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Signal Processing Lab

Subject- Digital Signal Processing

EXPERIMENT NO. 2

Aim: Study of Quantization of continuous-amplitude, discrete-time analog signals.

Software Used: V-Labs Portal (IIT Bombay)

Theory: A discrete time signal is the sampled version of the continuous-time signal, which can theoretically still take on any value within a certain range of values. Thus the next step to convert a discrete-time signal to a digital signal is by restricting the amplitude to certain fixed values from a discrete set. This process is known as quantization and the number of elements in the discrete set is known as the quantization levels. The quantized signal loses information due to rounding-off and thus are only an approximation to the continuous-time signals. The difference between the quantized signal and the continuous amplitude signal is known as quantization noise

A sample input-output characteristic of an uniform quantizer is shown in Fig. 1 below.

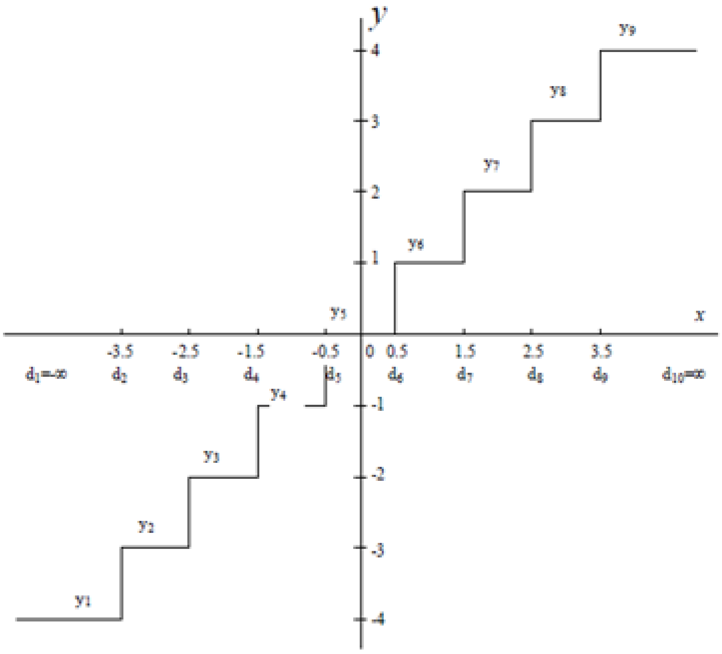
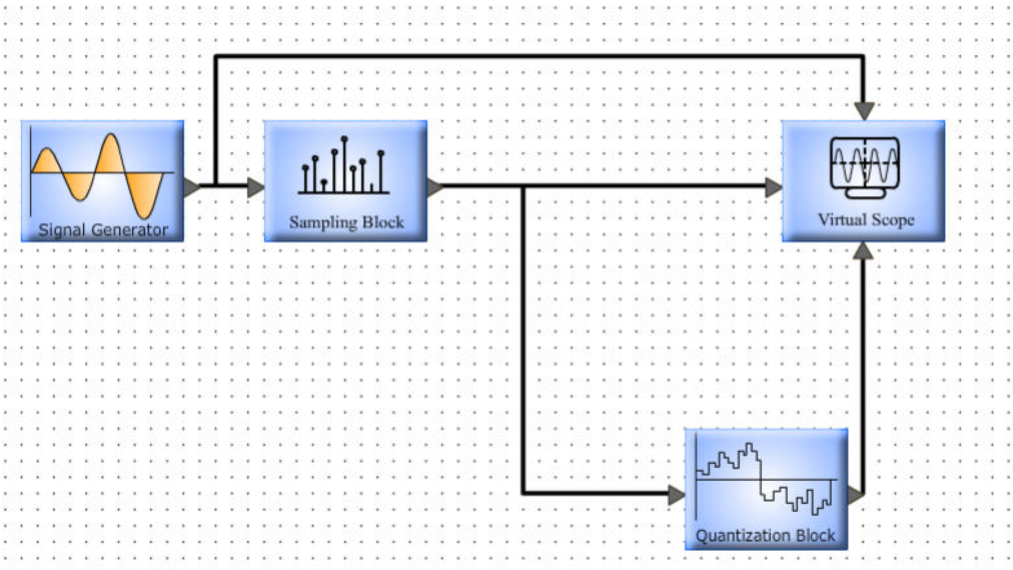


Fig:-1 Block diagram of an ADC.

