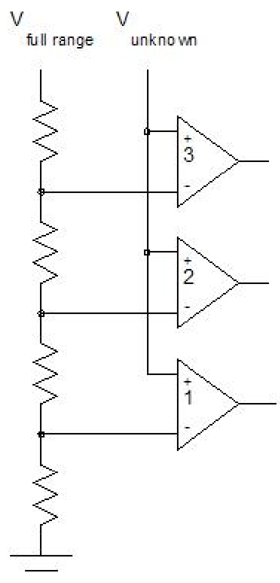
ADC and DAC practice problem

1. An analog signal in the range of -5V to 5V is to be converted to a digital signal. Suppose a 2 bit quantization will be implemented.

   a. What is the step size of the ADC circuit?
   b. How many quantization levels are there ?
   c. Find the maximum value of the quantization error.
   d. Calculate the number of resistors and OP-AMP required for the Flash ADC circuit.
   e. Make a table with quantization range, quantization level and encoded binary value.
   f. At some instances the signal values of the ADC circuit are 3.35V, -2.67V and 1.14 V. Find corresponding encoded binary value.
   g. Explain the input and output relationship osf the Encoder with a table.

2.



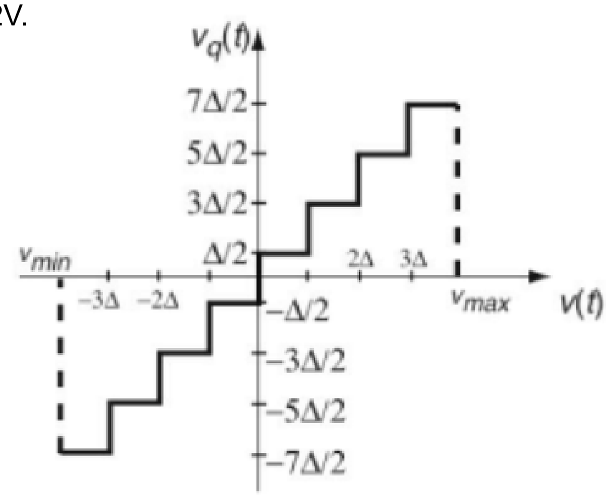
Here,
R = 10 k, Vfullrange = 10 V. (Reference Voltage)

   a. What will be the output binary bits line for the above circuit?
   b. Draw the quantization level vs Input signal plot.
   c. If Vunknown = 3.5 V, what will be the quantization error for this case? (Quantization error = Actual value - Quantized value)

3. x(t) = 5 + 5 sin (2*pi * f *t) V
Where f = 2 k Hz.
Above signal will be converted to a digital signal through an ADC circuit.

   a. What will be the minimum required sampling frequency for this signal?
   b. Suppose, the sampling frequency is set at 10 kHz. Find the first 5 sampling values as well as their corresponding quantized value and encoded value.

4. The following plot is the relationship between input and output of a midrise quantizer. Where the step size is 2V.

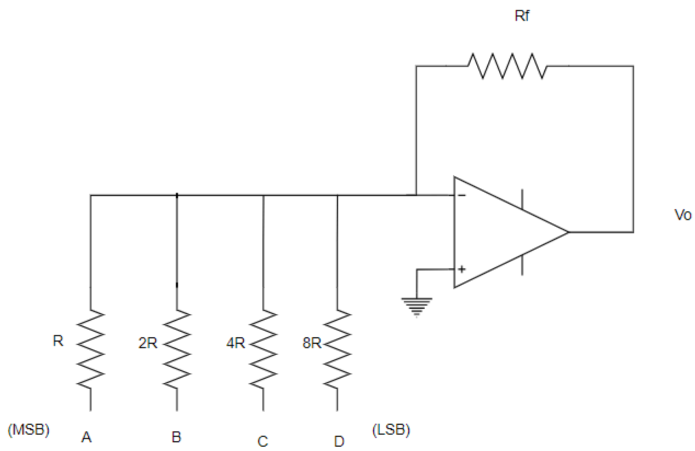


midrise quantizer

a. What is the number of binary bits required to express the quantization levels?
b. Find the corresponding quantized value if the inputs of the quantizer are -5.6 V and 7.34 V.
c. What will be the maximum value of the quantization error?
d. Design a full ADC circuit consisting of maximum current of the circuit should not exceed 0.1 mA.

