EXPERIMENT NO: 1

1. **Aim:** Study of the signal to de-quantization and down-sampling of the audio signal.

2. **Software Used**: MATLAB

3. Theory:

Quantization: Quantization refers to the process of mapping a large set of input values to a smaller set. In audio signal processing, it involves converting a continuous amplitude signal into discrete levels.

- **Bit Depth (B):** It represents the number of bits used to store each sample, determining the number of discrete levels. A higher bit depth results in better signal quality.
- **Quantization Levels:** The number of levels L is given by L = 2^B, where B is the bit depth.
- **Signal-to-Quantization-Noise Ratio (SQNR):**

  Theoretical SQNR:

  $$SQNR_{\text{theoretical}} = 6.02 \cdot B + 1.7609 \quad (\text{dB})$$

  Practical SQNR:

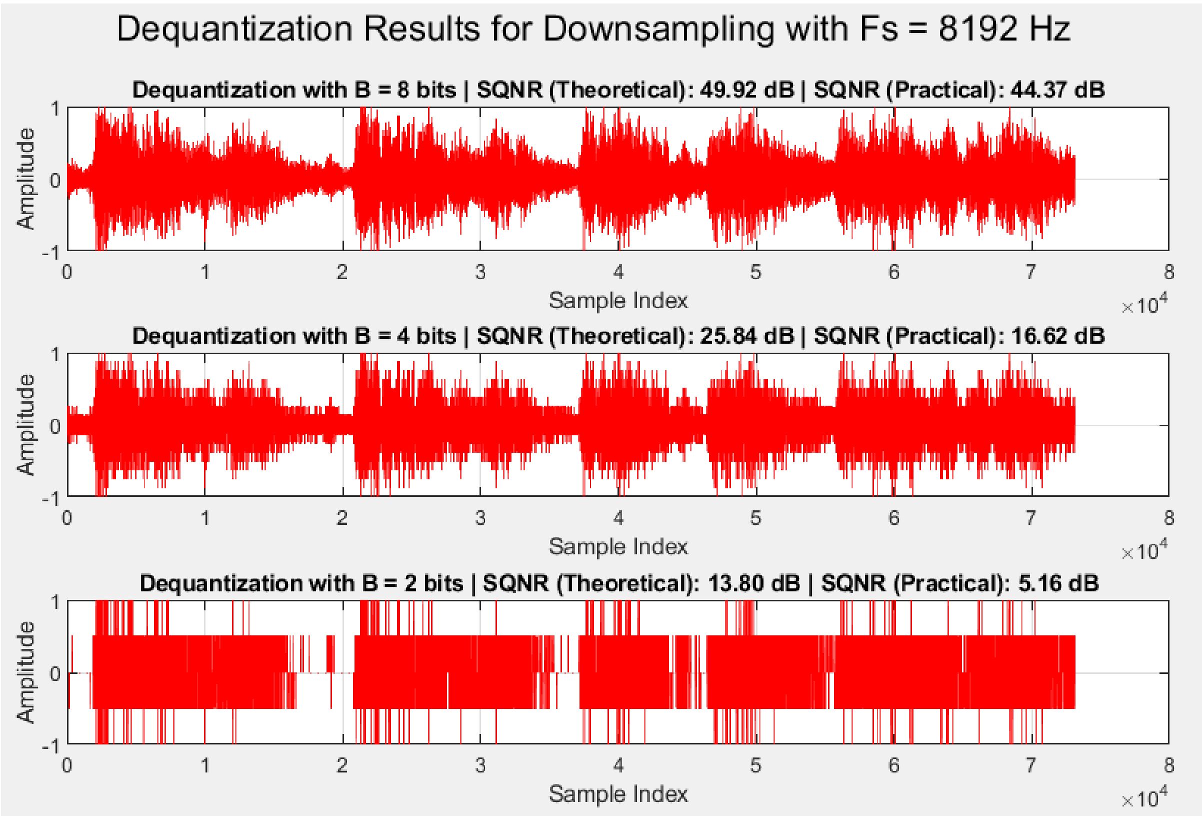
  $$SQNR_{\text{practical}} = 10 \cdot \log_{10}\left(\frac{\text{Signal Power}}{\text{Noise Power}}\right)$$

