Scilab case study project on Single-Digit DTMF Signal Generation and Detection using Goertzel Algorithm in Xcos

Aashwin Vaidya

Institute of Engineering and Technology, Devi Ahilya Vishwavidyalaya
Digital Signal Processing
01/07/2026

Abstract

This case study performs a partial replication of the reference paper focusing on DTMF generation and Goertzel-based detection in Scilab/Xcos. Dual Tone Multi Frequency (DTMF) is the signaling method used in telephones to represent keypad digits using sound. When a key is pressed, two tones are produced together, one from the low-frequency group and one from the high-frequency group. This project focuses on the generation and detection of DTMF signals using the Goertzel algorithm. In the generator section, each keypad digit is assigned its standard pair of frequencies, and the final DTMF signal is created by adding the two sine waves. In the detector section, the generated signal is passed through Goertzel blocks designed for all standard DTMF frequencies. The Goertzel algorithm is useful here because it can efficiently measure the energy present at selected frequencies without calculating the full spectrum. After calculating the energy values, the frequency with the highest energy in the low group and the frequency with the highest energy in the high group are selected. This pair is then mapped back to the corresponding keypad digit. The project helps in understanding how tone-based communication works in real telephone systems. It also shows how signal processing techniques can be used to detect information from an audio signal in an efficient and reliable way.

1. Introduction

Dual Tone Multi Frequency, or DTMF is a method for instructing a telephone switching system of the telephone number to be dialed, or to issue commands to switching systems or related telephony equipment. DTMF made telephone dialing faster and more reliable compared to older pulse dialing methods. Even today, it is used in many telecommunication and automated systems such as IVR menus, customer support services, banking helplines, and remote-control applications.

Since DTMF signals are based on frequency combinations, their generation and detection are important applications of digital signal processing customer support services, banking helplines, and remote-control applications. Since DTMF signals are based on frequency combinations, their generation and detection are important applications of digital signal processing.

2. Problem Statement

DTMF signaling is widely used in telephone and automated communication systems to identify keypad inputs. Each key on a telephone keypad is represented by two tones, one from the low-frequency group and one from the high-frequency group. The main problem in this case study is to design a system that can generate these DTMF tones for different keypad digits and then correctly detect the original digit from the received signal. The solution should first generate a valid DTMF signal by selecting the correct pair of frequencies for a given input digit and combining the two sinusoidal signals. After generation, the detector should analyse the signal and identify which two frequencies are present with the highest energy. Based on this detected frequency pair, the system should map the result back to the corresponding keypad digit. The accuracy of the detector can be improved by using proper sampling frequency, suitable signal duration, thresholding, and clear comparison of frequency energy values. To achieve this aim, the project uses the Goertzel algorithm for DTMF detection. Instead of calculating the complete frequency spectrum, the Goertzel algorithm checks only the required DTMF frequencies, making the detection process simpler and more efficient. In the project, the generator produces the DTMF tone and the detector computes energy values for all standard DTMF frequencies. The final digit is obtained by selecting the highest energy frequency from both the low and high frequency groups. Lastly, the validity of the detected signal is tested by energy threshold test, twist test, relative peak test.

3. Basic concepts related to the topic

3.1 Dual Tone Multi Frequency Signaling (DTMF)

DTMF is a system of signal tones used in communications, such as telephone banking, voice mail, and system control. A DTMF signal represents one of sixteen touchtone symbols like 0-9, A-D, #, * and each symbol is generated by adding two continuous sinusoidal tones together, one selected from a low-frequency group (697 Hz, 770 Hz, 852 Hz, 941 Hz) and one selected from a high-frequency group (1209 Hz, 1336 Hz, 1477 Hz, 1633 Hz).

The expression for generating DTMF signal is given by:

$$y(n) = A1sin(2\pi nf1/Fs) + A2sin(2\pi nf2/Fs)$$

Where,

A1 = Amplitude of low frequency signal
A2 = Amplitude of high frequency signal
f1 = Frequency of the low tone
f2 = Frequency of the high tone
Fs = Sampling Frequency

3.2 Goertzel Algorithm

The Goertzel algorithm is a highly efficient digital signal processing method used specifically for detecting digital DTMF signals. While a standard Discrete Fourier Transform (DFT) calculates the entire frequency spectrum, the Goertzel algorithm uses IIR (Infinite Impulse Response) filters tuned only to the eight specific DTMF frequencies.