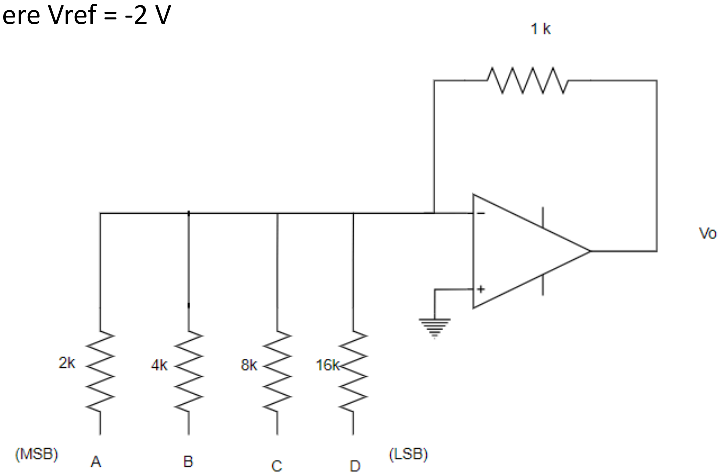
5. Design a 4 binary weighted DAC circuit with reference voltage of 5 V and maximum output voltage of 15V.

6. Here Rf = 2 kΩ and R = 4 kΩ, Vref = -5 V.



a. What will be the maximum and minimum output voltages?
b. What is the step size of this DAC circuit?
c. What is the resolution of this DAC scheme?
d. Make a table for all the combinations of inputs and outputs.
e. Find the output value for the binary inputs 1101, 0001 and 1110, 0001, 1000

7. Here Vref = -2 V



a. Calculate the output value for 1111 and 1010 input value.
b. What will be the resolution of this circuit?
c. Redesign the circuit by changing the value of the feedback resistor so that maximum output voltage will be 7.5 V.

Solution to ADC and DAC Practice Problem

1.a) Step size $= \dfrac{V_{max} - V_{min}}{2^n}$

$$= \frac{5+5}{2^2}$$

$$= 2.5V$$

1.b) Number of quantization level

$$= 2^n$$

$$= 2^2$$

$$= 4$$

1.c) Maximum value of quantization error

$$= \frac{4}{2}$$

$$= \frac{2.5}{2}$$

$$= 1.25V$$

1.d) # of resistor $= 2^n = 2^2 = 4$

# of OP-AMP $= 2^n - 1 = 2^2 - 1 = 3$

1.e.) Here, $\Delta = \frac{5-(-5)}{2^{v}} = 2.5V$

Q. Range	Q. level	Encoded Value ($b_2 b_1$)
-5 — -2.5	-3.75	00
-2.5 — 0	-1.25	01
0 — 2.5	+1.25	10
2.5 — 5	+3.75	11

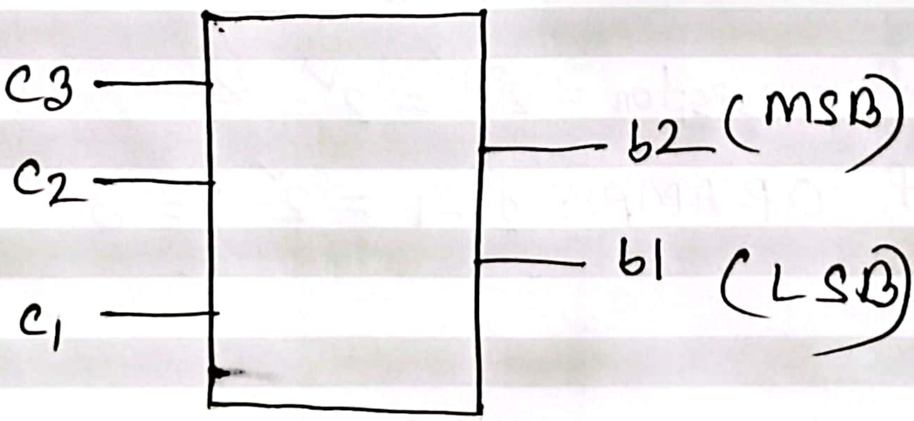
1.f) From previous table (1.e)

