Lab 6

Creating and Combining Sinusoids in MatLab

Student Name: Sean Balbale
Instructor: Dr. Iman Salama
Lab Partner Name: Krish Gupta
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1 Introduction

This lab focuses on the generation, analysis, and combination of discrete-time sinusoidal signals using MATLAB. Sinusoids, particularly sine and cosine waves, are fundamental to signal processing and electrical engineering applications, including biomedical signal analysis. The objective of this lab is to explore how varying parameters—amplitude, frequency, and phase—affect the behavior of sinusoidal signals in both visual and auditory contexts.

By generating, plotting, and combining sinusoids, we will observe the impact of these parameters on the shape, frequency content, and sound of the resulting signals. This hands-on approach deepens understanding of sinusoidal functions, which are integral to the study of circuits and signals, and prepares us for more complex applications in biomedical engineering and signal processing. MATLAB provides an efficient platform for simulating these signals and analyzing their properties, ensuring that we can accurately manipulate and study discrete-time signals.

2 Results

Part I

A.

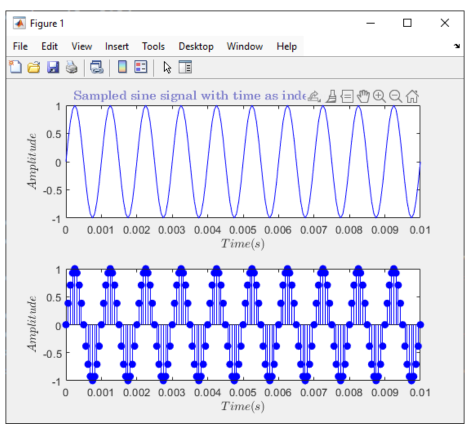

Figure 1: Sinusoidal with $A = 1$, f 1 kHz, $f_s = 16$ kHz, duration = 0.01, and Phase 0

In Figure 1, we observe a sinusoidal signal with an amplitude (A) of 1, frequency (f) of 1 kHz, sampling frequency (f_s) of 16 kHz, duration of 0.01, and phase of 0. This results in 16 samples per cycle. This can be calculated through the formula:

$$F = \frac{f}{f_s} = \frac{1000}{16000} = \frac{1}{16}$$

B.

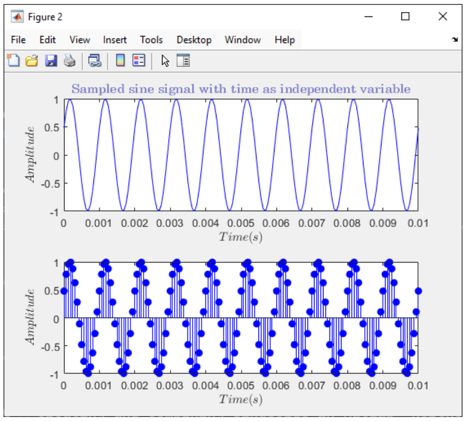

Figure 2: Sinusoidal with $A = 1$, f 1 kHz, $f_s = 16$ kHz, duration = 0.01, and Phase 0.5

As seen in Figure 2, the sinusoidal signal has the same parameters as in part A, with the exception of the phase, which is now 0.5. This phase shift can be seen in the plot, where the signal starts at a different point in the cycle compared to Figure 1. The F value remains the same as in part A and there are still 16 samples per cycle.

C and D.

For parts C and D, the sinusoidal signals have the same parameters as in parts A and B, but with a duration of 1 second. The plots aren't useful for visualizing the signals, but you can hear a beep that lasts one second. The phase shift between parts C and D is not audible.

E.

This part is the same as part D, but with an amplitude of 0.1. The amplitude of the signal is reduced, resulting in a quieter beep. The phase shift is not audible.

F.

For this part, part A is repeated but with sampling frequencies of 7000, 3000, and 1300 Hz.

