Dual-Tone Multi-Frequency (DTMF) Decoder

In this project, the concept of *dual-tone multi-frequency* (*DTMF*) signaling will be explored. As the name implies, DTMF signals are mixtures of two sinusoids at distinct frequencies. They are used in communications over analog telephone lines.

A particular version of DTMF signaling is utilized in dialing a number with push-button telephone handsets, a scheme known as touch-tone dialing. When the caller dials a number, the DTMF generator produces a dual-tone signal for each digit dialed.

The synthesized signal is in the form

$$x(t) = \sin(2\pi f_1 t) + \sin(2\pi f_2 t), \qquad 0 \le t \le T_{digit}$$

Frequency assignments for the digits on a telephone keypad are shown in Fig. 1.

f_1 \ f_2	1209 Hz	1336 Hz	1477 Hz
697 Hz	1	2	3
770 Hz	4	5	6
852 Hz	7	8	9
941 Hz	*	0	#

Figure 1

The goal of this project is to develop a DTMF synthesizer function using MATLAB.

a. For exploratory data analysis, **write** a MATLAB script to accomplish the following:

Express the signal $x(t) = \sin(2\pi f_1 t) + \sin(2\pi f_2 t)$ through the use of a MATLAB anonymous function with f_1 = 852 Hz and f_2 = 1477 Hz.

Compute the signal in the time interval $0 \le t \le 0.2$ with a time increment of Δt = 1/8000 s.

Play back the resulting sound $x(t)$ using the `sound` function of MATLAB.

If the signal was computed properly, you should hear a clean short tone.

Graph the resulting signal $x(t)$ using the `plot` function.

Repeat the same experiment with different frequencies and different time increments based on Fig. 1. You should hear different short tones.

b. **Develop** a function named `ss_dtmf1` to produce the signal for one digit.

The syntax of the function should be

```
x = ss_dtmf1(n, t)
```

The first argument "`n`" is the digit for which the DTMF signal is to be generated.

Let values $n = 0$ through $n = 9$ represent the corresponding keys on the keypad.

Map the remaining two keys "*" and "#" to values $n = 10$ and $n = 11$ respectively.

Finally, the value $n = 12$ should represent a pause, that is, a **silent period** ($f_1 = 0, \ f_2 = 0$).

The vector "`t`" contains the time instants at which the DTMF signal $x(t)$ is evaluated and returned in vector "`x`".

c. **Develop** a function named `ss_dtmf` with the syntax

```
x = ss_dtmf(number, delta, nd, np)
```

The arguments for the function `ss_dtmf` are defined as follows:

`number`: The phone number to be dialed, entered as a vector.

For example, to dial the number 5551212, the vector "`number`" would be entered as

```
number = [5, 5, 5, 1, 2, 1, 2]
```

`delta`: The time increment Δt to be used in computing the amplitudes of the DTMF signal.

`nd`: Parameter to control the duration of the DTMF signal for each digit.

The duration of each digit should be

$$T_{digit} = n_d \, \Delta t$$

`np`: Parameter to control the duration of pause between consecutive digits.

The duration of pause should be

$$T_{pause} = n_p \, \Delta t$$

The function `ss_dtmf` should use the function `ss_dtmf1` to produce the signals for each digit (and the pauses between digits) and append them together to create the signal $x(t)$.

d. **Write** a script to test the function `ss_dtmf` with the number 5551212.

Use a time increment of 125 microseconds (`delta = 1/8000`) corresponding to 8000 values per second. The duration of each digit should be 200 milliseconds (`nd = 1600`) with 80 millisecond pauses between digits (`np = 640`).

Play back the resulting signal $x(t)$ using the `sound` function.

Also, **graph** the resulting signal $x(t)$ using the `plot` function.

e. **Write** a MATLAB script to accomplish the following tasks:

Express the following three signals through the use of MATLAB anonymous functions with $f_1 = 852$ Hz and $f_2 = 1477$ Hz.

$$x_1(t) = \sin(2\pi f_1 t)$$
$$x_2(t) = \sin(2\pi f_2 t)$$
$$x(t) = \sin(2\pi f_1 t) + \sin(2\pi f_2 t)$$

Compute each signal for $n = 1600$ samples with a sampling frequency of $f_s = 8000$.

You can compute the time vector (`t`) using the following MATLAB code:

```
fs = 8000;
n = 1600;
t = (0:(n-1)) / fs;
```

Listen to each resulting signal **separately** using the `sound` function of MATLAB.

Graph the resulting signals $x_1(t)$, $x_2(t)$, $x(t)$ in **one graph** using the `subplot` function.

The Fourier transform of the sine function is

$$\mathcal{F}\{\sin(2\pi f_0 t)\} = \frac{1}{2j}\left[\delta(f - f_0) - \delta(f + f_0)\right]$$

Compute the discrete Fourier transform (DFT) of each signal using the function `fft`, then **shift** the zero-frequency component to center of spectrum using the function `fftshift`.

Graph the **magnitude of the DFT** of each signal in **one graph** using the `subplot` function.

You can compute the frequency vector (`f`) using the following MATLAB code:

```
f = (-n/2:n/2-1) * (fs/n);
```

Report

Deliver a report, show the main function, and discusses your implementation.

MATLAB Useful References

You may need the following MATLAB functions and references.

- plot
- subplot
- sound
- cat
- fft: How to Do FFT in MATLAB
- fftshift
- Plot FFT using MATLAB

Example

How to take FFT in Matlab | FFT Matlab Plot Frequency | FFT Matlab Easy Tutorial - YouTube

Bonus

Develop a GUI-based MATLAB program to model the operation of the DTMF decoder.

Your program should include an interactive telephone keypad are shown in Fig. 1.

GOOD LUCK,
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