if, $V_{sig} = 3.35V$, encoded binary ($b_2 b_1$) = 11

$V_{sig} = -2.67V$, " " " = 00

$V_{sig} = 1.14V$, " " " = 10

1.g) Encoder required,



Input output relation table,

C3C2C1	b2b1
0 0 0	0 0
0 0 1	0 1
0 1 1	1 0
1 1 1	1 1

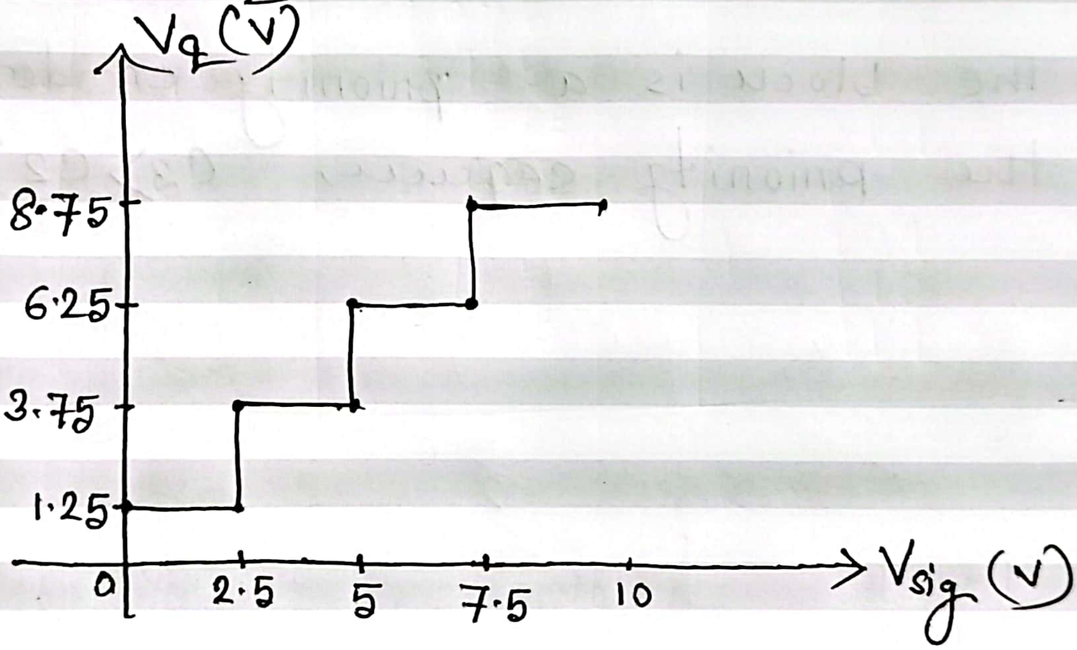
The block is a priority encoder with the priority sequence, $C_3 > C_2 > C_1$

2.a) There are 4 resistor.

$$4 = 2^n$$
$$\Rightarrow n = 2$$

$\therefore$ Number of output bits line $= 2$

2.b) $\Delta = \dfrac{10 - 0}{2^n} = 2.5\,V$



2.c) $V_{sig} = 3.5V$

This value is within the range 2.5V to 5V

$$V_q = \frac{2.5 + 5}{2} = 3.75V$$

Quantization Error $= 3.5 - 3.75 = -0.25V$

3. a) $f_{sampling} \geq 2 \times f_{sig}$

$f_{sampling} \geq 2 \times 2kHz$

$f_{sampling} \geq 4kHz$

∴ Minimum sampling freq. is 4kHz

3. b) $x(t) = 5 + 5\sin(2\pi f t)$

$f = 2kHz, \quad f_s = 10kHz$

Sampling interval, $T_s = \frac{1}{f_s}$

$\therefore f \times T_s = \frac{f}{f_s} = \frac{2k}{10k} = \frac{1}{5}$

$t = 0, \quad x(0) = 5 + 0 = 5V$

$t = T_s, \quad x(T_s) = 5 + 5\sin 2\pi f \times T_s = 5 + 5\sin 2\pi \times \frac{1}{5}$

