EE4-17
EE9-AO4

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2013

MSc and EEE PART IV: MEng and ACGI

HIGH PERFORMANCE ANALOGUE ELECTRONICS

Friday, 3 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) : P. Georgiou

The Questions

1.

(a) Explain briefly the need for modulation in a communication system.

[6]

(b) The RF signal received by a heterodyne receiver is centred at 10.7MHz. If the image signal is at 15MHz, what would be the frequency of the local oscillator?

[6]

(c) A prefilter for the receiver in (b) is designed as a second order low pass Butterworth function with a cut-off frequency of 12MHz and a DC gain of 1. The transfer function for the filter is:

$$\frac{5.685 \cdot 10^{15}}{s^2 + 1.066 \cdot 10^8 s + 5.685 \cdot 10^{15}}$$

What would be the attenuation of the image signal after the filter?

[2]

(d) Figure 1.1 shows a LC ladder implementation of a 3rd order filter with the same characteristics as the one described in (c). Find an equivalent implementation of the filter using only integrators and amplifiers.

[6]

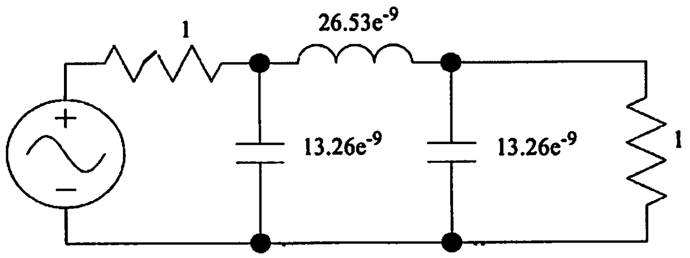

Figure 1.1.

2. For the circuit in Figure 2.1:

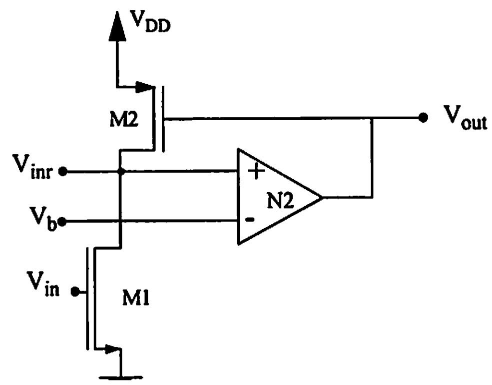

Figure 2.1

(a) Draw a small signal equivalent circuit, ignoring capacitive effects and assuming N2 is an ideal amplifier with voltage gain A.

[2]

(b) Find the small signal DC gain v_{out}/ v_{in}.

[2]

(c) Find the small signal DC gain v_{inr}/v_{in}.

[2]

(d) If a p-type transitor M3 identical to M2 had its source connected to V_{DD} and its gate connected to V_{out}, what would be its drain current assuming that V_b is a few millivolts, the input voltage minus the threshold voltage of transistor M1 (V_{th1}) is always larger than V_b, and A is very large? Express the solution as a function of β_1, V_{th1}, V_{in} and V_b, only.

[2]

(e) What is the generic name of the circuit block formed by the circuit in Figure 2.1 and transistor M3?

[2]

(f) What is the value of the transconductance of the previous circuit?

[2]

(g) Which devices in the previous circuit are the main contributors to the input noise?

[2]

(h) Find an expression for the noise in node V_{inr}. You can approximate it assuming an ideal feedback amplifier with a gain that tends to infinity.

[2]

(i) Find an expression for the noise in V_{out} as a function of the input noise of the different transistors. Assume an ideal feedback amplifier.