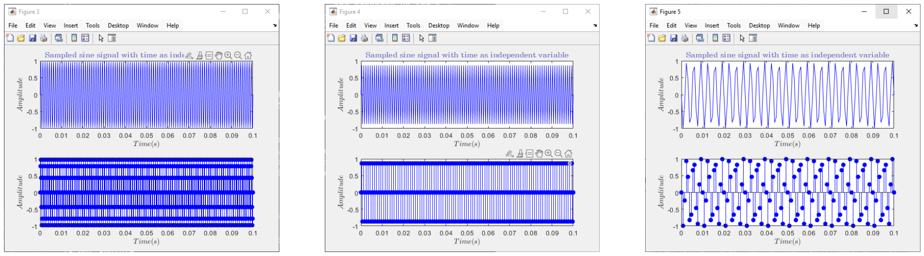

Figure 3: Sinusoidal with f_s = 7 kHz, 3 kHz, and 1.3 kHz

As seen in Figure 3, the sampling frequency affects the number of samples per cycle. The signal with a sampling frequency of 7000 Hz has 7 samples per cycle, the signal with a sampling frequency of 3000 Hz has 3 samples per cycle, and the signal with a sampling frequency of 1300 Hz has 1.3 samples per cycle.

G.

Here, part C is repeated with a sampling frequency of 7000 Hz, 3000 Hz, 1700 Hz, 1300 Hz, and 1100 Hz. The sound of the beep decreases in quality and volume as the sampling frequency decreases. This is because the amount of sound data produced decreases.

Part II

A.

In this part, three sinusoidal signals are generated with frequencies of 1 kHz and amplitude values of 0.1, 0.3, and 1. The signals are then combined and plotted. In 4, the three signals are shown. The signal with an amplitude of 0.1 is green, the signal with an amplitude of 0.3 is blue, and the signal with an amplitude of 1 is red.

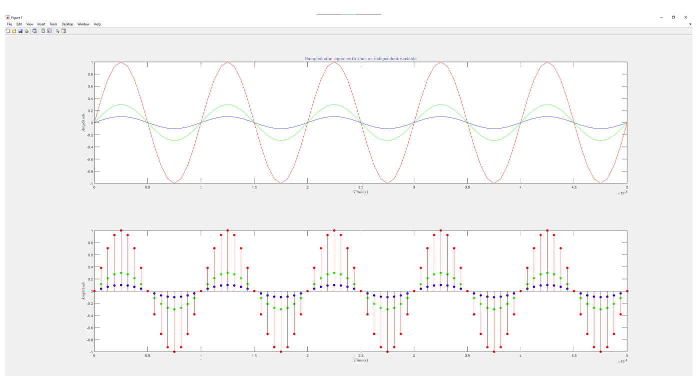

Figure 4: Sinusoidal with A = 0.1, 0.3, and 1

B.

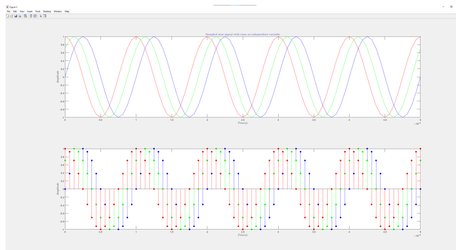

Figure 5: Sinusoidal with phase $\theta = 0, \pi/4$, and $\pi/2$

In this part, three sinusoidal signals are generated with phase shifts of 0, $\pi/4$, and $\pi/2$. The signals are then combined and plotted. In 5. This is then repeated with phase shifts of 0, π, and 4π. The signals are then combined and plotted. In 6, the signals are shown.

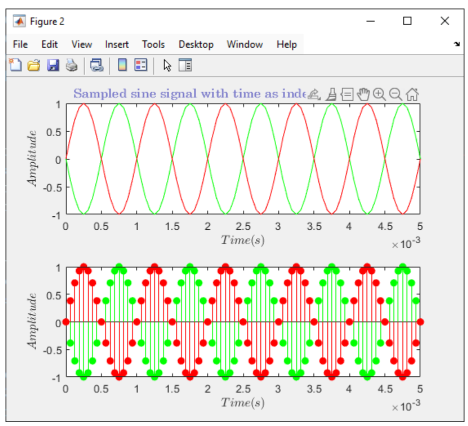

Figure 6: Sinusoidal with phase $\theta = 0, \pi$, and 4π

C.