$= 9.76V$

$t = 2T_s, \quad x(2T_s) = 5 + 5\sin 2\pi \times \frac{2}{5} = 7.94V$

$t = 3T_s \quad x(3T_s) = 5 + 5\sin 2\pi \times \frac{3}{5} = 2.06V$

$t = 4T_s \quad x(4T_s) = 5 + 5\sin 2\pi \times \frac{4}{5} = 0.2447V$

Table for ADC,

$$\Delta = \frac{V_{max} - V_{min}}{2^n} = \frac{10-0}{2^3} = 1.25$$

[correction: 3 bit binary system]

Q. Range	Q. level	Binary ($b_3 b_2 b_1$)
0 — 1.25	0625	000
1.25 — 2.5	1.875	001
2.5 — 3.75	3.125	010
3.75 — 5	4.375	011
5 — 6.25	5.625	100
6.25 — 7.5	6.875	101
7.5 — 8.75	8.125	110
8.75 — 10	9.375	111

From the Table

taking the lower range

	$x(t)$	V_q	$b_3 b_2 b_1$
$t = 0$	5	4.375	011
$t = T_s$	9.76	9.375	111
$t = 2T_s$	7.94	8.125	110
$t = 3T_s$	2.06	1.875	001
$t = 4T_s$	0.2447	0.625	000

4.a) There are 8 quantization level in y axis

$$2^n = 8$$
$$n = 3$$

4.b) Given, $\Delta = 2V$

$v(t) = -5.6V$

This value will ~~be~~ fall in the range,

-3Δ to -2Δ or $-6V$ to $-4V$ range

$V_q = -2.5\Delta = -2.5 \times 2 = -5V$

$v(t) = 7.34$

This value will ~~be~~ fall in the range,

3Δ to 4Δ or $6V$ to $8V$ range.

