AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Specialized Credit Hours Engineering Programs

Electronics & Communications Engineering Program

ECE 451s : Digital Signal Processing Basics - Fall 2022

Project Description

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1 Objectives:

- Become familiar with the dual-tone multi-frequency (DTMF) signalling scheme.
- Become familiar with the notion of time-frequency analysis and spectrograms.
- Become familiar with Matlab.

2 Introduction:

2.1 DTMF:

- Dual-tone multi-frequency (DTMF) is a generic name for a push-button signalling scheme used in Touch-Tone systems in which a combination of high-frequency tone and a low-frequency tone represent a specific digit or the characters "$*$" and "#."
- In one version of this scheme, there are eight frequencies arranged as shown below in Figure 1, to accommodate 16 characters. The system operates at a sampling rate of 8 kHz.

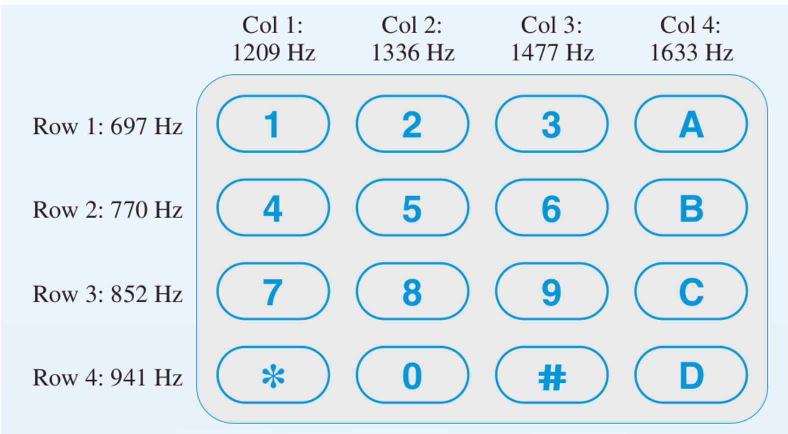

Figure 1: Dual-Tone Multi-Frequency (DTMF) Signalling Scheme

2.2 Time-Frequency Analysis:

- In practical applications, many signals are non-stationary. This means that their frequency-domain representation (i.e. their spectrum) changes over time. DTMF is an example of such signals.
- The time-frequency analysis is usually performed in order to answer the following question: *When* is a particular frequency component present in a given signal?
- Performing the "regular" Fourier analysis (e.g. DTFT or DFT) results in a high frequency resolution where the amplitude and phase of every frequency component is computed, yet it provides no information whatsoever about the time of occurrence of such frequencies.

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- Almost any non-stationary signal can be divided into time intervals short enough that the signal is essentially stationary in each section. Time-frequency analysis is most commonly performed by segmenting a signal into short intervals (windows) and estimating the spectrum over sliding windows, hence creating a "spectrogram". An example of a spectrogram is shown in Figure 2.

