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EEE/ECE F311
Communication Systems
Tutorial-7

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1. A signal $x_1(t)$ is bandlimited to 2 kHz while $x_2(t)$ is bandlimited to 3 kHz. Find the Nyquist sampling rate for:

(a) $x_1(2t)$

(b) $x_2(t-3)$

(c) $x_1(t) + x_2(t)$

(d) $x_1(t)x_2(t)$

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Solution: $x_1(t)$ is bandlimited to 2 kHz while $x_2(t)$ is bandlimited to 3 kHz

(a) $x_1(2t)$: the Nyquist sampling rate = (2×4) kHz = 8 kHz.

(b) $x_2(t-3)$: the Nyquist sampling rate = (2×3) kHz = 6 kHz.

(c) $x_1(t) + x_2(t)$: the Nyquist sampling rate = (2×3) kHz = 6 kHz.

(d) $x_1(t)x_2(t)$: the Nyquist sampling rate = (2×5) kHz = 10 kHz.

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2. Given the signal $m(t) = 10 \cos(2000\pi t) \cos(8000\pi t)$.

(a) What is the minimum sampling rate based in the low pass uniform sampling theorem?

(b) Repeat the problem based on bandpass sampling theorem.

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Solution 2

Baseband or Low Pass Sampling Theorem

Nyquist sampling rate considering baseband or LP sampling theorem
$f_S = 2f_M = 10$ kHz.

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Solution 2

Bandpass Sampling Theorem

Sampling rate considering bandpass sampling theorem
$f_S = (2f_U/k) = 5$ kHz.

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3. A binary channel with a bit rate of 36000 bps is available for PCM voice transmission. Find the appropriate values of the sampling rate, quantization level, and number of bits level assuming f_M = 3.2 kHz

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Solution 3

n = 5 (5 bits are required to represent the quantization levels)

No. of quantization levels L = $2^n = 2^5 = 32$.

$f_S \leq$ (36000 / 5) = 7.2 kHz.

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4. An audio signal $s(t) = 3\cos(2\pi\times500t)$ is quantized using 10-bit PCM. Determine the signal-to-quantization noise ratio.

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Solution 4

$$\frac{S_i}{N_q}(\text{dB}) = 10 \times \log(1.57 \times 10^6) = 62 \text{ dB}$$

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5. A PCM system used for an analog signal with maximum frequency of 4 KHz. If the minimum dynamic range of the quantizer used is 46 dB, and the maximum decoded voltage at the receiver is ±2.55 V, determine the minimum sampling rate, the number of bits used in the PCM code, the step size, the maximum quantization error, and the coding efficiency.

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Solution 5

For given $f_m = 4$ kHz, $f_s = 2 \times 4$ kHz $= 8$ kHz

For given DR = 46 dB, we get $n \approx 46/6 \approx 7.66$.

But for given maximum decoded voltage of ±2.55 V, one additional sign bit is required.

Hence, the minimum number of bits used in the PCM code = 9 bits

$$\Delta = 2.55\text{V}/\left(2^8 - 1\right) = 0.01\text{V}$$

Maximum quantization error = $\Delta/2 = 0.01$ V$/2 = 0.005$ V

$$\eta_{\text{PCM}}(\%) = \frac{\text{min\_bits}}{\text{actual\_bits}} \times 100$$

$$\eta_{\text{PCM}}(\%) = [(7.66 + 1 \text{ sign bit})/9 \text{ bits}] \times 100 \approx 95.9\ \%$$