[4]

3. For the circuit in Figure 3.1:

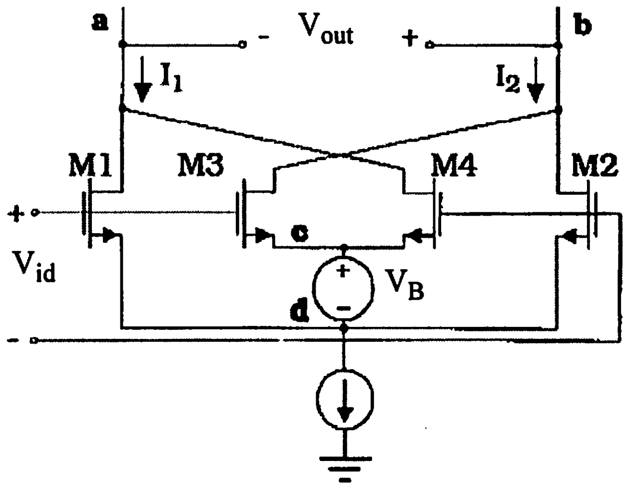

Figure 3.1

(a) Assuming that the input voltage is such that the transistors are always deep in strong inversion saturation, find an expression for the output current $I_{out}=(I_1-I_2)$ as a function of technological parameters of the transistors, V_{id} and V_B, only.

[4]

(b) Assuming that all the transistors are equally sized, draw the small signal equivalent circuit for the circuit and calculate the output resistance, Rout. (Hint: Rout= $v_{out}/(i_1-i_2)$ for input voltage equal to zero.)

[4]

(c) If the circuit in Figure 3.1. was to be loaded as shown in Figure 3.2, what would be the new output resistance? Assume that V_A is at a constant voltage different to V_{DD}, and the g_{ds} of all the transistors is approximately the same. (Hint: Find the small signal equivalent for the load and from there its equivalent resistance at the output. Then combine with the result obtained in (b).)

[4]

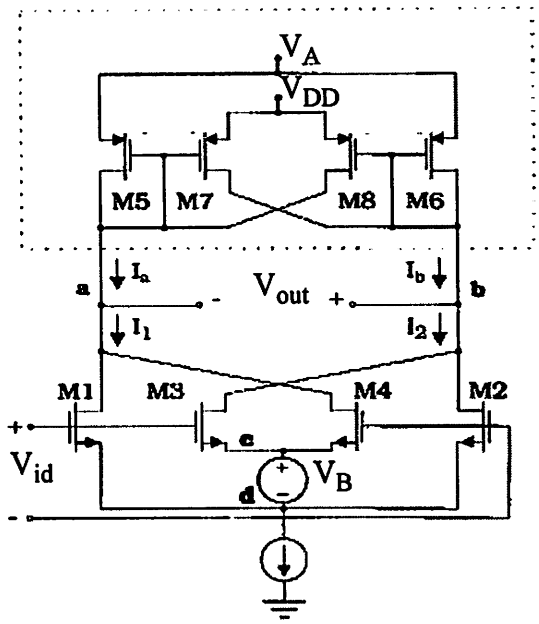

Figure 3.2

(d) What do you think the purpose of having transistors M5 and M6 is? (As opposed to just having a single transistor load).

[2]

(e) If instead of a constant voltage source V_B, nodes c and d were to provide another input to the circuit, what would be the name of the resulting circuit block?

[2]

(f) How could you use a circuit like the one in (e) in a receiver?

[2]

(g) How would you build an integrator with the circuit in Figure 3.2?

[2]

4. For the circuit in Figure 4.1 where v_{ns} represents the noise power spectral density for Z_s, and v_n and i_n the input equivalent noise sources for the bipolar transistor:

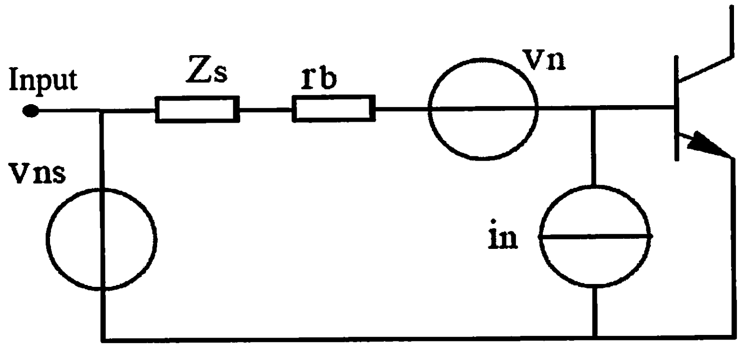

Figure 4.1

(a) Find the equivalent power spectral density of noise at the input as a function of v_{ns}, v_n, i_n, Zs and r_b.

