IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2005

EEE PART II: MEng, BEng and ACGI

Corrected Copy

ANALOGUE ELECTRONICS 2

Monday, 13 June 2:00 pm

Time allowed: 2:00 hours

There are FOUR questions on this paper.

Q1 is compulsory.
Answer Q1 and any two of questions 2-4.

Q1 carries 40% of the marks. Questions 2 to 4 carry equal marks (30% each)

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

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

1. **[Compulsory]**

(a) Define an amplifier and an attenuator. What is the essential difference between the two? [5]

(b) Two identical amplifiers are connected to a 50Ω and a 100 kΩ load respectively. Do these amplifiers present the same input impedance? Why? [5]

(c) An non-ideal amplifier needs to be made to behave as an ideal current amplifier. What polarity of feedback and which feedback connection is necessary to turn the amplifier into an ideal current amplifier? Why? [5]

(d) What is the input admittance of the circuit in figure 1.1? The voltage gain of the amplifier is G = 29, as indicated. The amplifier is an otherwise ideal voltage amplifier. [5]

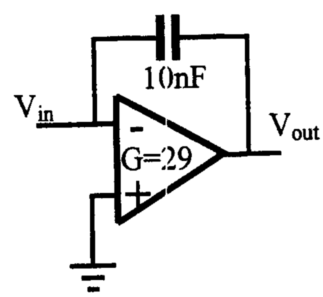


Figure 1.1 Circuit for (d)

(e) Write an expression for the general form of the second order low-pass filter transfer function. Identify any parameters appearing in this equation. [5]

(f) The FET Differential amplifier is a two-stage amplifier. Name the two stages, and describe the terminal characteristics (input-output impedance) and function of each stage. Why does the Differential amplifier have a wider bandwidth than a single stage amplifier with the same voltage gain? [5]

(g) Which family of 2-port parameters is the most suitable to represent the small signal behaviour of a bipolar transistor? Write equations defining the response of a BJT in terms of these parameters. [5]

(h) Prove that if an amplifier is unilateral when considered as a voltage amplifier it is also unilateral when considered as a transconductance amplifier, and conversely. [5]

(a) Calculate the voltage gain of the amplifier in Figure 2.1 if the op-amp is ideal, and all resistors equal.

[10]

(b) Now consider a finite gain op-amp, but one whose input admittance and output impedance are both zero. Write expressions for, and calculate the values of, the feedback path gain, the feedback factor, the loop gain and the closed loop voltage gain. Calculate the minimum op-amp open loop gain that will lead to a closed loop gain deviation of less than 1% from the gain of the ideal op-amp circuit.

[10]

(c) Now assume the op-amp is a real dominant pole amplifier, with a low frequency open loop gain of $A = 1.3 \times 10^4$ and a gain bandwidth product of $GBW = 1.3 \times 10^5$ Hz. Plot a magnitude and phase bode plot for the closed loop amplifier.

[10]

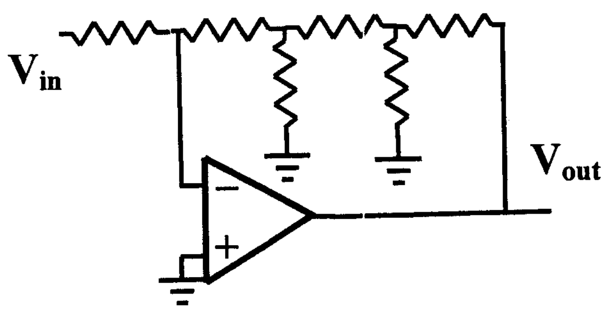


Figure 2.1: Circuit for Question 2.

3. Active ideal op-amp filters can be made without positive feedback. This problem analyses such a filter. This filter is called a "negative KRC" filter.

(a) Derive the transfer function of the filter in Figure 3.1 [15]

(b) What function does the filter perform? [5]

(c) Write expressions for the filter's maximum gain, quality factor and corner frequency. [5]

(d) Draw a magnitude Bode plot for the filter if $R_1 = R_2 = 1\ \text{k}\Omega, C_1 = C_2 = 100\ \text{nF}$ and K = 80. [5]

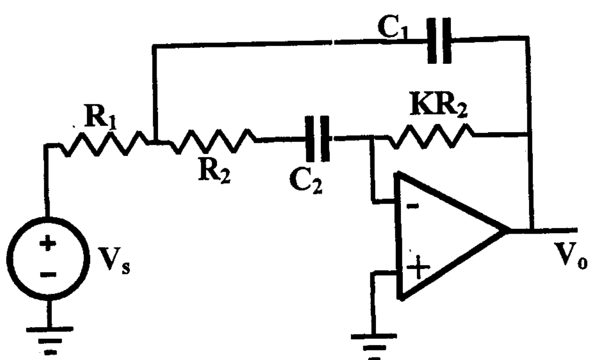


Figure 3.1: A negative KRC filter for Question 3.