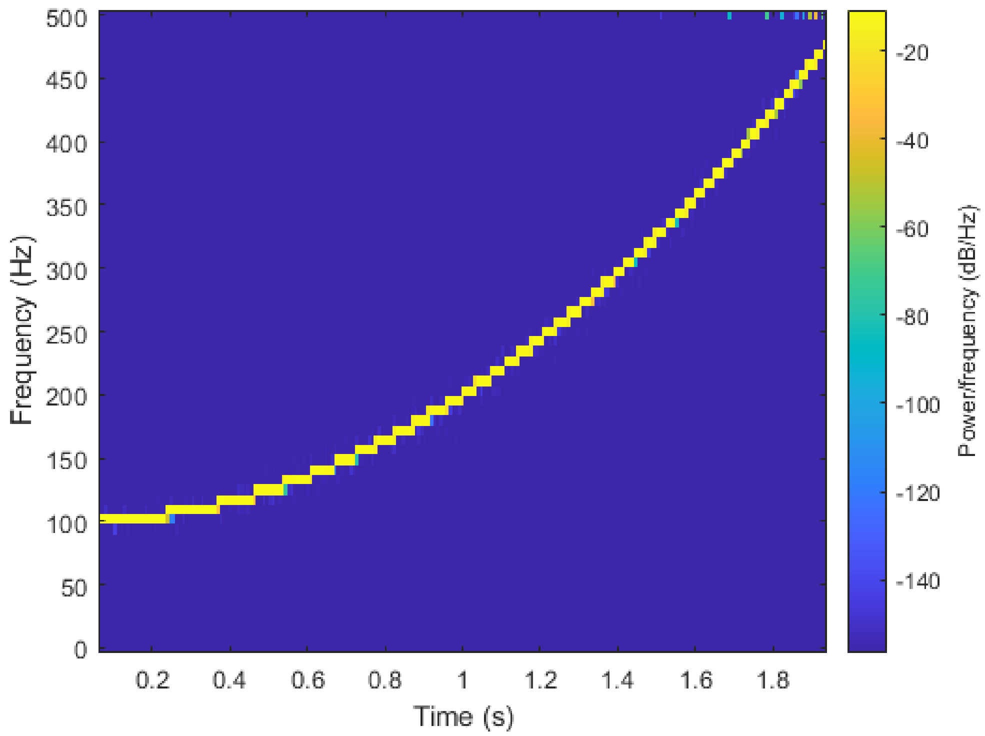

Figure 2: Spectrogram of a Quadratic Chirp Signal

- A spectrogram is a way of visualizing the time-frequency information where it shows the frequency components of a signal along with the time of occurrence of such frequencies.
- In order to obtain the spectrogram, the time-domain signal is divided into segments (by means of a sliding window), then the FFT of each time-domain segment is computed.
- Longer time-domain segments provide better frequency resolution, whereas shorter time-domain segments provide better time resolution.
- There is a trade-off between time resolution and frequency resolution. At one extreme is the time-domain signal $x[n]$ with the highest time resolution but with no frequency information at all. At the other extreme, is the spectrum of the entire signal which provides no information about the time domain.

3 Steps:

Use Matlab to perform the following steps:

1. (10%) Write a Matlab function x = sym2TT(S) that generates a 100 milliseconds time-domain signal corresponding to a given DTMF symbol S. The set of all DTMF symbols and their corresponding frequencies are indicated in Figure 1.

2. (10%) Generate a signal $x(t)$ which contain a sequence of DTMF symbols corresponding to your cell phone number. Add a 20 milliseconds guard interval between consecutive DTMF symbols.

3. (10%) Create a signal $y(t)$ which is the signal $x(t)$ contaminated with additive white Gaussian noise with variance 0.1.

4. (10%) Store the generated signal $y(t)$ as an audio file with extension (*.wav)

5. (10%) Plot the signal $y(t)$. Note that, this plot does not provide any frequency-domain information about $y(t)$.

6. (10%) Use the FFT command to obtain the spectrum $Y(f)$ of the signal $y(t)$, hence plot the magnitude spectrum (in dB) in the frequency range $600\text{Hz} \leqslant f \leqslant 1700\text{Hz}$. Note that, this plot does not provide any time-domain information about $y(t)$.

7. Write your own Matlab code to create a set of spectrograms of the signal $y(t)$ using the following parameters:

   - Overlap between the sliding windows: 50%
   - FFT size: 2^{14}, this is the total number of samples in time-domain and in frequency-domain as well.
   - Time-domain window size: use the following values $\{16, 64, 256, 1024, 4096\}$.
   - (10%) Create a spectrogram for each window size ($\{16, 64, 256, 1024, 4096\}$) using a rectangular time-domain window.
   - (2%) Which window size provides the worst time-domain resolution?
   - (2%) Which window size provides the worst frequency-domain resolution?
   - (2%) Which window size provides a ”kind-of” optimal trade-off between time and frequency resolutions?
   - (4%) Change the time-domain window to a blackman window and create a spectrogram for each window size ($\{16, 64, 256, 1024, 4096\}$). For a given window size, which window type (rectangular or blackman) provides a better frequency resolution ?
   - (10%) Do your research on how to use the Matlab function “goertzel” to decode DTMF symbols.
   - (10%) Write your own Matlab code to decode the signal $y(t)$, verify that you will obtain your cell phone number.

4 Useful Matlab Commands:

1. randn
2. fft , fftshift
3. audioread, audiowrite
4. rectwin
5. blackman
6. imagesc
7. flipud
8. colorbar
9. set(gca,'YDir','normal')
10. axis
11. goertzel

5 Notes:

1. Each **group of 4/5 students** should work together and submit one report.
2. Please prepare one compressed file that includes the following items:
   (a) Your Matlab codes (*.m files).
   (b) A report (pdf files Only) that includes the following:
      i. A brief overview on the "goertzel" Matlab function, how it works, and the theory behind its operation.
      ii. Your waveforms, spectra, spectrograms, etc.
   (c) The generated audio file.
3. Project should be submitted on LMS before 11 : 59 PM on December 10^{th} 2022.

Good Luck