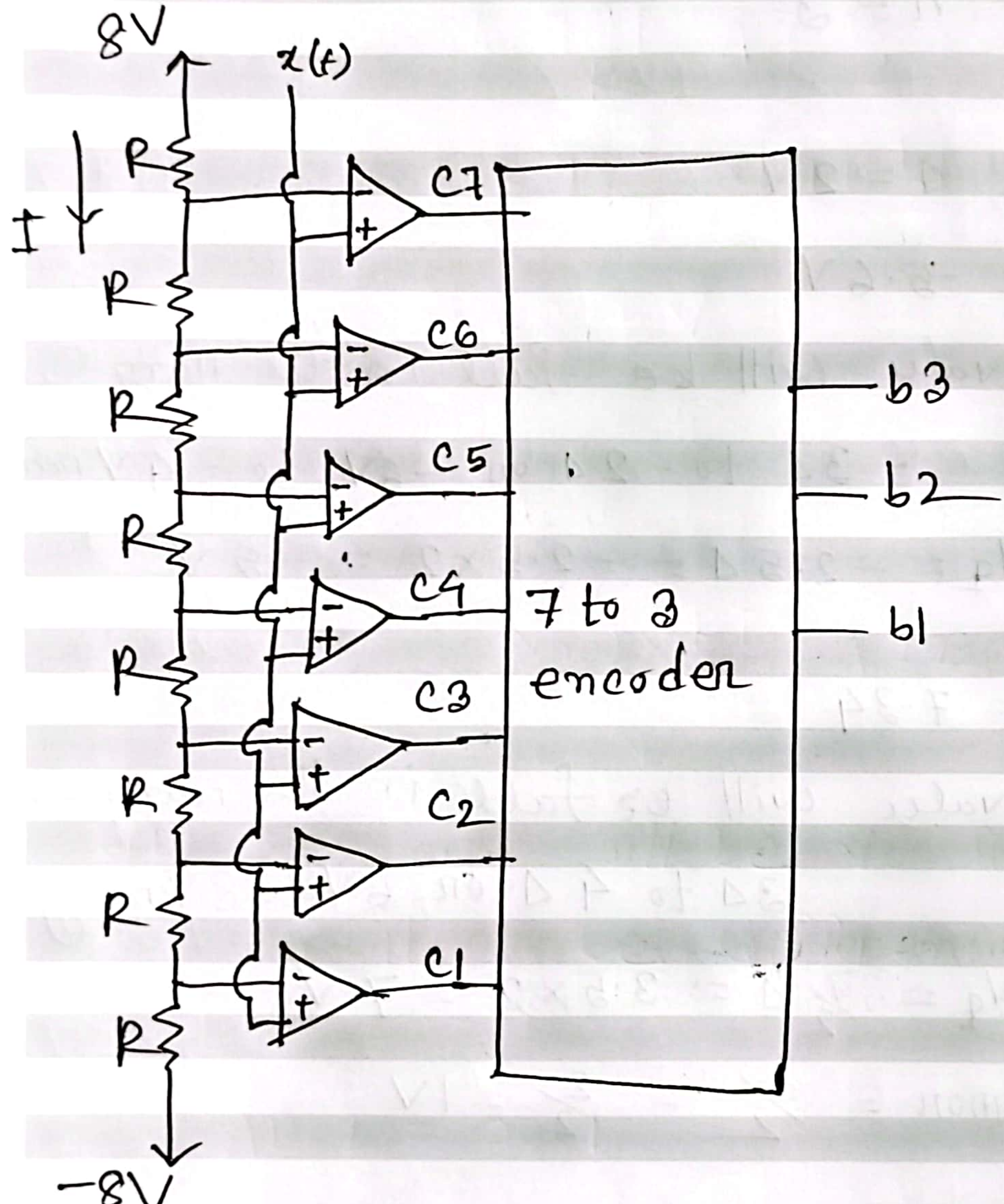
$V_q = \frac{7}{2}\Delta = 3.5 \times 2 = 7V$