Here y is the continuous amplitude of the signal within the range of [-4,4]. Any value less than -4, is mapped to the digit d1. Any value between the range [-4,-3] is mapped to the digit d2. Any value within the range of [1,2] is mapped to the digit d7. This kind of quantizer is known as mid tread quantizer.

Digital systems like computers however do not represent numbers using decimal digits. Instead they use binary system of representation. Each number there is represented by a binary digit - known as bits. With 'b' bits, we can represent 2b distinct numbers.
In the above example, the quantized sits at the mid-point of a particular range i.e. [-4, -3] essentially is represented by a quantized value -3.5, the range [-3, -2] by -2.5 and so on. This gives rise to error known as quantized error. The number of such ranges available with b bits of quantization is 2b.
Let us define step size i.e. width of each level as Δ.
Let us further define quantization error e(t) = f(t) - fq(t) where the analog signal is f(t) and its quantized version is fq(t). Then e(t) lies within the range ±Δ/2. The range of the analog signal that can be covered by b bits within above error range, R = 2b.Δ
If the quantization error is uniformly distributed about ±Δ/2 then
p(e)=1Δ
Then Mean Square Error (MSE) for the quantization process, also known as quantization noise power is given by
Nq=∫+Δ2−Δ21Δe2(t)de=Δ212
Now, if the range or maximum excursion of the analog signal is fixed then we can write,
Δ=R2b
We can see that increasing the value of b or the no. of bits Nq decreases
Let us further investigate the effect of no. of bits used in quantization by assuming the input signal is sinusoidal with amplitude A.
s=A22
Also, R = 2A thus
Δ=A2b−1
Substituting, Signal to Noise Ratio, SNR = 10 log10 S/N_4= 10log10 (6.22b – 2) ≈ 6.b dB
Thus each additional bit improves SNR by 6 dB.

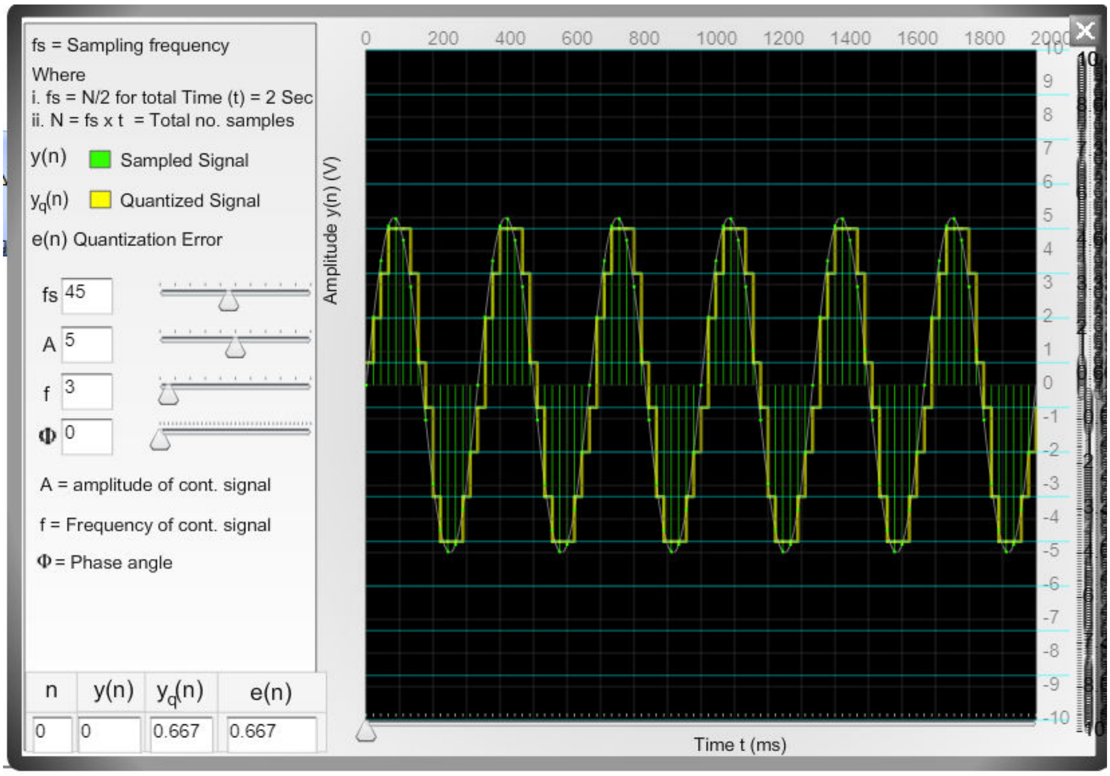
Circuit Diagram:



Output:

a) A = 5
   $f_s = 45$
   f = 2
   No. of Quantization Bits = 4

n	y(n)	$y_q(n)$	e(n)
1	1.37	2	0.6218
2	2.64	2	0.6496
3	3.71	3.33	0.3827
4	4.49	4.667	0.173
5	4.92	4.667	0.257
6	4.97	4.667	0.3056
7	4.63	4.667	0.0311
8	3.94	3.333	0.6071
9	2.93	3.333	0.3941
10	1.71	2	0.2899
11	0.34	0.667	0.3182
12	-1.03	-0.667	0.3726
13	-2.34	-2	0.3474
14	-3.47	-3.333	0.1403
15	-4.33	-4.667	0.3369



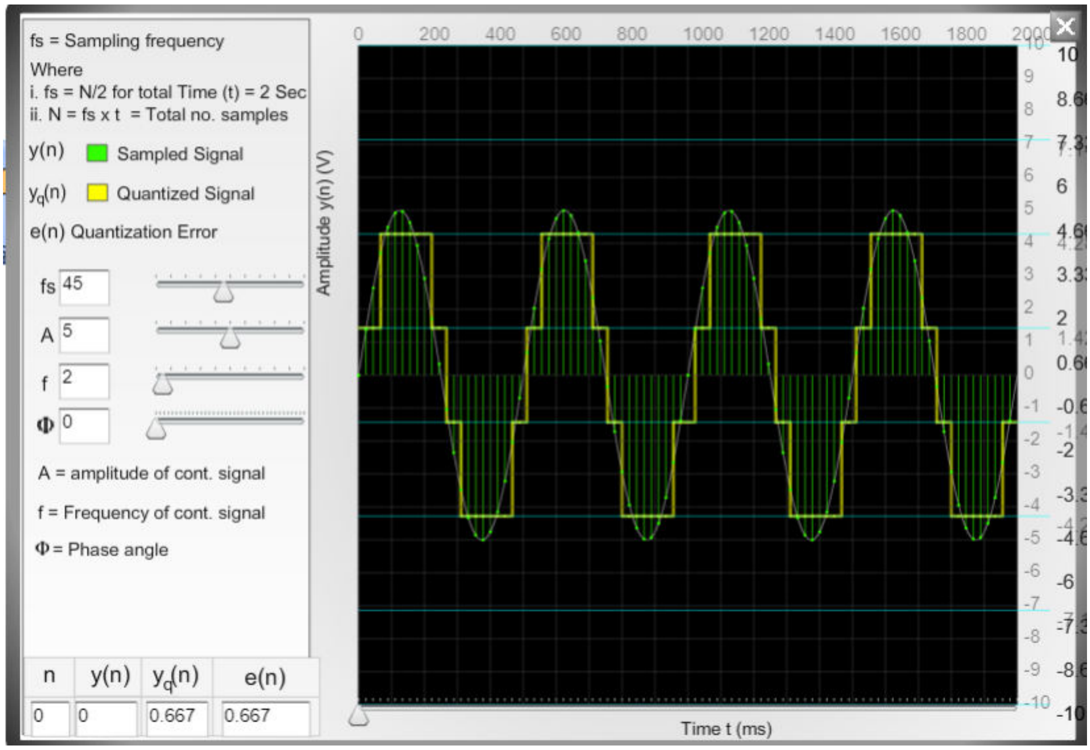
b) A = 5

$f_s = 45$

f = 2