4

(a) Show that the circuit in Figure 4.1 simulates a grounded inductance Write an equation expressing the inductance in terms of the values of the components.

[15]

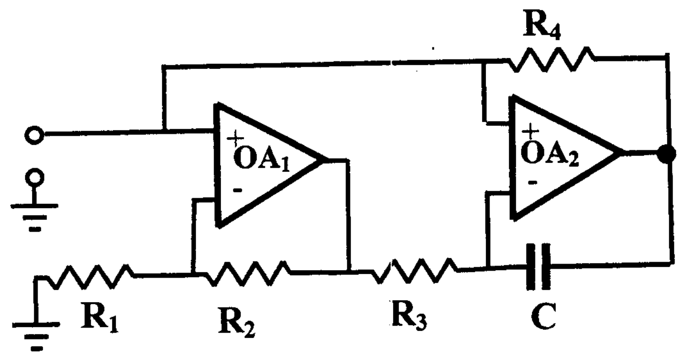


Figure 4.1: A synthesized inductor for Question 4.

(b) Use the results of (a) above to synthesize a second order high pass filter with $\omega_0 = 10$ krad/s and $Q = 2$, operating between signal source of $R = 50\ \Omega$ and driving an ideal voltmeter. All resistors used in your design should be equal to a suitable value R_0, and all capacitors equal to a suitable value C_0. Compute the values of R_0 and C_0.

[15]

EE2 Analogue Electronics 2

Solutions 2005

ANSWERS: (each worth 5)

(a) **[bookwork]** An amplifier has a power gain greater than unity, an attenuator has power gain less than unity. Both can show a voltage gain or a current gain, but if the product of voltage and current gain is less than unity the device is an attenuator.

(b) **[app of theory]**In general the input impedance will be different, unless the amplifier is unilateral.

(c) **[app of theory]**An ideal current amplifier has Zin=0 and Yout=0. These can be achieved only with positive feedback. A series connection at the input will multiply the input impedance by 1-GH while a shunt connection at the output will multiply the output admittance by 1-GH. So, unity loop gain, series-shunt positive feedback will turn this amplifier into an ideal current amplifier.

(d) **[computed example]** Capacitive, 10nF*(29+1)=300nF. (miller effect)

(e)

$$H(s)=\frac{H_0}{s^2/\omega_0^2+2\zeta s/\omega_0+1}$$

ω_0 is the break frequency, ζ=1/2Q the damping factor and H_0 the DC gain.

(f) **[bookwork]**The differential amplifier is a cascade of a common drain and a common gate stage. The common drain is a power amplifier dropping the signal impedance to match the input impedance of the common gate stage that does the bulk of the voltage amplification by acting as a unity current gain amplifier.

(g) **[bookwork]**A BJT is a natural current amplifier, so h parameters are most suitable for its description.The following equations define the h parameters:

$v_1 = h_{11}i_1 + h_{12}v_2$

$i_2 = h_{21}i_1 + h_{22}v_2$

(h) **[app of theory]**by the definition of a voltage amplifier,

$$i_1 = g_{11}v_1 + g_{12}i_2$$

a transconductor, on the other hand has

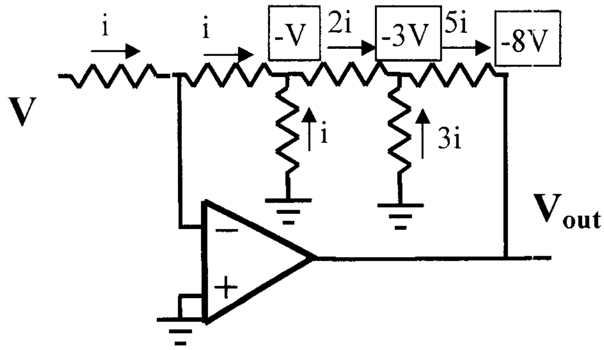
$$i_1 = y_{11}v_1 + y_{12}v_2$$

If the voltage amplifier is unilateral, then

$g_{12} = 0 \Rightarrow i_1 = g_{11}v_1$ independent of what is happening at port 2. By comparison in the y-parameter definition, it must be $y_{12} = 0$, i.e. the amplifier is unilateral also when considered a transconductor.

