CENG4480 2021F Homework 2

Due: Nov. 07, 2021

Solutions

All solutions should be submitted to the blackboard in the format of **PDF/MS Word**.

Q1 (10%) A 8 bits ADC with full scale output voltage of 2.56V is designed to have a ± 0.5 LSB accuracy. If the ADC is calibrated at 50°Cand the operating temperature ranges from 0°Cto 100°C, then what's the maximum net temperature coefficient of the ADC should not exceed?

A1

$$N = 8 \text{ bits} \tag{1}$$
$$\text{FSO} = 2.56 \text{ V} \tag{2}$$
$$1 \text{ LSB} = \frac{\text{FSO}}{2^{N-1}} \approx 10 \text{ mV} \tag{3}$$
$$\pm 0.5 \text{ LSB} = \pm 5 \text{ mV} \tag{4}$$
$$\alpha \times \Delta T \leq \pm 5 \text{ mV} \tag{5}$$
$$\alpha \leq 100 \mu V/\text{°C} \tag{6}$$

Q2 (20%) Given a low-pass filter as shown in Figure 1.

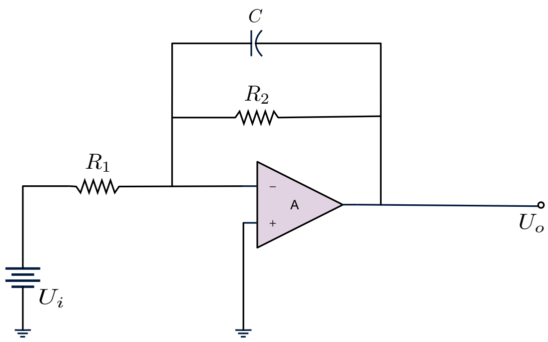

Figure 1: Q2 Circuit

1. If $R_1 = 10K\Omega$, $R_2 = 100K\Omega$, determine low-frequency gain $A_u(dB)$;
2. If cutoff frequency $f_c = 5Hz$, determine C value.

A2

$$u_o(j\omega) = -\frac{R_2 // \frac{1}{j\omega C}}{R_1} u_i(j\omega) \tag{7}$$

So

$$A_u(j\omega) = \frac{u_o(j\omega)}{u_i(j\omega)} = -\frac{R_2}{R_1} \frac{1}{1 + j\omega R_2 C} = \frac{A_{u_o}}{1 + j\frac{\omega}{\omega_c}} \tag{8}$$

where $A_{u_o} = -\frac{R_2}{R_1}$ is low-frequency gain, $\omega_c = \frac{1}{R_2 C}$ is cutoff angular frequency. If $R_1 = 10K\Omega$, $R_2 = 100K\Omega$, low-frequency gain

$$20 \log \frac{R_2}{R_1} = 20 \log \frac{100}{10} = 20dB \tag{9}$$

cutoff frequency:

$$f_c = \frac{\omega_c}{2\pi} = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi \times 100 \times 10^3 \times C} = 5Hz \tag{10}$$

so

$$C = \frac{1}{2\pi \times 100 \times 10^3 \times f_c} = \frac{1}{2\pi \times 100 \times 10^3 \times 5} = 3.18 \times 10^{-7}F = 0.318\mu F \tag{11}$$

Q3 (20%) Given the the circuit shown in Figure 2, $R_1 = R_2 = 1k\Omega$, $R_3 = 10k\Omega$, $R_4 = R_5 = R_6 = 20k\Omega$, $C_1 = 0.05\mu F$, $C_2 = 0.02\mu F$, please answer the following questions.

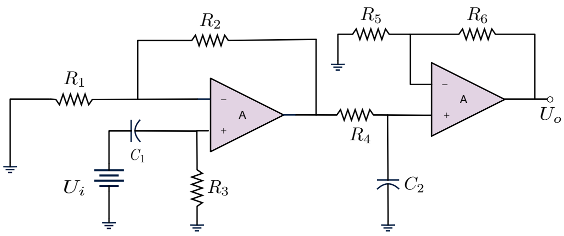

Figure 2: Q3 Circuit

(1) Which kind of filter the circuit is?

(2) Calculate the cutoff frequencies of the circuit. If it has both the lower and upper cutoff frequency, then you should calculate both.

A3 (1) bandpass filter (2) The lower cutoff frequency f_{OL} is given by

$$f_{OL} = \frac{1}{2\pi R_3 C_1} = 318.3Hz \tag{12}$$

The upper cutoff frequency f_{OH} is given by

$$f_{OL} = \frac{1}{2\pi R_4 C_2} = 397.9Hz \tag{13}$$

Q4 A 5-bit D/A converter has a voltage output. For a binary input of 10100, an output voltage of 18 mV is produced. Determine the output voltage when the binary input is 11100.