[6]

(b) Give expressions for v_n and i_n as a function of the transistor parameters.

[5]

(c) If both rb and Zs are 50 Ohms, and beta is 100 Ohms, what would be the ideal value of re=(1/gm) for which the noise would be minimum? (Assume medium to large frequencies.)

[3]

(d) Using the values given in (c) calculate the minimum possible value of the noise power at room temperature in a 120kHz to 125kHz band (Note: Boltzman costant=8.6×10^{-5} eV/K.)

[3]

(e) Calculate the minimum output noise if the circuit was used as a single stage amplifier with the collector connected to a 1k Ohm load. The output resistance of the transistor can be considered negligible.(Hint: gm=1/re.)

[3]

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1.

(a) (Theory)

Modulation is used to convert signals to different parts of the electromagnetic spectrum and hence separate them. Each signal is given its own frequency location, which is known by the receiver.The modulation frequency is also chosen to make transmission feasible. For efficient radiation and reception the antenna should have a length which is comparable to a quarter wavelength of the signal.

(b) (Application of theory)

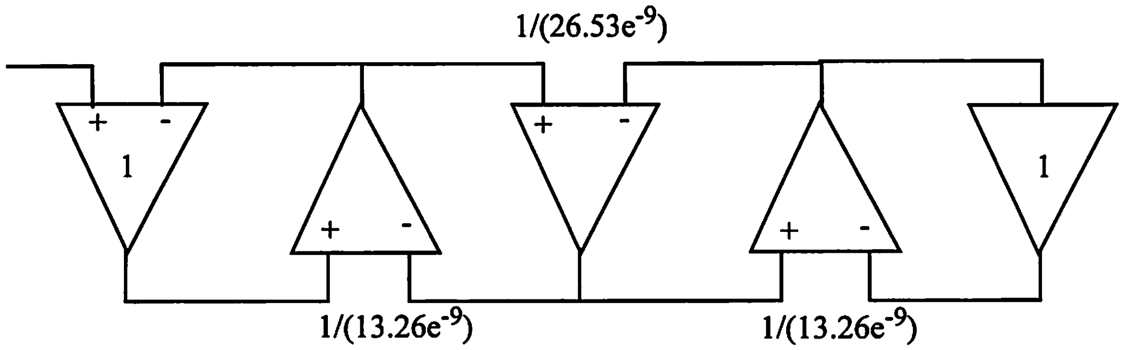
(15-10.7)/2= 2.15MHz

f_{Lo}= 12.85 MHz

(c) (Application of theory)

-5.4dB

(d) (Application of theory)



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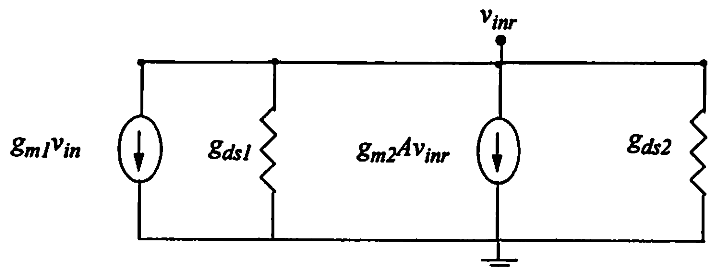
2.

(a), (b) and (c) (New theory)



$$\frac{v_{inr}}{v_{in}} = \frac{-g_{m1}}{(g_{m2}A + g_{ds1} + g_{ds2})}$$

$$\frac{v_{out}}{v_{in}} = -\frac{g_{m1}A}{(g_{m2}A + g_{ds1} + g_{ds2})}$$

(d) (New theory)

$$I \approx \beta_1(V_{in}-V_{th1})V_b$$

(e) (Theory)

Transconductor

(f) (Theory)

$$G_m = \beta_1 V_b$$

(g) (Application of theory)

The input transistor

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(h) (Application of theory)

Under the assumption of a very large gain, the noise tends to zero.