For each incoming sample x(n), the algorithm recursively computes an intermediate state using the equation:

$$Vk(n) = coeff(k) * Vk(n-1) - Vk(n-2) + x(n)$$

Where coeff(k) is given by:

$$coeff(k) = 2cos\,(2pi * f\_k/Fs)$$

Where,

f_k = DTMF frequency being detected

Fs = Sampling Frequency

3.3 Twist Test

Twist is the ratio of low-frequency power to high-frequency power. If the row tone energy is larger than the column tone energy, it is known as a "Normal Twist" with a maximum allowable threshold of 8 dB. If the column tone energy is larger, it is a "Reverse Twist" with a maximum allowable threshold of 4 dB.

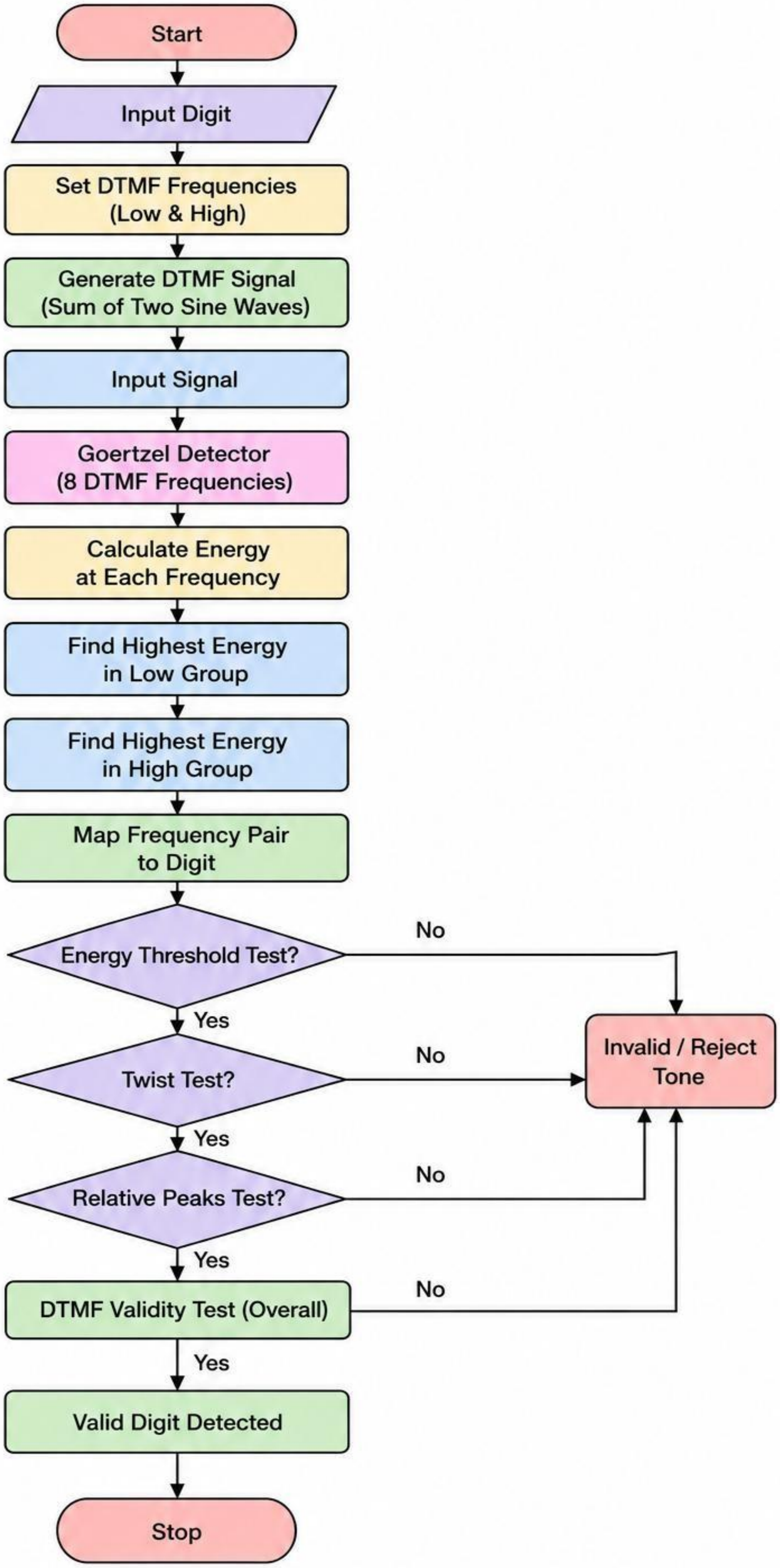
3.4 Relative Peaks Test

The energy of the strongest signal in each group (row and column tones) is compared to the energies of the rest of the tones in its group. The strongest tone must stand out from the noise and other tones by a certain ratio to be accepted.

3.5 Signal Energy and Duration