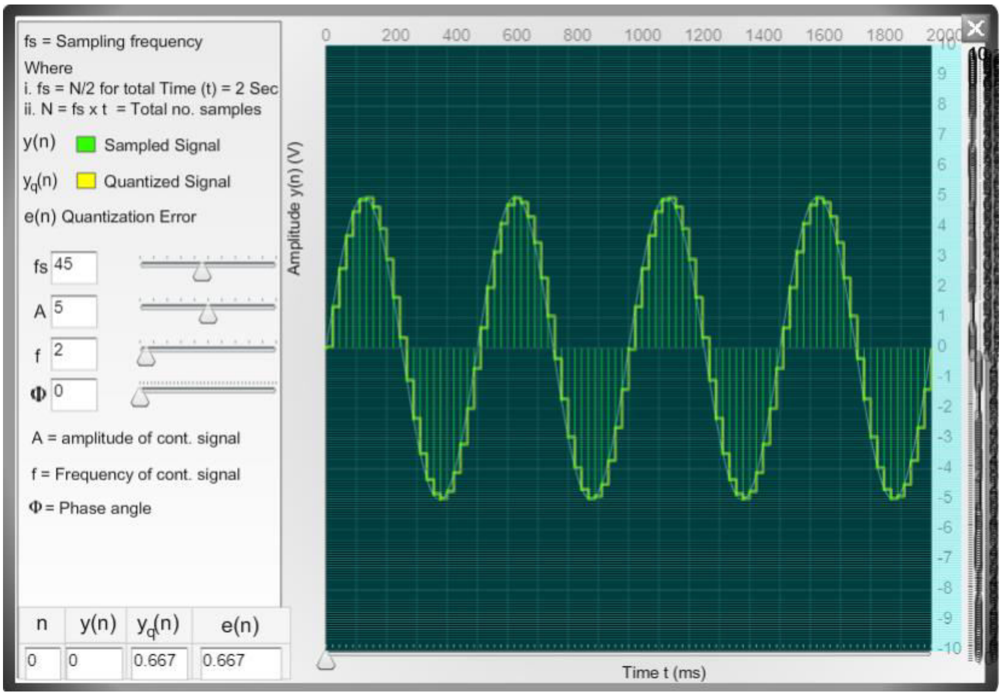
No. of Quantization Bits = 3

n	y(n)	$y_q(n)$	e(n)
1	1.37	1.429	0.0508
2	2.64	1.429	1.2206
3	3.71	4.286	0.5703
4	4.49	4.286	0.208
5	4.92	4.286	0.638
6	4.97	4.286	0.6866
7	4.63	4.286	0.3499
8	3.94	4.286	0.3459
9	2.93	4.286	1.3471
10	1.71	1.429	0.2811
11	0.34	1.429	1.0802
12	-1.03	-1.429	0.3894
13	-2.34	-1.429	0.9184
14	-3.47	-4.286	0.8127
15	-4.33	-4.286	0.0441



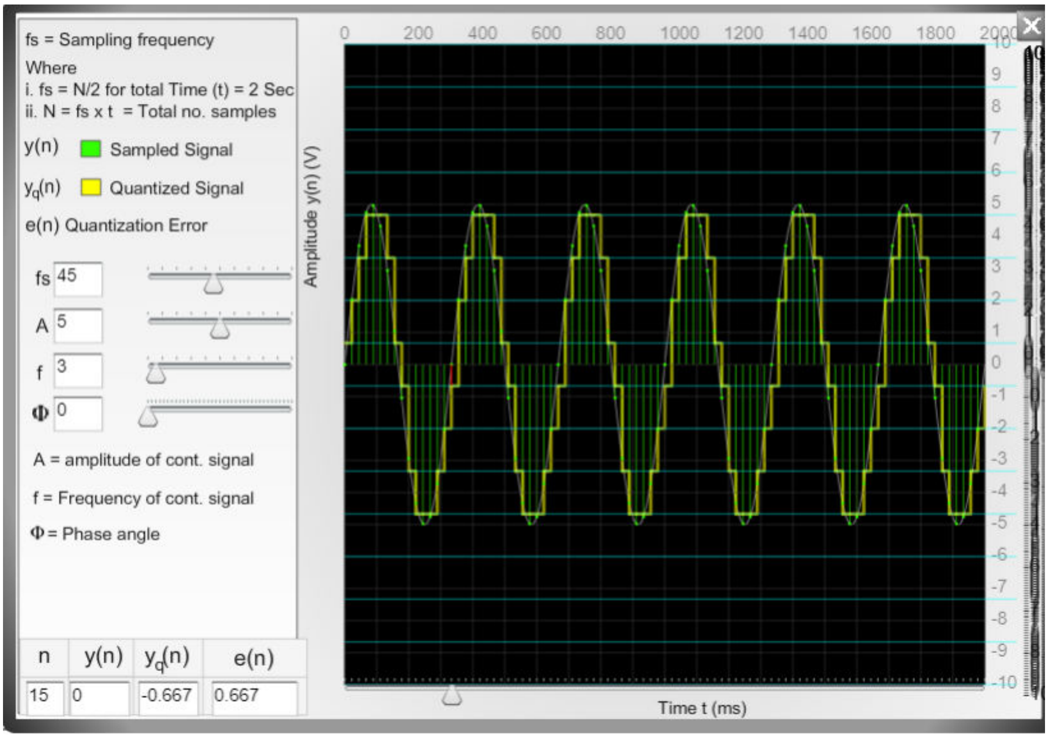
c) A = 5
$f_s = 45$
f = 2
No. of Quantization Bits = 8