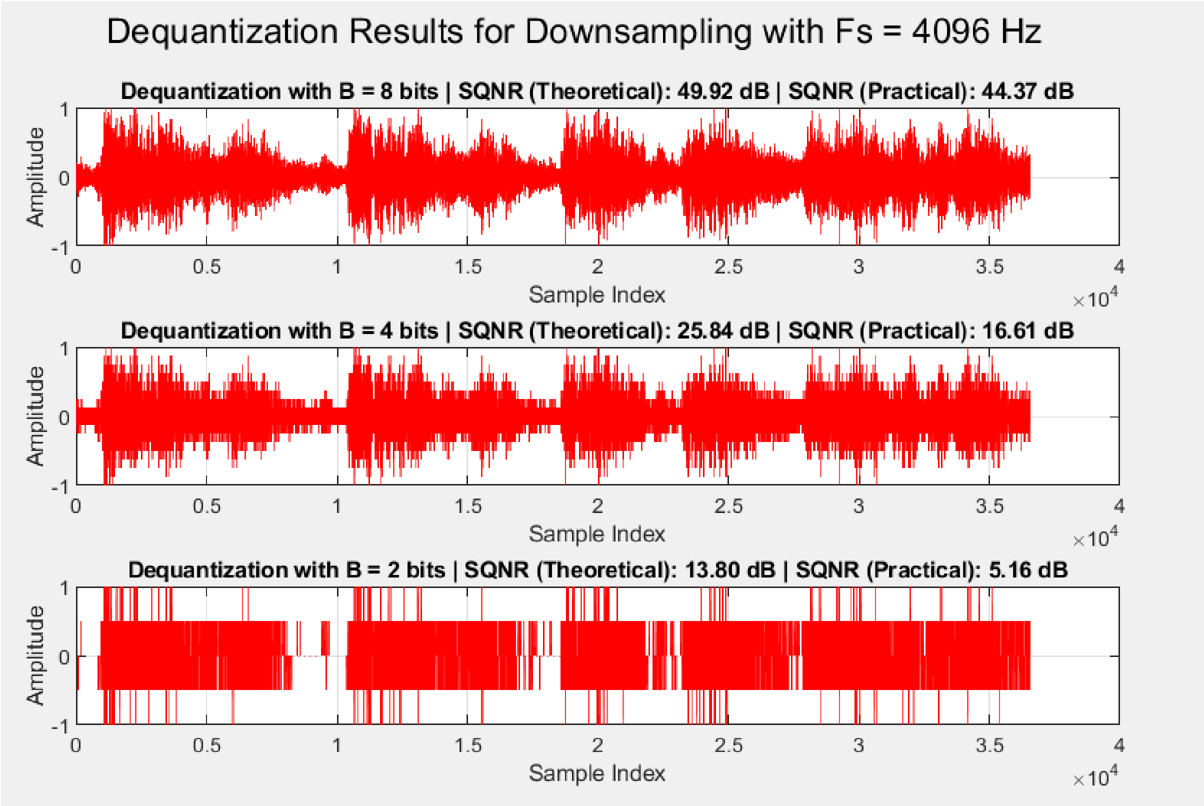
Down sampling: Downsampling involves reducing the sampling rate of a signal by keeping only every N-th sample. This helps in reducing the data size but can introduce aliasing if the signal is not properly low pass filtered before downsampling.