The algorithm uses an adaptive threshold for the signal energy test to ensure it is loud enough to be a valid press. Additionally, the duration of the DTMF signals should be at least 40 ms.

4. Flowchart



Start
Input Digit
Set DTMF Frequencies (Low & High)
Generate DTMF Signal (Sum of Two Sine Waves)
Input Signal
Goertzel Detector (8 DTMF Frequencies)
Calculate Energy at Each Frequency
Find Highest Energy in Low Group
Find Highest Energy in High Group
Map Frequency Pair to Digit
Energy Threshold Test?
No
Yes
Twist Test?
No
Yes
Relative Peaks Test?
No
Yes
DTMF Validity Test (Overall)
No
Yes
Invalid / Reject Tone
Valid Digit Detected
Stop

5. Software/Hardware used

- Operating System: Windows 11
- Toolbox: None
- Hardware: None
- Software: Scilab 2026.0.1

6. Procedure of execution

Step 1: Open dtmf_simulation.xcos.

Step 2: Go to Simulation -> Set Context.

Step 3: At the first line, there will be a digit variable. Set it to the digit or alphabet you want to send. Example “6” or “D”. Click on Ok.

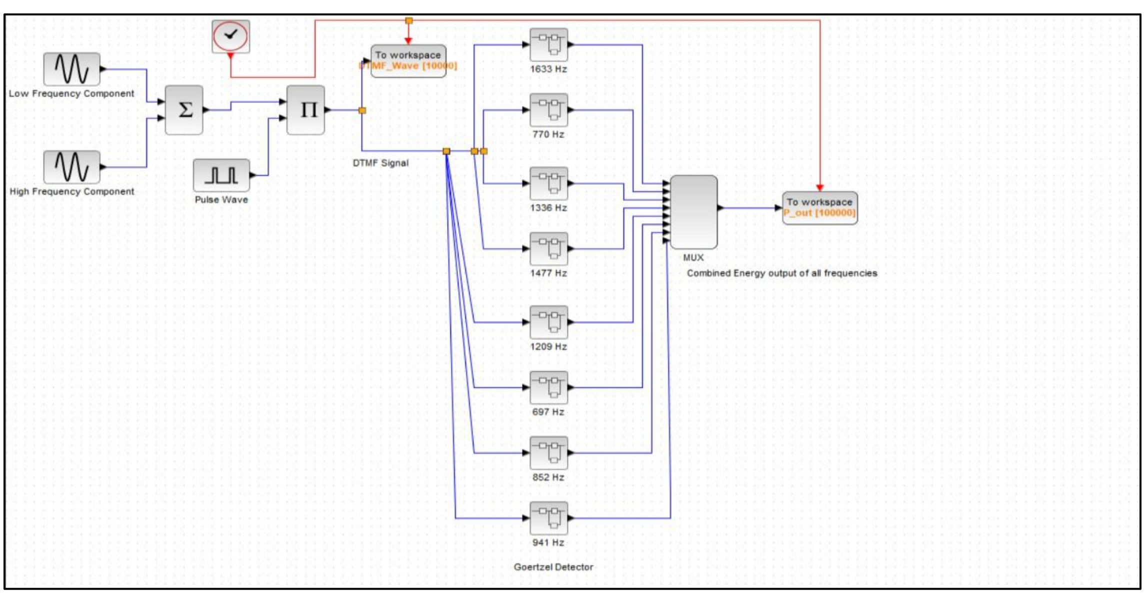
Step 4: Now go to Simulation -> Start. Step 5: Open dtmf.sce.