(i) (Application of theory)

From (b), under the assumption of very large gain:

$$\frac{v_{in}}{v_{out}} \approx -\frac{g_{m2}}{g_{m1}}$$

The noise at the input is:

$$v_{M1}^2 + \left(\frac{g_{m2}}{g_{m1}}\right)^2 (v_{M2}^2 + v_{M3}^2)$$

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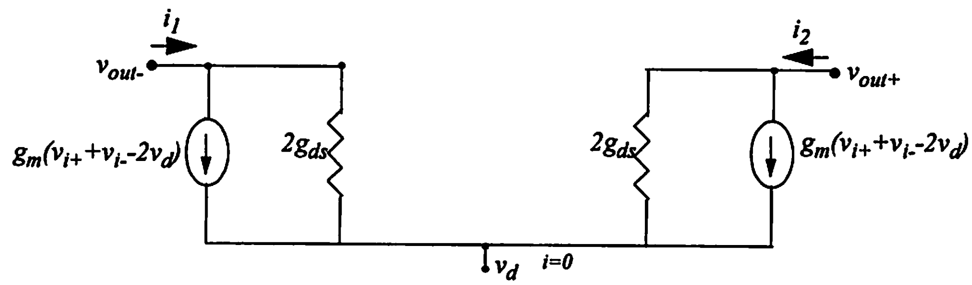
3.

(a) (Application of theory)

$$I_{out} = I_1 - I_2 = 2k_n V_B V_{id}$$

where $k_n = 0.5\mu C'_{ox}\frac{W}{L}$

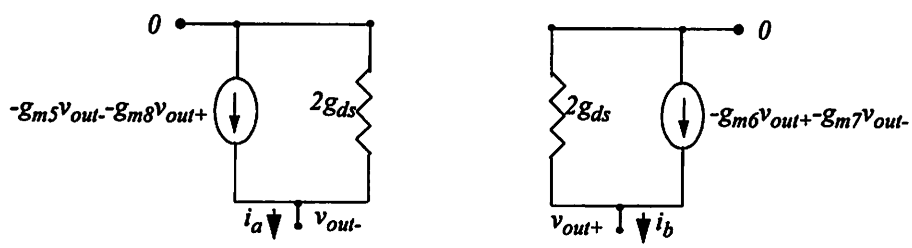
(b) (New derivation)



Analyzing the small signal circuit above, since $v_{id}=v_{i+}-v_{i-}=0$

$$R_{out} = -\frac{1}{2g_{ds}}$$

(c) (New theory and derivation)



Considering that

$$g_{m5} = g_{m6}$$
$$g_{m7} = g_{m8}$$

$$R_{out} = -[2g_{ds} + (g_{m8} - g_{m6})]^{-1}$$

And the overall output resistance is the parallel of the two:

$$R_{out} = -[4g_{ds} + (g_{m8} - g_{m6})]^{-1}$$

(d) (New theory)
Ideally the output resistance of a transconductance should be infinity. Having those transistors can be used to create a negative term via the difference of the transconductances, and hence increase the output resistance.

(e) (Application of theory)
A multiplier.

(f) (Application of theory)
As a mixer to downconvert the input signal to an intermediate frequency.

(g)(Application of theory)
Just adding a capacitor between the two nodes of the output.

4.

(a) (Theory)

$$veq^2 = vns^2 + vn^2 + in^2|Z_s + r_b|^2$$

(b) (Theory)

$$vn^2 = 4kT(rb + re/2)$$

$$in^2 = \frac{2kT}{\beta re}\left(1 + \frac{f_1}{f}\right)$$

(c) (Application of theory)

- To minimise the equivalent input noise, set $d(veq^2)/dre = 0$:

$$\frac{d(veq^2)}{dre} = 4kT\Delta f\left(\frac{1}{2} - \frac{(rb + Rs)^2}{2\beta re^2}\right) = 0$$

Thus $re(opt) = \dfrac{rb + Rs}{\sqrt{\beta}}$

re(opt)=10ohms

(d) (Application of theory)

$$veq^2(min) = 4kT\Delta f\,(Rs + rb + re(opt)) = 4kT\Delta f\,(Rs + rb)(1 + 1/\sqrt{\beta})\ V^2$$

$veq^2(min) = 22.9e^{-16}V^2$

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(e) (New derivation)

$$v_{out}^2 = veq^2 Gain^2 = 22.9e^{-14} V^2$$