ANSWER Q2: [computed example]

a) Let A be the op-amp open loop gain, and H the gain of the feedback network. This is an inverting amplifier, so in the ideal case $V_- = 0$. If all resistors are R, nodal analysis gives Av=-8, the solution in the diagram:



[10]

b) if the op-amp has a finite gain G, then $V_- = V_{out}/G = 8V/13 + V_{out}/13 \Rightarrow$ The feedback path gain is therefore 1/13 and the loop gain is G/13.

Then, $A_v = \frac{8}{13}\frac{-G}{1+G/13} = -8\frac{1}{1+13/G} \approx -8(1-13/G)$

If we want 13/G<0.01 thenG>1300.

[10]

c) the dominant pole amplifier has a response:
$G(s) = A/(1+s\tau)$ and the gain bandwidth product is :
$GBW = A/\tau$. Then $A = 1.3\cdot 10^4$ and $\tau = (10Hz)^{-1} = 15.9m\sec$
The gain expression becomes

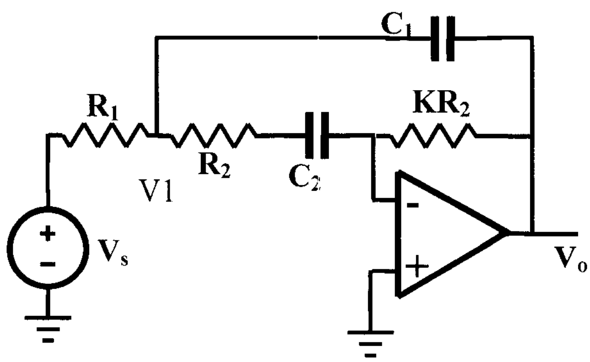
$$A_v = \frac{8}{13}\frac{-G/1+\tau s}{1+G/13(1+\tau s)} = \frac{-8}{13}\frac{G}{1+\tau s+G/13} = \frac{-8G}{13(1+G/13))}\frac{1}{1+s\tau/(1+G/13))}$$

This is a single pole LPF with a trivial bode plot.

-mag plot: starts at G=8=18dB, breaks at 10kHz and slopes at -20dB/decade afterwards.
-phase plot: -45deg. At 10kHz, extends 0- -90deg. From 5kHz to 20kHz.

[10]

ANSWER Q3: [computed example]



(a-c) The only free node is V_1 so we can write KCL on that:

$$(V_s - V_1)\frac{1}{R_1} + (V_o - V_1)sC_1 - V_1\frac{sC_2}{1+sR_2C_2} = 0 \Rightarrow$$

$$V_s - V_1 + (V_o - V_1)s\tau_1 - \frac{R_1}{R_2}\frac{s\tau_2}{1+s\tau_2} = 0 \Rightarrow$$

$$V_s - V_1\left(1 + s\tau_1 + \rho\frac{s\tau_2}{1+s\tau_2}\right) + V_o s\tau_1 = 0$$

$$\rho = \frac{R_1}{R_2}$$

but also, at the V- terminal:

$$V_1\frac{sC_2}{1+sR_2C_2} + V_o\frac{1}{KR_2} = 0 \Rightarrow V_1\frac{Ks\tau_2}{1+s\tau_2} + V_0 = 0$$

with

$$\tau_1 = R_1C_1, \tau_2 = R_2C_2$$

Substituting we get:

$$V_s - V_o\frac{1+s\tau_2}{Ks\tau_2}\left(1 + s\tau_1 + \rho\frac{s\tau_2}{1+s\tau_2}\right) + V_o s\tau_1 = 0 \Rightarrow$$

$$\frac{V_o}{V_s} = \frac{-Ks\tau_2}{(K+1)s^2\tau_1\tau_2 + s(\tau_1 + \tau_2 + \rho\tau_2) + 1} \Rightarrow$$

$$\omega_0 = \sqrt{\frac{1}{(K+1)\tau_1\tau_2}}$$

$$2\zeta = \frac{1}{Q} = (\tau_1 + \tau_2 + \rho\tau_2)\omega_0 = \frac{\tau_1 + \tau_2 + \rho\tau_2}{\sqrt{(K+1)\tau_1\tau_2}}$$

$$H_0 = \frac{-K\tau_2}{2\zeta/\omega_0} = \frac{-K\tau_2}{\tau_1 + \tau_2 + \rho\tau_2}$$

So this is a bandpass filter with ω_0, ζ, H_0 as shown.