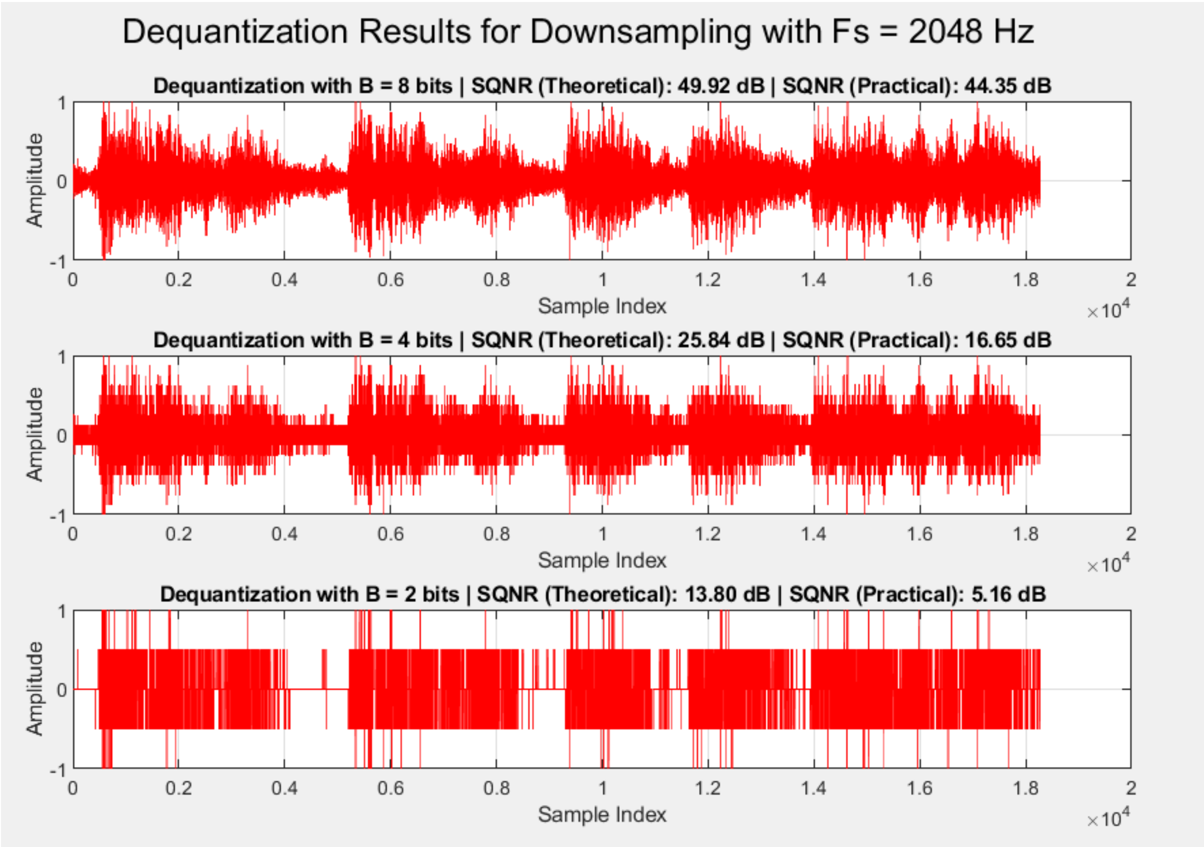
- **Downsampling Factor (D):** The factor by which the sampling rate is reduced.
- **Sampling Frequency after Downsampling**

$$F_s^{\text{down}} = \frac{F_s}{D}$$

4. Result:




Dequantization Results for Downsampling with Fs = 4096 Hz
Dequantization with B = 8 bits | SQNR (Theoretical): 49.92 dB | SQNR (Practical): 44.37 dB
Dequantization with B = 4 bits | SQNR (Theoretical): 25.84 dB | SQNR (Practical): 16.61 dB
Dequantization with B = 2 bits | SQNR (Theoretical): 13.80 dB | SQNR (Practical): 5.16 dB
Amplitude
Sample Index
×10^4


Dequantization Results for Downsampling with Fs = 2048 Hz
Dequantization with B = 8 bits | SQNR (Theoretical): 49.92 dB | SQNR (Practical): 44.35 dB
Dequantization with B = 4 bits | SQNR (Theoretical): 25.84 dB | SQNR (Practical): 16.65 dB
Dequantization with B = 2 bits | SQNR (Theoretical): 13.80 dB | SQNR (Practical): 5.16 dB
Amplitude
Sample Index
×10^4

5. Discussion:

1. Downsampling Analysis: Down-sampling reduces the sampling rate of the audio signal by factors of 1, 2, and 4, corresponding to sampling rates Fs, Fs/2, Fs/4. This simulates how audio quality is affected when fewer samples per second are used to represent the signal.

