Audio Signal Analysis Report

Lost in Sync - Time Domain Observations

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1 Amplitude Slider Effect

1.1 Parameter Range

The amplitude slider ranges from **1.0 to 2.0**, allowing users to increase the loudness of the audio signal.

1.2 Technical Implementation

The amplitude modification is achieved through scalar multiplication of the audio signal:

$$\text{output} = \text{input} \times \text{amplitude\_factor} \tag{1}$$

The result is then clipped to the range $[-1.0, 1.0]$ to prevent distortion from exceeding the dynamic range limits.

1.3 Time Domain Observations

When examining the time domain waveforms:

- **At amplitude = 1.0**: The waveform remains identical to the original signal, with no change in peak-to-peak amplitude
- **At amplitude = 1.5**: The waveform shows a 50% increase in amplitude, meaning peaks that were at 0.6 are now at 0.9
- **At amplitude = 2.0**: The waveform doubles in amplitude, but portions that would exceed ± 1.0 are clipped (flattened), creating visible "plateau" regions at the peaks

Key Observation: The clipping effect becomes increasingly visible as amplitude approaches 2.0, particularly for signals that already have high peak values. This clipping introduces harmonic distortion, which can be seen as the smooth sinusoidal peaks being "cut off" into flat lines in the time domain plot.

2 Pitch Slider Effect

2.1 Parameter Range

The pitch slider ranges from **0.5 to 2.0**, where:

- **1.0** = original pitch (no change)
- < 1.0 = lower pitch (deeper sound)
- > 1.0 = higher pitch (sharper sound)

2.2 Technical Implementation

Pitch shifting is performed using Fast Fourier Transform (FFT) frequency domain manipulation. The algorithm:

1. Converts the time-domain signal to frequency domain using FFT
2. Redistributes frequency components by the pitch factor
3. Converts back to time domain using inverse FFT
4. Normalizes to 95% of maximum amplitude to prevent clipping

2.3 Time Domain Observations

When examining the time domain waveforms:

- **At pitch = 0.5** (lower pitch):
  - The waveform appears "stretched" horizontally
  - Oscillations become slower with longer wavelengths
  - The audio plays approximately half as fast
  - Overall duration increases (time-stretching effect)
- **At pitch = 1.0** (original):
  - Waveform matches the original signal
  - No temporal distortion
- **At pitch = 1.5 to 2.0** (higher pitch):
  - The waveform appears "compressed" horizontally
  - Oscillations become faster with shorter wavelengths
  - The audio plays faster (up to 2× speed at pitch = 2.0)
  - Overall duration decreases (time-compression effect)

Key Observation: The pitch shift algorithm creates a **time-scaling effect** in addition to pitch change. This is because the FFT-based frequency redistribution effectively speeds up or slows down the playback rate. In the time domain plots, this manifests as more frequent zero-crossings for higher pitch and less frequent zero-crossings for lower pitch.

Additionally, the normalization step reduces the overall amplitude of the pitch-shifted signal to 95% of its maximum, which can be observed as slightly lower peak amplitudes compared to the original waveform, regardless of the amplitude slider setting.

3 Combined Effects

When both sliders are adjusted simultaneously:

- The amplitude effect is applied first to the original signal
- The pitch shift is then applied to the amplified signal
- However, the pitch shift's normalization step reduces the volume back down to 95% of max

This means that **setting amplitude = 2.0 with any pitch shift will NOT result in a** $2\times$ **louder output** in the final pitch-shifted file. The pitch shift's internal normalization overrides the amplitude increase to prevent clipping artifacts from the frequency domain manipulation.

4 Conclusion

The time domain analysis reveals that:

1. **Amplitude control** provides straightforward linear gain with clipping protection
2. **Pitch shifting** introduces both frequency and temporal changes, causing time-stretching/compression effects visible in the waveform periodicity
3. The interaction between both effects is non-linear due to the normalization in the pitch shift algorithm

For pure amplitude control without normalization side effects, users should only adjust the amplitude slider and keep pitch at 1.0. For pitch manipulation, users should be aware that the output will be normalized to prevent distortion, which may reduce the effectiveness of simultaneous amplitude increases.