ECE280 - Lab 4: Touch-Tone Phone System

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I have adhered to the Duke Community Standard in completing this assignment.

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Contents

1 Objectives

1. Understand how DTMF dialing system tones are generated.
2. Use MATLAB to model and test a 4x3 DTMF dialing system.
3. Build a simple binary frequency decoder in Simulink
4. Study and explain a real-time DTMF decoder in Simulink

2 Background

The DTMF encoder works by associating every row and column in the key pad to a unique frequency. Once a key is pressed, the two frequencies mapping to the row and column where that key is located are used to generate two sinusoidal signals that are added together, resulting in a DTMF tone. The decoder works by correlating the input signals with sinusoidal waves of frequencies in the DTMF table (table 4.1 in the manual). The frequencies resulting in the highest correlations are used to determine the column and row (every column and row in the DTMF table has a unique frequency) mapping to the key generating the input tone/wave.

3 Results and Discussion

1. Include your dtmfdial.m file.

```
function PhoneNum = dtmfdial(KeyNames, fs)
% DTMFDIAL        Create a signal vector of tones which will dial a DTMF
%                 telephone system.
%
% usage: PhoneNum = dtmfdial(KeyNames, fs)
%  KeyNames = a vector of characters containing valid key names
%  fs = sampling frequency
%  PhoneNum = signal vector that is the concatenation of DTMF tones
%

%create time vectors
del  = [0  :  1/fs:  0.05-1/fs];
half  = [0  :  1/fs:  0.5-1/fs];

dtmf.Keys = ['1', '2', '3';
             '4', '5', '6';
             '7', '8', '9';
             '*', '0', '#'];

dtmf.colTones = ones(4,1)*[1209, 1336, 1477];
dtmf.rowTones = [697; 770; 852; 941]*ones(1,3);
PhoneNum = 0;

for key = KeyNames
    [R,C] = find(dtmf.Keys == key);
    f1 = dtmf.colTones(R,C);
    f2 = dtmf.rowTones(R,C);
    ret = sin(2 * pi * f1 * half) + sin(2 * pi * f2 * half);
    if PhoneNum == 0
        PhoneNum = [ret];
    else
```

```
            delay= sin(0*del);
            PhoneNum = [PhoneNum delay ret];
        end
    end
    end
```

2. Include a printout of your completed

$$Simple_Corr.mdl$$

. Explain how this model works.
This model works by correlating the input wave with two sinsusoidal waves with frequencies of 697 Hz and 1477 Hz. For each correlation, the maximum value is taken using the min/max block and passed to the relational operator block. This block is used to determine which of the two max values is higher. If the top input (max value of correlation with 697 Hz) is higher, the output of the relational operator is 1; otherwise, it's 0. The output of the relational operator is passed to the switch which is set to pass the value in the top constant block (1) to the scope if the input is not 0 (i.e., the correlation of the input with a sin wave of 697 Hz resulted in higher max value); otherwise, 7 from the bottom constant block is passed to the scope.