Step 6: Go to Execute -> Save and Execute.

Step 7: Observe the graphs and Scilab outputs.

7. Result

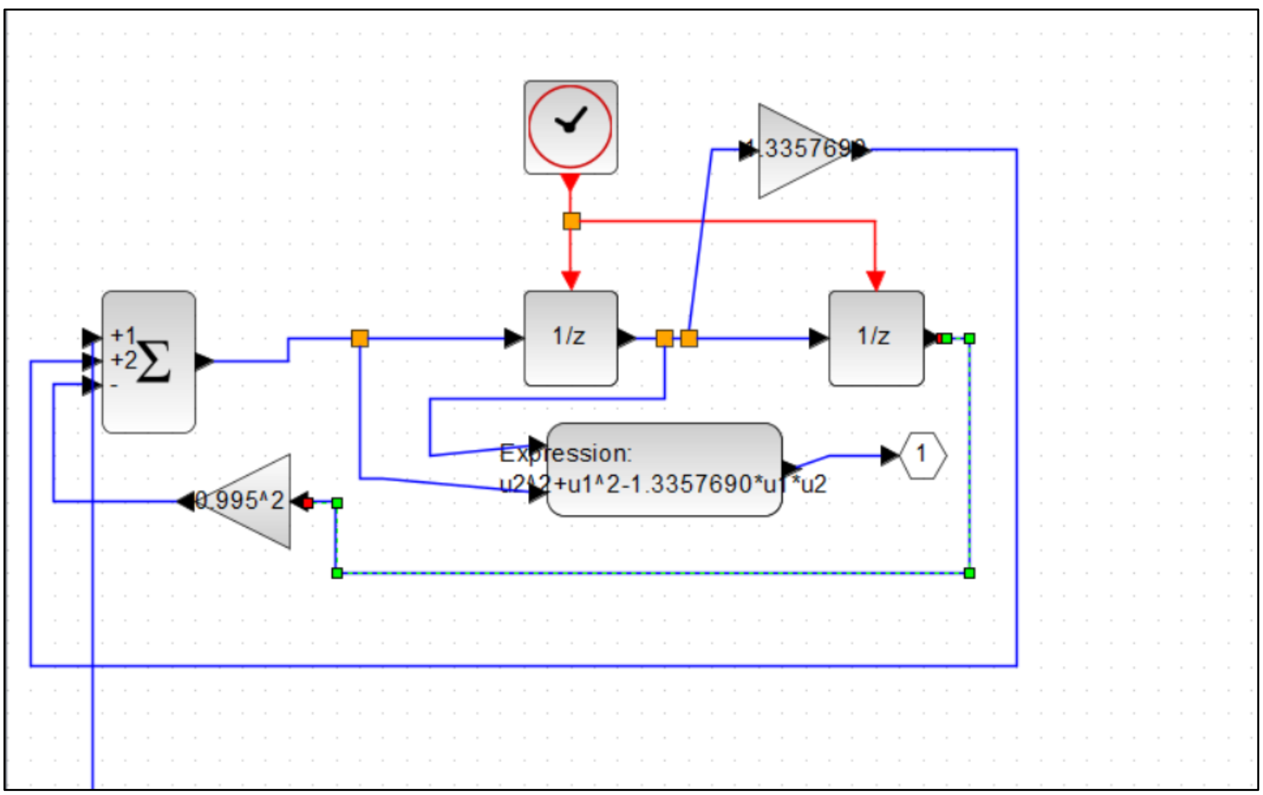
7.1 Xcos Block Diagram



Inferences

When the user inputs the digit in set context menu, the corresponding values of low frequency and high frequency are changed in the sine generator parameters. The pulse wave generator is used to make sure the DTMF signal is triggered for 40 milliseconds only. The eight super blocks together constitute the Goertzel detector which calculates energy for all the DTMF frequencies. Finally, the outputs from the Goertzel blocks are combined by using an 8X1 MUX and sent to the workspace. The results confirm that the Goertzel-based detector can accurately distinguish DTMF tones while requiring less computation than a full frequency spectrum analysis, making it suitable for real-time communication systems.