Part B is repeated but with 8000 samples. Just like the results in Part I, the phase shift is not audible.

Part III

A.

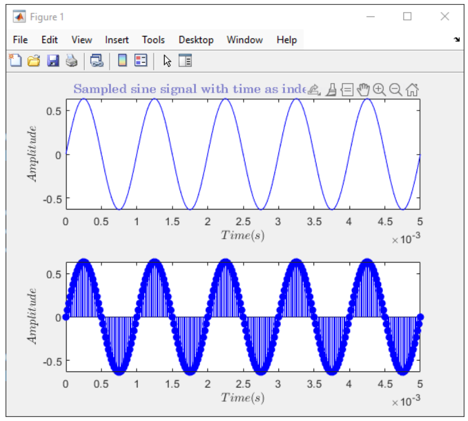

Figure 7: Sinusoidal with $A = \frac{2}{\pi}$, f 1 kHz, f_s = 5 kHz, duration = 0.005, and Phase 0

In Figure 7 we have a sinusoidal signal with an amplitude of $\pi/2$, a frequency of 1 kHz, a sampling frequency of 5 kHz, a duration of 0.005, and a phase of 0. The signal has a period of 5 samples per cycle. The total number of samples (N) is 250. This can be calculated through the formula:

$$N = f_s \times \text{duration} = 5000 \times 0.005 = 250$$

B.

Now a sinusoidal signal with an amplitude of $\frac{2}{3\pi}$, a frequency of 3 kHz, a sampling frequency of 50 kHz, a duration of 0.005, and a phase of 0 is generated and added to the previous signal. The signals are then combined and plotted. The result is shown in Figure 8.

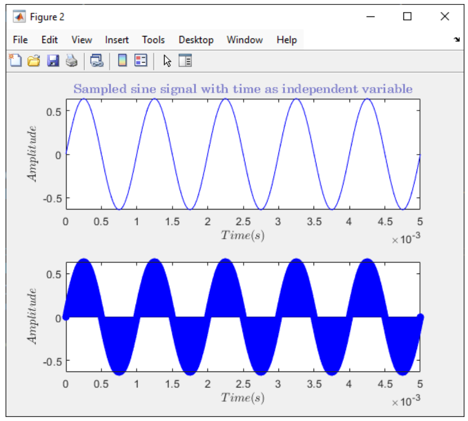

Figure 8: Both Sinusoidal Signals Combined

C.

In this part, sinusoids with amplitude $\frac{2}{n\pi}$ and amplitude nf_0, where $f_0 = 1000\ kHz$ and $n = 5, 7, 9, ...$ are generated. The signals are then combined and plotted. The result is shown in Figure 9.

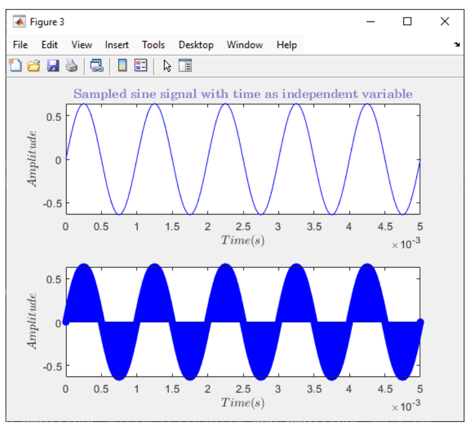

Figure 9: Multiple Sinusoidal Signals Combined

D.

Parts A and C are repeated, but with a duration of 1 second. The audio for the signals is played. They are all beeps, but the pitch of the beep increases.

