The University of Sheffield
Department of Electronic and Electrical Engineering

Electronic Devices in Circuits Tutorial Sheet

Second Order Circuits and Noise

Q1 For the circuit of figure 1

(i) Find the transfer function v_o / v_i .

(ii) What type of response is v_o / v_i ?

(iii) What is the undamped natural frequency of the circuit ? (5kHz)

(iv) What is the circuit q ? (3.16)

(v) Find the transfer function $(v_L + v_C) / v_i$

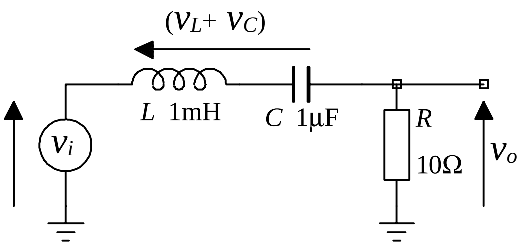

Figure 1

(vi) See if you can sketch an amplitude response for the transfer function of part **(v)**. (***Hint:*** *The transfer function is the sum of two transfer functions whose amplitude and phase behaviour are known. Think carefully about the amplitude and phase of these two responses when* $\omega = \omega_o$.)

(vii) Bearing in mind the name of the response derived in part **(i)**, what do you think a suitable name for the response of part **(v)** might be ?

Q2 **(i)** Find the transfer function, v_o / v_i, of the circuit of figure 2.

(ii) What is the undamped natural frequency of the circuit ?

(iii) What is the circuit q ?

(iv) What is the maximum value of q that can be obtained using a circuit like this ? (0.5)

(v) What is the ratio $R_1C_1:R_2C_2$ that will give maximum q ? (1:1)

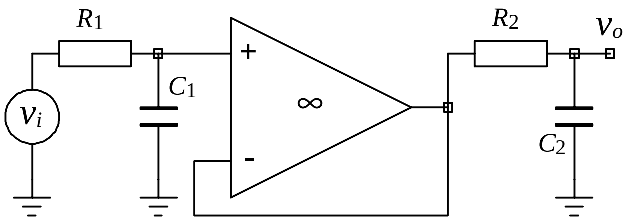

Figure 2

Hint: *In parts* **(iv)** *and* **(v)** *try to express 1/q in a form (x+ 1/x) where x is some constant containing* R_1, R_2, C_1 *and* C_2*, and then differentiate to minimise 1/q. If you can find a minimum for 1/q you have also found a maximum for q.*

Q3 The circuit of figure 3 is commonly known as a "Friend" circuit after its inventor.

(i) Work out the transfer function, v_o / v_i , of the circuit.

(ii) What type of response does the circuit produce ?

(iii) If $C_1 = C_2$ what ratio $R_1 : R_2$ is required for a q of 3 ? (36:1)

(iv) What is the circuit gain at the undamped natural frequency if $q = 3$? (***Hint:*** *Remember that at the undamped natural frequency, the* s^2 *term in the denominator= -1.*) (-18)

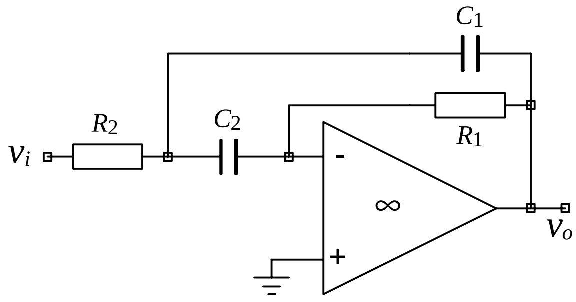

Figure 3

Q4 Work out the transfer function of the high pass Sallen and Key circuit of figure 4.

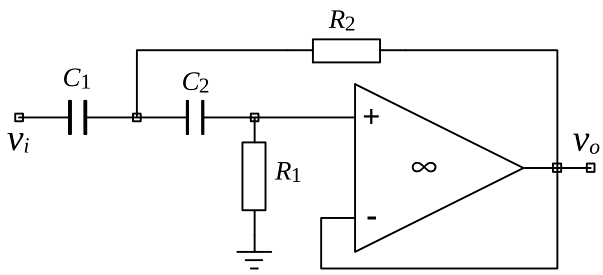

Figure 4

Q5 The frequency normalised (ie, cut off frequency = 1rad s^{-1}) polynomial for a fifth order Chebychev filter with 0.5dB passband ripple is:

$$(s + 0.362)(s^2 + 0.224s + 1.036)(s^2 + 0.586s + 0.477)$$

If the filter is required to have an overall cut off frequency of 1kHz, identify:

(i) The corner frequency required of the first order section. (362Hz)

(ii) The undamped natural frequency required of each of the second order sections. (1020Hz, 690Hz)

(iii) The q required of each of the second order sections. (4.53, 1.18)

Hint: *Remember that the polynomial forms the denominator of the filter transfer function. Get each factor into a standard form and remember that each corner / undamped natural frequency must have the same relative position to the required cut off frequency as the normalised factors have to 1rad* s^{-1}

Q6 Using Sallen and Key circuits with equal Rs, choose suitable component values to synthesise a 4th order Butterworth low pass filter with a cut off frequency of 10kHz. The frequency normalised 4th order Butterworth polynomial is:

$$(s^2 + 0.765s + 1)(s^2 + 1.848s + 1)$$

Your values should be suitable for use with the AD711 Analog Devices op-amp for which data was given out in the lectures.

