{ds} < V_{gs} - V_T$): $I_{ds} = \beta[(V_{gs} - V_T)V_{ds} - (V_{ds}^2/2)]$

MOSFET in Saturation Operation (i.e. when $V_{ds} \geq V_{gs} - V_T$) - without channel length modulation: $I_{ds} = (\beta/2)(V_{gs} - V_T)^2$

MOSFET in Saturation Operation (i.e. when $V_{ds} \geq V_{gs} - V_T$) - with channel length modulation: $I_{ds} = (\beta/2)(V_{gs} - V_T)^2(1 + \lambda V_{ds})$
Here, λ is the channel length modulation parameter.

MOSFET Small Signal Parameters

Transconductance: $g_m = \partial I_{ds}/\partial V_{gs}$

Noise

Thermal Noise voltage in resistor (V^2/Hz): $< v_n^2 >= 4kTR$
Here, $k = 1.38 \times 10^{-23}$ J/K is the Boltzmann's coefficient, T is the temperature, R is the resistance of the resistor.

Thermal Noise current in resistor (A^2/Hz): $< i_n^2 >= 4kT/R$

Thermal Noise voltage in a MOSFET (V^2/Hz): $< v_n^2 >= 4kT(2/3)(1/g_m)$
Here, g_m is the transconductance of the MOSFET.

Thermal Noise current in a MOSFET (A^2/Hz): $< i_n^2 >= 4kT(2/3)g_m$

Flicker Noise voltage in a MOSFET (V^2/Hz): $< v_n^2 >= \alpha/(C_{ox}WLf)$
Here, α is a process dependent coefficient, f the frequency.