- As the down-sampling factor increases (i.e., sampling rate decreases), the signal's resolution deteriorates, leading to a loss in high-frequency components.
- With Fs (original sampling rate), the signal remains intact.
- At Fs/2, some high-frequency details are lost, but the signal is still recognizable.
- At Fs/4, significant aliasing may occur, and the signal quality degrades further.

Dequantization Analysis: Dequantization simulates the effect of reducing the bit depth used to represent each sample in the audio signal. Bit depths of **8 bits**, **4 bits**, and **2 bits** were used.

- As the bit depth decreases, the quantization noise increases, resulting in a lower SQNR.
- For B=8 bits, the signal is well-represented, with minimal quantization noise, and the **practical SQNR** closely matches the **theoretical SQNR**.
- For B=4 bits, noticeable distortion is introduced, and the SQNR decreases. The practical SQNR still follows the theoretical trend but is lower.
- For B=2 bits, severe distortion occurs, making the signal nearly unrecognizable. The SQNR is very low, indicating significant quantization noise.

High Sampling Rate with Low Bit Depth:

- When using a high sampling rate (e.g., fs) with a low bit depth (e.g., B=2), the audio retains its general shape but suffers from high quantization noise.

Low Sampling Rate with High Bit Depth:

- When using a low sampling rate (e.g., Fs4) with a high bit depth (e.g., B=8), aliasing artifacts dominate the audio signal despite minimal quantization noise.

Low Sampling Rate with Low Bit Depth:

- This combination results in poor signal quality due to both significant aliasing (caused by downsampling) and high quantization noise (caused by low bit depth).

6. Conclusion:

This experiment demonstrated the impact of downsampling and dequantization on audio quality. Lower sampling rates caused loss of high-frequency components, while lower bit depths increased quantization noise. As bit depth decreased, the practical SQNR deviated more from theoretical values, indicating higher distortion. Overall, higher sampling rates and bit depths are crucial for better signal fidelity, balancing quality and storage efficiency.

7. Code:

```
load handel.mat
filename = 'handel_original.wav';
audiowrite(filename, y, Fs);
info = audioinfo(filename);

Fs_downsampled = [Fs, Fs/2, Fs/4];
downsampling_factors = [1, 2, 4];
bit_depths = [8, 4, 2];

for i = 1:length(downsampling_factors)
    y_down = downsample(y, downsampling_factors(i));
    Fs_down = Fs_downsampled(i);
```

```
    y_down_norm = y_down / max(abs(y_down));
    disp(['---------- Downsampling with Fs = ', num2str(Fs_down), ' Hz ----------']);
    figure;

    for j = 1:length(bit_depths)
        B = bit_depths(j);
        num_levels = 2^B;
        y_quantized = round(y_down_norm * (num_levels / 2)) / (num_levels / 2);
        SQNR_theoretical = 6.02 * B + 1.7609;
        signal_power = mean(y_down_norm.^2);
        noise_power = mean((y_down_norm - y_quantized).^2);
        SQNR_practical = 10 * log10(signal_power / noise_power);

        subplot(length(bit_depths), 1, j);
        plot(y_quantized, 'r');
        grid on;
        title(['Dequantization with B = ', num2str(B), ' bits | SQNR (Theoretical): ', ...
            num2str(SQNR_theoretical, '%.2f'), ' dB | SQNR (Practical): ', ...
            num2str(SQNR_practical, '%.2f'), ' dB']);
        xlabel('Sample Index');
        ylabel('Amplitude');
        disp(['Bit Depth: ', num2str(B), ' bits']);
        disp(['Theoretical SQNR: ', num2str(SQNR_theoretical, '%.2f'), ' dB']);
        disp(['Practical SQNR: ', num2str(SQNR_practical, '%.2f'), ' dB']);
        disp('-----------------------------------');
    end

    sgtitle(['Dequantization Results for Downsampling with Fs = ', num2str(Fs_down), ' Hz']);
end
```