2.1 Part IV

A.

You either get constructive or deconstructive interference. If the two signals are in phase, then you get constructive interference and the volume increases. If the two signals are out of phase, then you get deconstructive interference and the volume decreases.

B.

If Part III C is repeated but the phase change ius 2π, then the signals will be out of phase and cancel out.

3 Discussion and Conclusion

3.1 Discussion

In this lab, the generation, manipulation, and combination of discrete-time sinusoidal signals were explored using MATLAB, focusing on the effects of amplitude, frequency, and phase on the signals. Each part of the lab contributed to a deeper understanding of these parameters in both visual and auditory forms.

In **Part I**, amplitude, frequency, sampling rate, and phase were varied to observe how each affects the waveform's appearance and sound. The impact of the sampling frequency was particularly important. When the sampling frequency decreased (as seen in Part I, section F), the number of samples per cycle decreased, resulting in increasingly poor representations of the original signal. This led to noticeable degradation in both visual quality (fewer data points in each cycle) and auditory quality (lower fidelity). This demonstrated the importance of maintaining a sufficiently high sampling rate to avoid aliasing and signal distortion in digital systems. Moreover, the phase shifts tested (Part I, sections B and D) had no noticeable effect on sound but significantly altered the waveforms' visual representations.

Part II involved combining sinusoids of varying amplitudes and phase shifts. It was observed that amplitude affects the magnitude of the signal, while phase shifts influence the starting point of the wave within a cycle. By combining sinusoids with different amplitudes, constructive and destructive interference was effectively visualized. The combination of signals with different phase shifts further highlighted the principle of interference, where in-phase signals amplified each other and out-of-phase signals partially or fully canceled each other out.

Part III involved generating and combining sinusoids with different amplitudes and frequencies. A sinusoid with a frequency of 1000 Hz and an amplitude of $\frac{2}{\pi}$ was combined with another sinusoid at 3000 Hz and $\frac{2}{3\pi}$. The resulting waveform was more complex, containing components of both frequencies.

As more sinusoids with odd harmonic frequencies (e.g., 5000 Hz, 7000 Hz) were added, the waveform increasingly resembled a square wave. This demonstrated the principle of Fourier synthesis, where complex periodic signals are constructed by summing sinusoids of different frequencies. When extended to 1 second, the sound produced became richer due to the addition of harmonic content, highlighting how complex sounds are synthesized in signal processing.

Part IV examined how constructive and destructive interference depends on phase relationships. Signals that were in phase resulted in constructive interference, amplifying the overall signal (increased volume in audio), while signals that were out of phase caused destructive interference, leading to diminished signals or complete cancellation when the phases differed by multiples of π.

3.2 Conclusion

The lab demonstrated how the fundamental parameters of sinusoids—amplitude, frequency, phase, and sampling frequency—affect signal behavior. MATLAB simulations showed how these parameters influence the shape and sound of the signals, emphasizing the importance of phase in determining the starting point of a wave, amplitude in controlling signal strength, and frequency in determining the rate of oscillations.

Key findings include:

- **Phase Shifts**: While inaudible in short-duration signals, phase shifts alter the appearance of sinusoidal waveforms.
- **Sampling Rate**: High sampling rates are crucial for accurately representing and reconstructing signals; lower sampling rates result in signal distortion and poor sound quality.
- **Combining Sinusoids**: When multiple sinusoids are combined, their relative phases and amplitudes determine whether constructive or destructive interference occurs, impacting both the visual waveform and auditory perception.

Overall, the lab reinforced essential signal processing concepts, particularly in the context of digital systems where discrete-time representations of continuous signals are critical. The use of MATLAB facilitated both the visualization and auditory interpretation of the signals, offering practical insights that will be valuable in more complex applications like biomedical signal processing.

4 References

[1] Dr. Iman Salama. “Lab 6 – Creating and Combining Sinusoids in MatLab” Northeastern University. 18 October 2024.