n	y(n)	$y_q(n)$	e(n)
1	1.37	1.373	0.0052
2	2.64	2.627	0.0226
3	3.71	3.725	0.0093
4	4.49	4.51	0.016
5	4.92	4.902	0.022
6	4.97	4.98	0.0074
7	4.63	4.667	0.0311
8	3.94	3.961	0.0209
9	2.93	2.941	0.0021
10	1.71	1.686	0.0241
11	0.34	0.353	0.0042
12	-1.03	-1.059	0.0194
13	-2.34	-2.314	0.0334
14	-3.47	-3.49	0.0167
15	-4.33	-4.353	0.0229



d) A = 5
$f_s = 45$
f = 3
No. of Quantization Bits = 4

n	y(n)	$y_q(n)$	e(n)
1	2.03	2	0.0337
2	3.71	3.333	0.3827
3	4.75	4.667	0.0883
4	4.97	4.667	0.3056
5	4.33	4.667	0.3369
6	2.93	3.333	0.3941
7	1.03	0.667	0.3726
8	-1.03	-0.667	0.3726
9	-2.93	-3.333	0.3941
10	-4.33	-4.667	0.3369
11	-4.97	-4.667	0.3056
12	-4.75	-4.667	0.0883
13	-3.71	-3.333	0.3827
14	-2.03	-2	0.0337
15	0	-0.667	0.667



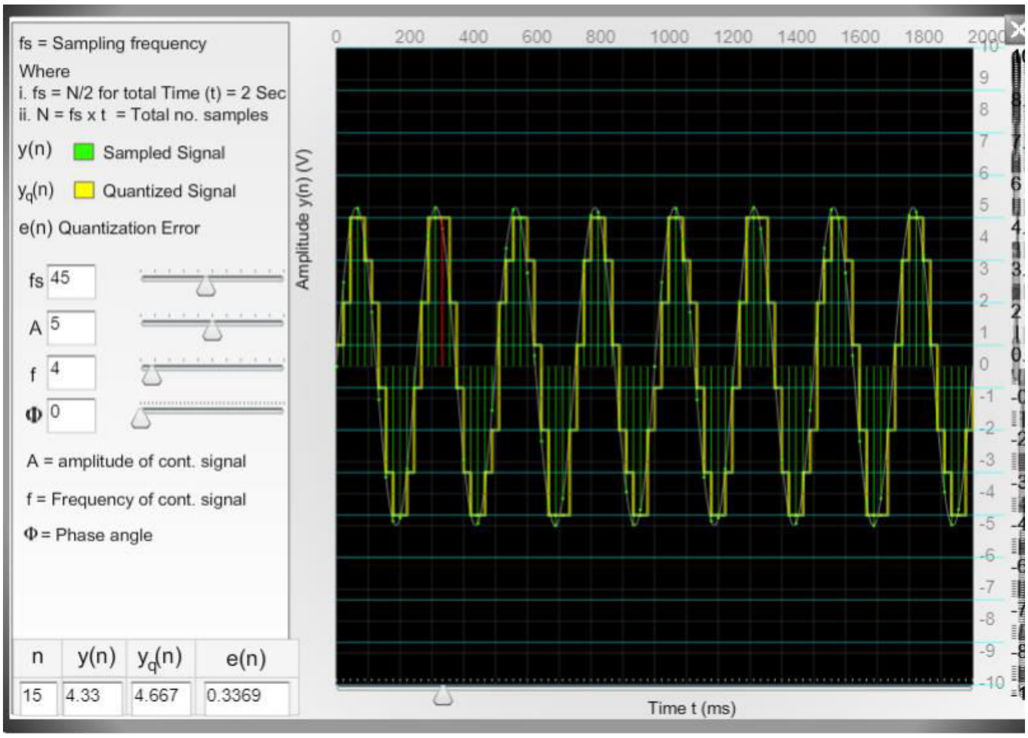
e) A = 5

$f_s = 45$

f = 4

No. of Quantization Bits = 4

n	y(n)	$y_q(n)$	e(n)
1	2.64	2	0.6496
2	4.49	4.667	0.173
3	4.97	4.667	0.3056
4	3.94	3.333	0.6071
5	1.71	2	0.2899
6	-1.03	-0.667	0.3726
7	-3.47	-3.333	0.1403
8	-4.85	-4.667	0.1845
9	-4.75	-4.667	0.0883
10	-3.21	-3.333	0.1191
11	-0.69	-0.667	0.0289
12	2.03	2	0.0337
13	4.14	4.667	0.5218
14	4.99	4.667	0.33
15	4.33	4.667	0.3369