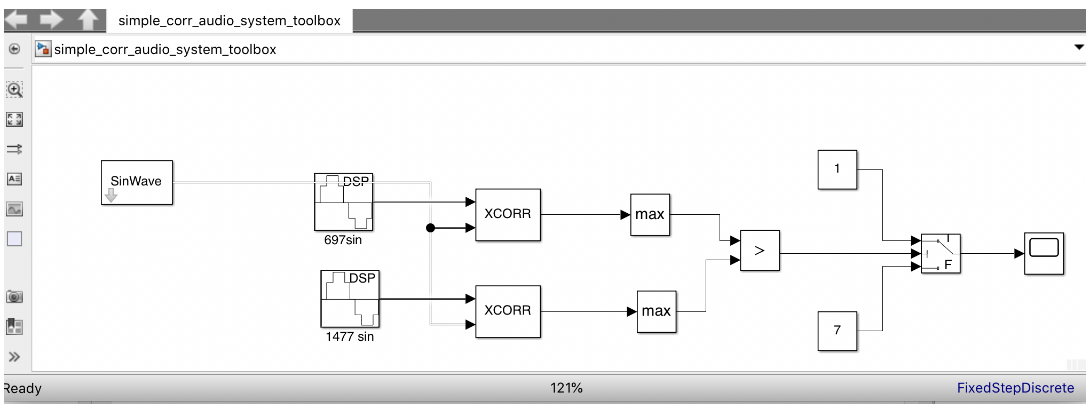

Figure 1: Completed Simplecorr.mdl

3. Include plots of the signals corresponding to the keys 1, 5, and 9.

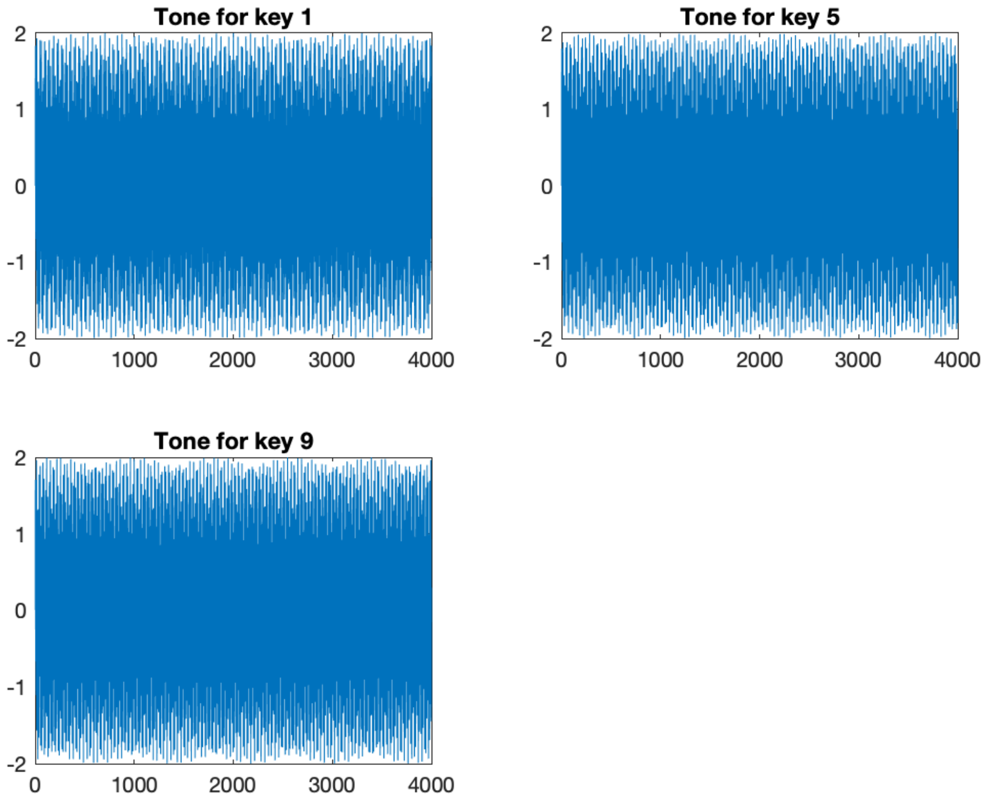

Figure 2: Plots of the signals corresponding to the keys 1, 5, and 9

4. Include plots of the correlation of the keys 1, 5, and 9 to the seven individual DTMF tones.

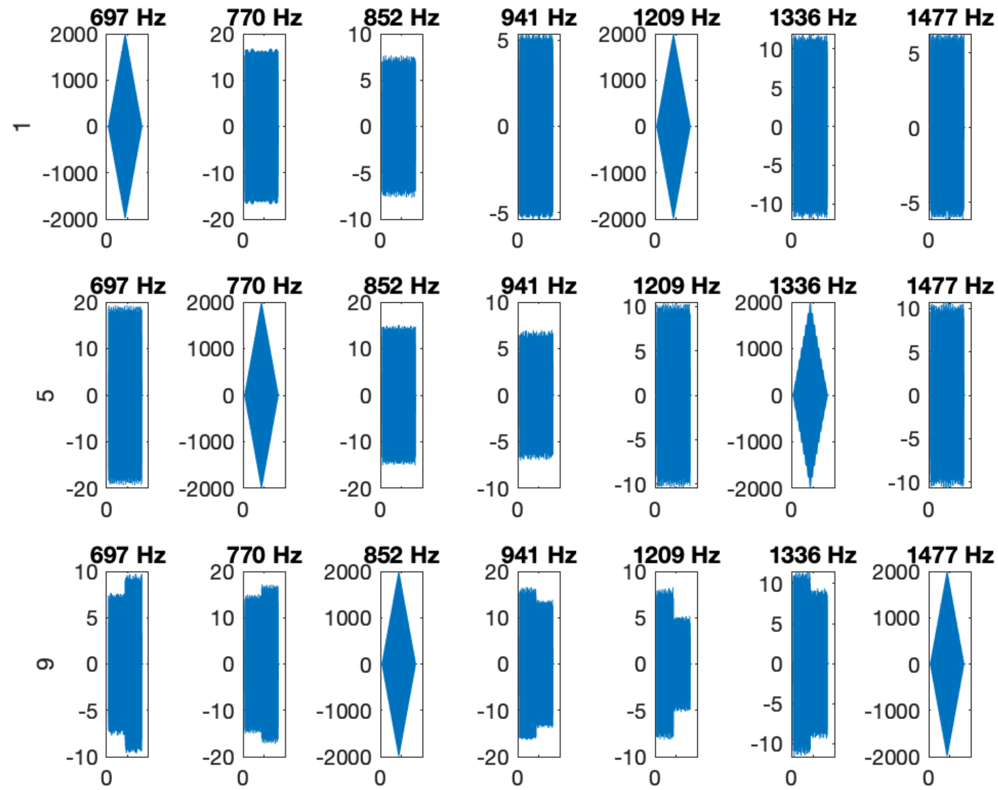

Figure 3: Plots of the correlation of the keys 1, 5, and 9 to the seven individual DTMF tones

5. Discuss what you observed about the correlation plots you generated for the three keys (1, 5, 9).

   For the key "1," a high correlation with the tones corresponding to 697 Hz and 1209 Hz was observed. For the key "5," a high correlation with the tones corresponding to 770 Hz and 1336 Hz was observed. For the key "9," a high correlation with the tones corresponding to 852 Hz and 1477 Hz was observed.

6. How did you go about determining the value of the UnknownKey?

   The correlation of the unknown key with the DMTF tones was plotted (figure 4). As shown in figure 4, there is high correlation of the unknown key with the tones corresponding to 697 Hz and 1477 Hz. These two frequencies map to the key 3.