[25]

(d) With the numbers given,

$$\tau_1 = \tau_2 = 100\mu s, \rho = 1 \Rightarrow$$

$$\omega_0 = \sqrt{\frac{1}{(K+1)\tau_1\tau_2}} = \frac{1}{9} \cdot 1.1 krad/s \simeq 300Hz$$

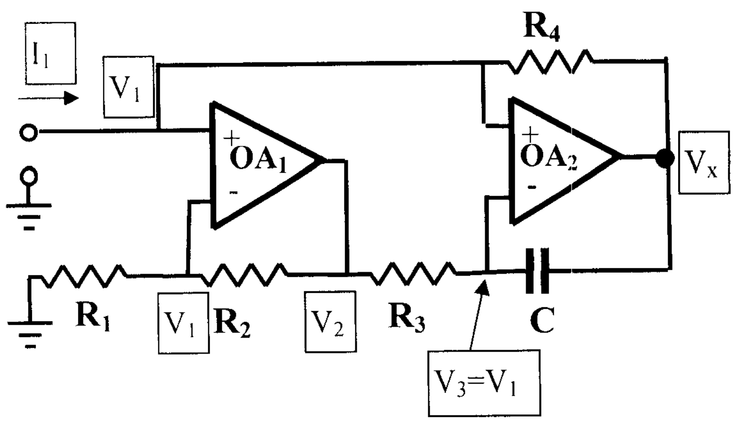
$$2\zeta_0 = 1/Q = 300\mu s \cdot \frac{10}{9} krad/s = 1/3$$

$$H_0 = \frac{-K\omega_0\tau_2}{2\zeta} = -\frac{80}{3}$$

The bode plot is that of a BPF with these parameters.

[5]

ANSWER Q4: [computed example]



(a) To show this is equivalent to an inductor it suffices to show that at the input $v = iLs$.

$$V_2 = \left(\frac{R_2}{R_1}+1\right)V_1$$

$$I_{R3} = I_C = (V_2 - V_1)/R_3 = (V_1 - V_x)sC \Rightarrow$$

$$V_x = \frac{V_1 - (R_2/R_1+1)V_1}{s\tau_3} + V_1 = V_1\left(\frac{-R_2/R_1}{sR_3C}+1\right) \Rightarrow$$

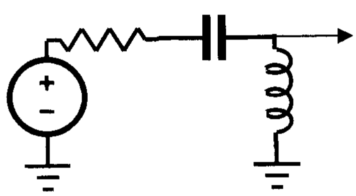
$$I = (V_1 - V_x)/R_4 = \frac{V_1}{R_4}\left(1-\left(\frac{-R_2/R_1}{sR_3C}+1\right)\right) = \frac{V_1R_2}{sR_1R_4R_3C}$$

So this circuit is indeed a grounded inductance:

$$L = \frac{R_1R_3R_4C}{R_2}$$

[15]

(b) A second order LC HP filter is:



The response is:

$$\frac{V_o}{V_i} = \frac{sL}{sL+R+1/sC} = \frac{s^2LC}{s^2LC+RsC+1} \Rightarrow$$

$$\omega_0 = \frac{1}{LC}, 2\zeta = \frac{1}{Q} = RC\omega_0 = R/\sqrt{\frac{L}{C}}$$

We then need:

$$\omega_0 = \frac{1}{\sqrt{LC}} = 10^4$$

$$2\zeta = R / \sqrt{\frac{L}{C}} = \frac{1}{2} \Rightarrow \sqrt{\frac{L}{C}} = 100\Omega \Rightarrow$$

$$L = 10^4 C \Rightarrow ... \Rightarrow C = 10^{-6} F \Rightarrow L = 10mH$$

Since we only use one resistor value, the value of the synthetic inductance is:
$L = R^2 C = 10^{-6} R^2$ so that R needs to be $R = 100\Omega$

[15]