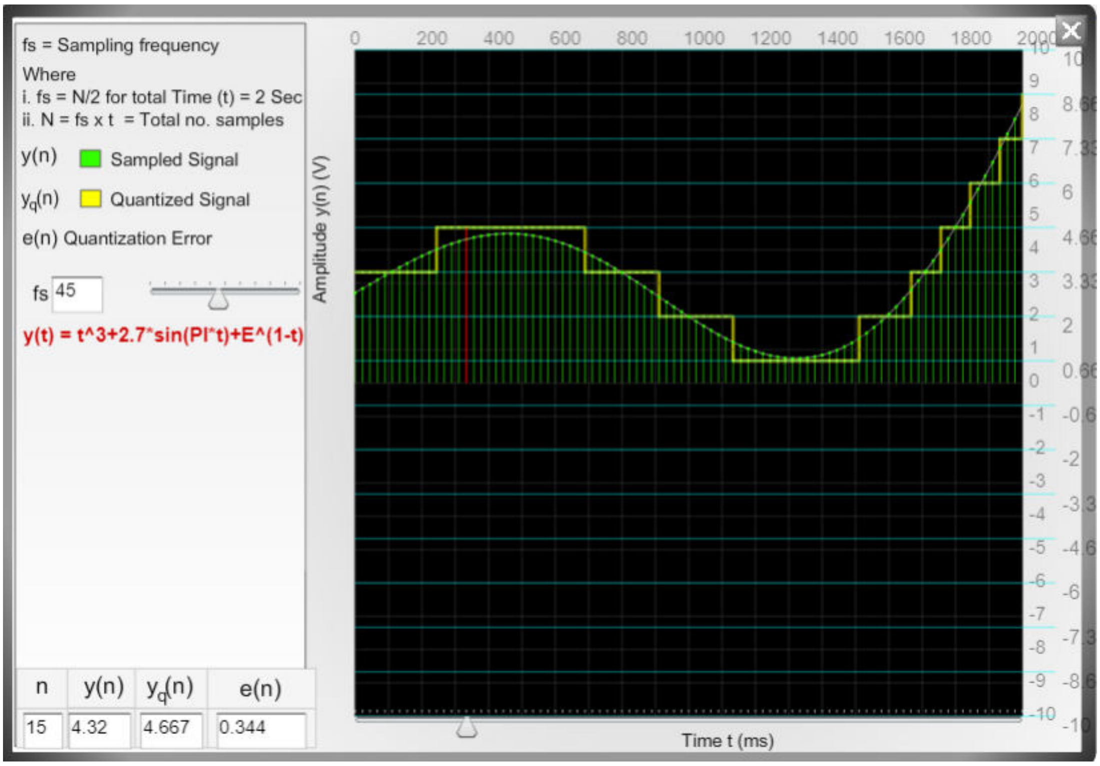


f) $f_s = 45$

$y(t) = t^3+2.7*sin(PI*t)+E^(1-t)$

No. of Quantization Bits = 4

n	y(n)	$y_q(n)$	e(n)
1	2.84	3.333	0.4861
2	2.97	3.333	0.357
3	3.1	3.333	0.2284
4	3.23	3.333	0.101
5	3.35	3.333	0.0243
6	3.47	3.333	0.1465
7	3.59	3.333	0.265
8	3.71	3.333	0.379
9	3.82	3.333	0.4876
10	3.92	3.333	0.5901
11	4.01	4.667	0.648
12	4.1	4.667	0.5595
13	4.18	4.667	0.479
14	4.26	4.667	0.407
15	4.32	4.667	0.344



Conclusion:

This experiment taught me how to set the number of levels of a quantizer and calculate the error involved after quantization of the signal. It also made me understand the principle of quantization of continuous-amplitude discrete-time analog signals.