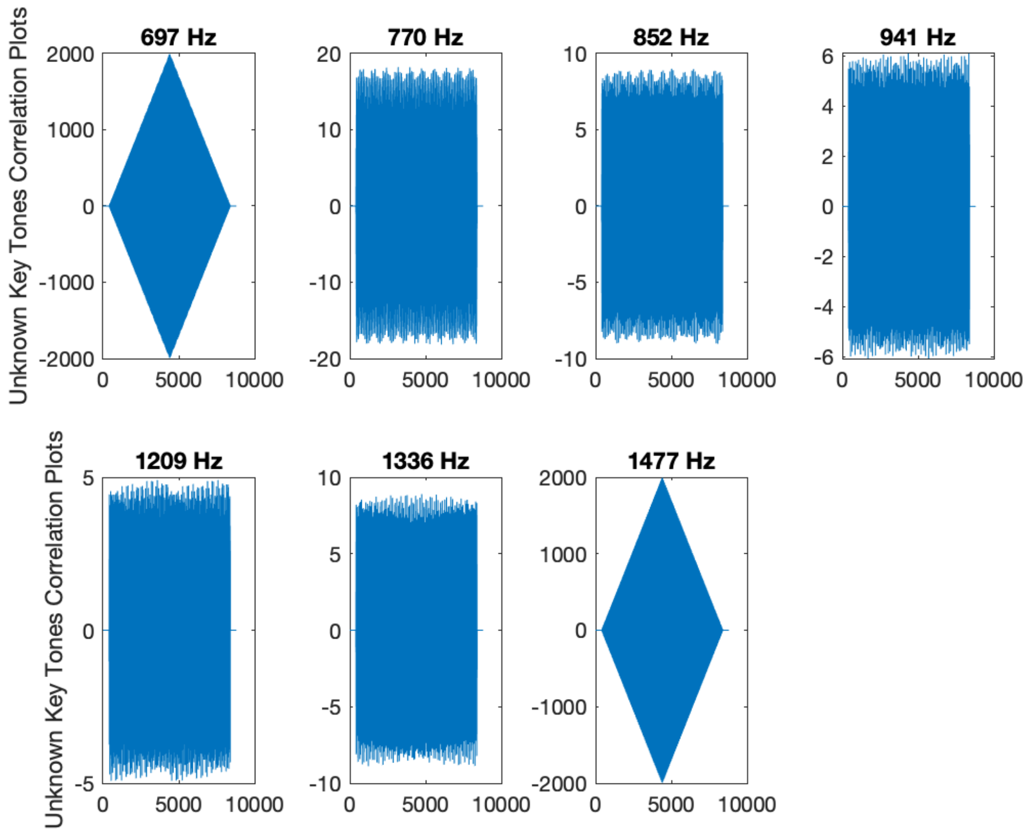

Figure 4: Plots of the correlation of the unknown key to the seven DTMF tones.

7. Explain, step-by-step, how the DTMF decoding algorithm presented in

$$DTMF.mdl$$

works.

The input waveforms of each input tone is correlated with the waveforms for the 4 DTMF tones in the column of table 4.1 in the manual and the 3 DTMF tones in the row of table 4.1 separately. The max value of each correlation is taken as input to two mux and sort blocks combinations (one for column frequencies and the other for row frequencies) that outputs the sorted indices and values. The sorted values are terminated; the sorted indices are passed into a demux where the indices corresponding to highest values are outputted at the top and those corresponding to lowest values at the bottom. All sorted indices except the first are terminated. The indices that are not terminated are passed to a look-up table block (emulates the format of table 4.1) in order to determine the key corresponding to the input DTMF tone (the indices represent the column and row pair that map to keys in table 4.1).

8. When you used the Scope to decode the phone number, you should have noticed erroneous values that did not correspond to the numbers you Ã¢â¬Å“dialedÃ¢â¬Â. Comment on why those values occur and how you could improve the system so that they are eliminated.
These errors occur due to the max value of the correlation of the input with the wave of the correct frequency mapping to that input being lower than the max value of the correlation of the input with the wave with wrong frequency at that particular instant of time resulting in wrong the indices/row and column numbers for the direct look up table. This can be eliminated by computing the highest 0.5 second average value instead for the correlations and passing it to the mux.

9. Answer all questions asked in the instructions.
For which tones do you expect a large correlation for each key (1,5,9)? Are your results what you expect?
For the key "1," a high correlation with the tones corresponding to 697 Hz and 1209 Hz is expected. For the key "5," a high correlation with the tones corresponding to 770 Hz and 1336 Hz is expected. For the key "9," a high correlation with the tones corresponding to 852 Hz and 1477 Hz is expected. The results match the expectations; for each of the three keys, there are peaks in the plots of the frequencies mentioned.

What do you observe when you zoom in one of the correlation plots? Why does this happen?

The correlation plots are close to being sinusoidal. This happens because the plot is a correlation of two sinusoidal waves; thus, it's expected that the correlation plot is close to being sinusoidal.

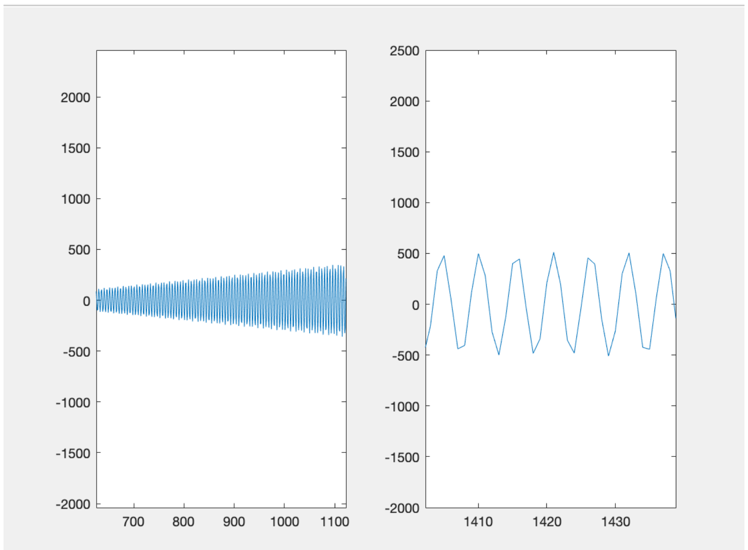

Figure 5: Zoomed subplots at one of the correlation plots.