A4 The binary input 10100 is equivalent to 20_{10}, then

$$\text{The proportionality factor} = \frac{18}{20} = 0.9 \tag{14}$$

It follows that the output voltage is 0.9 times the binary value. The binary input 11100 is equivalent to 28_{10}, hence

$$\text{Output voltage} = 0.9 \times 28 = 25.2mV \tag{15}$$

Q5 For the DAC circuit shown in Figure 3 (using an ideal op-amp), what value of R_F will give an output range of $-10 \leq V_0 \leq 0V$? Assume that logic $0 = 0V$ and logic $1 = 5V$.

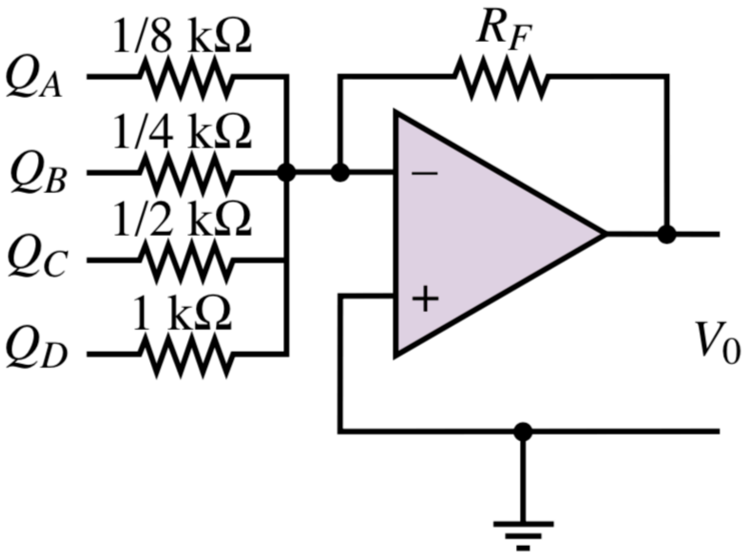

Figure 3: Q5 Circuit

A5 We have the above equation:

$$\frac{-V_0}{R_F} = \frac{(8Q_A + 4Q_B + 2Q_C + Q_D) \times 5V}{1k\Omega} \tag{16}$$

when input equals 0000, $V_0 = 0V$, when input equals 1111, $V_0 = -10V$. So we get:

$$R_F = \frac{10}{15 \times 5} = \frac{2}{15}K\Omega \tag{17}$$

Q6 For the 4-bit R-2R DAC shown in Figure 4, calculate V_0 in terms of $V_{b,0} - V_{b,4}$ if V_{ref} is grounded.

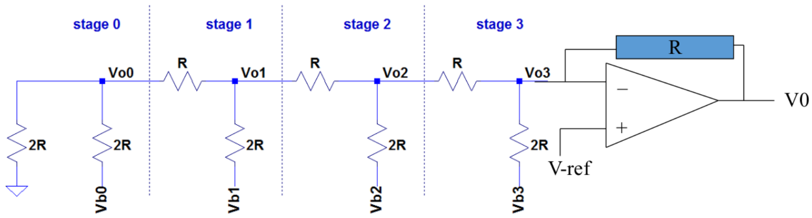

Figure 4: Q6 Circuit

A6 As shown in Figure 5, first we calculate the equivalence seen from V_{o3},

$$R_{eq} = R \tag{18}$$

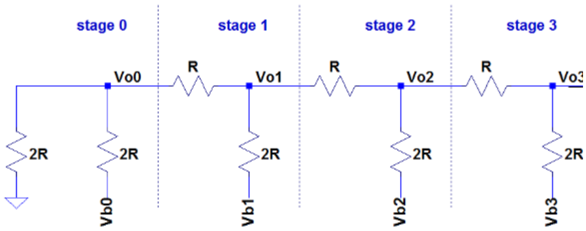

Figure 5: Load of R-2R ADC

Get contribution at V_{o3i} of each digital input V_{bi}, i=0,1,2,3 separately, it's easy to derive from Thevenin equivalent analysis,

$$V_{o30} = \frac{V_{b0}}{16} \quad (19)$$

$$V_{o31} = \frac{V_{b1}}{8} \quad (20)$$

$$V_{o32} = \frac{V_{b2}}{4} \quad (21)$$

$$V_{o33} = \frac{V_{b3}}{2} \quad (22)$$

$$(23)$$

then, we have,

$$V_{o3} = \frac{V_{b0}}{16} + \frac{V_{b1}}{8} + \frac{V_{b2}}{4} + \frac{V_{b3}}{2} \quad (24)$$

Using the quality of op amp,

$$V_{o} = \frac{V_{b0}}{16} + \frac{V_{b1}}{8} + \frac{V_{b2}}{4} + \frac{V_{b3}}{2} \quad (25)$$