A zoologist wants to record the echo-location sounds emitted by a bat. The species of bat to be recorded emits only sounds in the frequency range 40 kHz to 80 kHz and the microphone used includes an analog filter with that passband.

(a) Explain for each of the following sampling techniques how it can be used to convert a continuous ultrasonic microphone signal \( x(t) \) into a discrete-time sequence \( \{ x_n \} \) and state for each technique the lowest sampling frequency \( f_s \) that enables the exact reconstruction of \( x(t) \) from \( \{ x_n \} \):

(i) Passband sampling [3 marks]

(ii) IQ downconversion [5 marks]

(b) Using a 32-bit floating-point data type, how many bytes per second are required to store each of the two resulting discrete sequences from part (a)? [2 marks]

(c) Compare your answers to part (b) with the memory required for storing \( x(t) \) sampled at the Nyquist rate of 160 kHz and explain the difference in terms of redundancy in the acquired spectrum. [2 marks]

(d) If the sampling techniques from part (a) are applied to a test signal \( x(t) = \cos(2\pi ft) \) with \( f = 45 \) kHz, what does the discrete-time Fourier transform of the resulting discrete sequence \( \{ x_n \} \) look like (over the normalized frequency range \(-\pi < \omega \leq \pi\)) for each technique? [4 marks]

(e) For both sampling techniques described in part (a), briefly outline the steps needed to reconstruct the original continuous waveform from the discrete sequence. [4 marks]