4 Conclusions

In this laboratory, experience was gained in DTMF dialing systems. Furthermore, a MATLAB function that takes in keys on dialing key pad as input to generate the corresponding DTMF tones was created. In Simulink, a simulation that uses the correlation, relational operator, min/max, and switch blocks to display 1 on a scope if the input tone has frequency 697 Hz or 7 if the input tone has frequency 1477 Hz was built. Lastly, a Simulink model that implements a real-time DTMF tone decoder was examined.

5 Extension

In laboratory 1 (music synthesis), the sinusoidal signals were generated using cosine rather than sine. In the extension section for the lab 1 report, the difference when the signals were generated using sine was investigated. The study suggested that using sine resulted in higher volume and more pronounced echo. In this extension, using the effect of using cosine on the tone will be investigated. The null hypothesis is the tones will not sound different when using a cosine function rather than a sine function.

The sequence of keys chosen for testing was '159.' 5 subjects were chosen and played both sine and cosine versions (without being told there is a difference in the implementation of the two tones) to judge if there an audible difference between the two. All 5 subjects couldn't detect a difference in the tone quality and claimed the tones sounded identical.

Furthermore, no difference was noticed by the student conducting the study. Figure 6 shows the plot of the waveforms of the signals for the three keys separately. When compared to figure 2, no visible changes can be detected. Therefore, the null hypothesis can not be rejected. There is not enough evidence to claim the tones are generated using a cosine function.

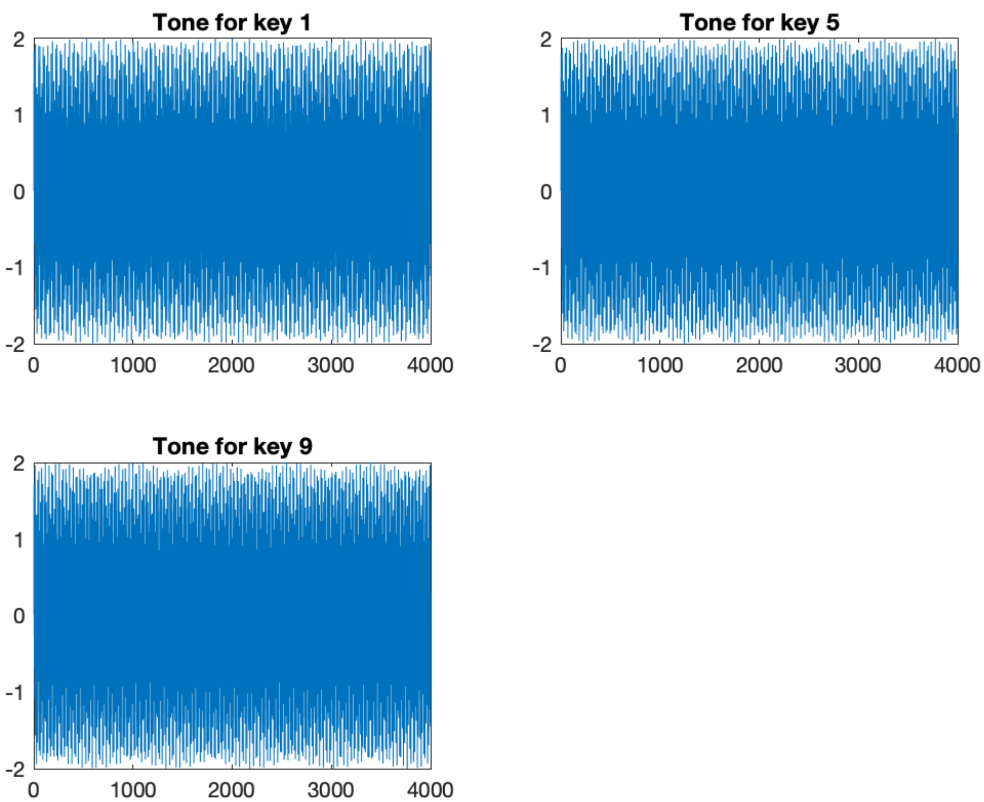

Figure 6: Plots of the signals corresponding to the keys 1, 5, and 9 using cosine function.