Q7 If the two resistors in the circuit of figure 7 are noise free,

(i) Find the rms noise voltage, v_{on}, in V $Hz^{-1/2}$. (19.4nV$Hz^{-1/2}$)

(ii) What is the total rms noise voltage, v_{on}, over a 20kHz bandwidth ? (2.74µV)

(iii) If the circuit is represented by its Thevenin equivalent consisting of a noise voltage source and series resistance, what is the noise temperature of the series resistance if it is assumed that this resistance is responsible for all the noise? (880K)

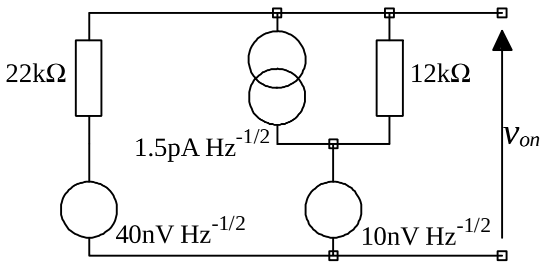

Figure 7

(iv) What would the answer to part **(iii)** be if the two resistors in figure 7 were in fact noisy ? (1179K)

The noise generated by a resistor R is $4kTR$ V^2Hz^{-1} where $k = 1.38 \times 10^{-23} JK^{-1}$ and $T = 300K$

Q8 In the circuit of figure 8, only the 20V source is noise free.

(i) What is the noise voltage across the diode in terms of V $Hz^{-1/2}$? (868pV$Hz^{-1/2}$)

(ii) What is the Thevenin equivalent resistance from which that noise comes ? (91Ω)

(iii) What is the effective noise temperature of the resistance calculated in part **(ii)**? (150K)

(iv) If the output is loaded by a 10pF capacitor, what is the total rms noise voltage at the output? (14.4µV)

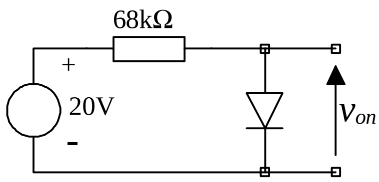

Figure 8

The noise generated by a resistance is $4kTR$ V^2Hz^{-1} and that generated by a diode is $2eI$ A^2Hz^{-1} where $k = 1.38 \times 10^{-23}$ J K^{-1}, $e = 1.6 \times 10^{-19}$C and $T = 300K$. (***Hint:*** *Remember that the diode has a slope or incremental resistance and that this resistance will affect the noise but will not itself contribute to it*)

Q9 A particular amplifier has a noise free input resistance of 50kΩ and equivalent input noise voltage and current generators of 6nV $Hz^{-1/2}$ and 0.3pA $Hz^{-1/2}$ respectively. The amplifier gain is 100V/V.

(i) What value of source resistance, R_S, will minimise the noise factor of the amplifier? (20kΩ)

(ii) What is the output noise voltage, in terms of V $Hz^{-1/2}$, with the source resistance calculated in part **(i)** ? (1.43μV$Hz^{-1/2}$)

(iii) If the source is a microphone with a fixed resistance of 50Ω and a transformer is to be used to achieve the appropriate impedance matching for noise purposes, what turns ratio is required in the transformer to ensure that the amplifier is operating at the minimum noise factor? (*Assume a turns ratio is 1:n with the 1 on the microphone side. You need to find n*) (20)

(iv) If a transformer with a turns ratio as calculated in part **(iii)** is used to couple the microphone to the amplifier, what signal voltage would appear at the amplifier output as a result of a 1mV rms signal at the terminals of the microphone? (1.43V)

(v) What is the signal to noise ratio at the amplifier output for the conditions of part **(iv)** if the system bandwidth is 20kHz? (77dB)

Q10 A wideband amplifier in a matched 50Ω system is made from two thin film amplifier modules with gains of 25dB and 15dB and noise figures of 4.50dB and 7.00dB respectively such that the overall amplifier bandwidth, Δf, is 1000MHz.

(i) What is the gain of the series combination? (40dB)

(ii) What is the noise factor of each amplifier module? (2.82 and 5.01)

(iii) What is the noise figure of the combination if the higher gain module is at the input end of the amplifier? (4.53dB)

(iv) What is the total added noise power delivered to the load? (76.2nW)

(v) What is the signal to noise ratio at the amplifier output if the input signal power is 10pW? (-0.7dB)

(vi) What is the effective noise temperature of the amplifier cascade? (549K)

The maximum available noise power is $kT\Delta f$ W where $k = 1.38 \times 10^{-23}$, T = 300K and Δf is as defined in the question. This question uses the notation *(noise figure)* = 10 log *(noise factor)*.