4.c) Max error $= \frac{\Delta}{2} = \frac{2}{2} = 1V$

4.d) # bits = 3

resistor $= 2^3 = 8$

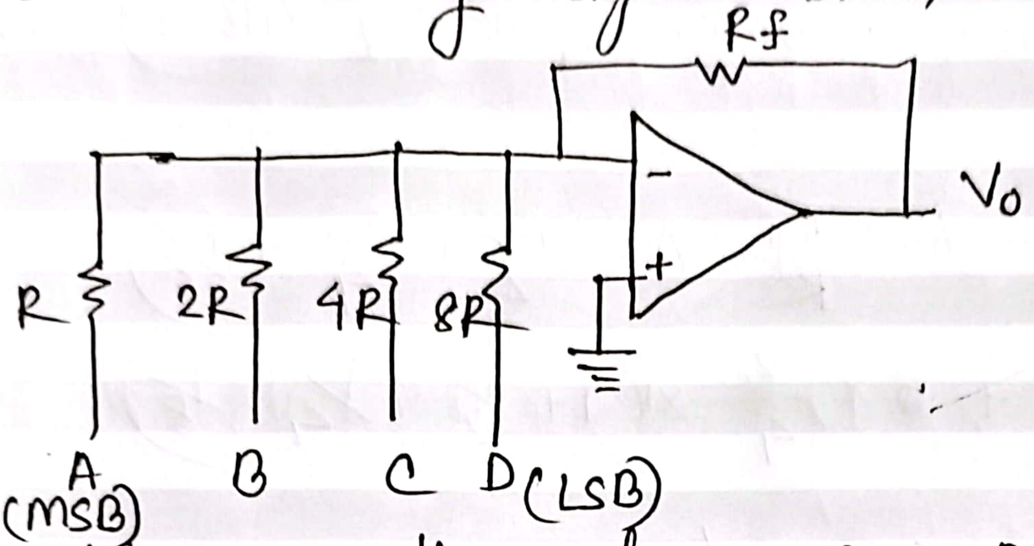
OP-AMP $= 2^3 - 1 = 7$



Given, $I = 0.1mA$, and, $I = \frac{8-(-8)}{8R} = \frac{2}{R}$

$\therefore \frac{2}{R} = 0.1m \Rightarrow R = 20k\Omega$

5. 4 bit binary weighted DAC,



We can either choose R or Rf.

Let's choose, R=1kΩ

$$V_o = -\frac{V_{ref}\, R_f}{R}\left(A + \frac{B}{2} + \frac{C}{4} + \frac{D}{8}\right)$$

Vo will be maximum by value, when input bits 1111

$$V_o = -\frac{5 \times R_f}{R}\left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8}\right)$$

Taking modulus value,
~~Neglecting (-) value~~, and assigning Vo=15

$$\cancel{15} = \frac{5 \times R_f}{R}\left(\frac{\cancel{15}}{8}\right)$$

$$\frac{R}{R_f} = \frac{5}{8}$$

$$R_f = \frac{8}{5} \times 1k\Omega = 1.6\,k\Omega$$

6. a) For max output, Input seq (ABCD) = 1111

$$V_o = -V_{ref}\frac{R_f}{R}\left(A + \frac{B}{2} + \frac{C}{4} + \frac{D}{8}\right)$$

$$= +5 \times \frac{2}{4} \times \left(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8}\right)$$

$$= 4.6875\,V$$

For min output, Input seq (ABCD) = 0000

$$V_o = -V_{ref} \times \frac{R_f}{R}\left(A + \frac{B}{2} + \frac{C}{4} + \frac{D}{8}\right)$$

$$= 0\,V$$

6. b) Step size will be Vo for 0001 seq. or it can be difference between two consequitive input sequence.

ABCD = 0001

$$\text{step size} = V_o = -V_{ref}\frac{R_f}{R}\left(A + \frac{B}{2} + \frac{C}{4} + \frac{D}{8}\right)$$

$$= 5 \times \frac{2}{4} \times \left(0 + 0 + 0 + \frac{1}{8}\right)$$

$$= 0.3125\,V$$

6.c) Resolution = Step size = 0.3125 V

6.d)

Inputs ABCD	V_0
0000	0
0001	Δ
0010	2Δ
0011	3Δ
0100	4Δ
0101	5Δ
0110	6Δ
0111	7Δ
1000	8Δ
1001	9Δ
1010	10Δ
1011	11Δ
1100	12Δ
1101	13Δ
1110	14Δ
1111	15Δ

where, $\Delta = 0.3125V$

6.e) From the above table,

$$1101 \longrightarrow V_0 = 13\Delta = 13 \times 0.3125V$$

Rest are similar/ use formula

7.a)

$$V_o = -V_{ref} \times R_f\left(\frac{A}{R_A} + \frac{B}{R_B} + \frac{C}{R_C} + \frac{D}{R_D}\right)$$

For, ABCD = 1111

$$V_o = 2 \times 1k\left(\frac{1}{2k} + \frac{1}{4k} + \frac{1}{8k} + \frac{1}{16k}\right)$$
$$= 1.875V$$

7b) Resolution will be the value for LSB,

$$V_o = 2 \times 1k\left(0 + 0 + 0 + \frac{1}{16k}\right)$$

$$\text{Resolution} = \frac{1}{8}V \quad (\text{Ans;})$$

7.c) For $V_o \longrightarrow$ Max

ABCD = 1111

$$V_o = 7.5 = 2 \times R_f\left(\frac{1}{2k} + \frac{1}{4k} + \frac{1}{8k} + \frac{1}{16k}\right)$$
$$R_f = 4k\Omega$$