7.2 The Goertzel Detector Superblock



Inferences

The superblock shows the structure of one Goertzel filter used in the DTMF detector. The input signal enters the summation block, where it is combined with feedback values from the previous two samples. The two 1/z blocks act as unit delays and store the values **v(n-1) and v(n-2).**

The gain block uses the Goertzel coefficient whose value is 2cos(2πf/F_s) for the selected target frequency. The other feedback path uses a negative gain, completing the recursion:

$$v(n)=x(n)+ coeff \cdot v(n-1)-v(n-2)$$

The clock block controls when the detector updates during simulation. The output of the filter becomes strong when the incoming DTMF signal contains the tuned frequency. Thus, this block acts like a narrow frequency detector. Similar Goertzel blocks are created for all eight standard DTMF frequencies, and their outputs are later used to calculate energy and identify the two dominant frequencies of the pressed digit.

The energy of the signal is calculated by the following formula:

$$u2^2 + u1^2 - 2\cos(2*pi*f/Fs) * u1 * u2$$

Where,

u1 = First input of the energy block

u2 = Second input of the energy block.

7.3 DTMF Signal Graphs

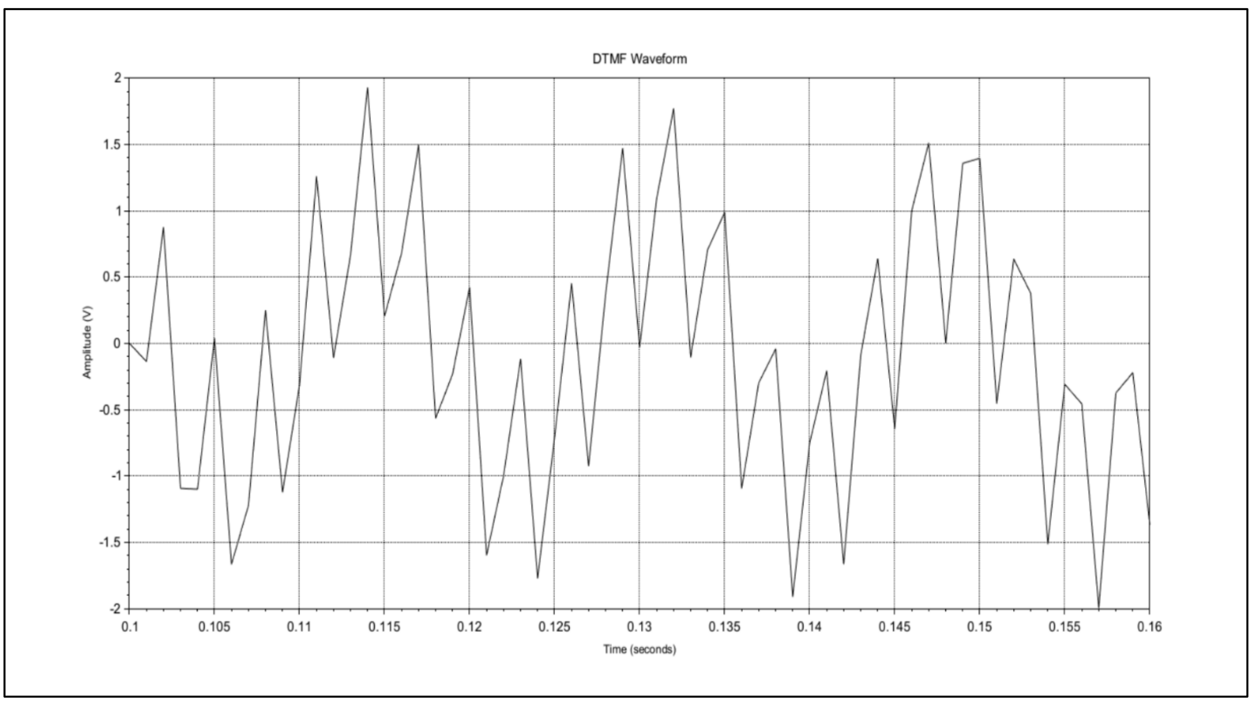


Figure 1: Digit '0'

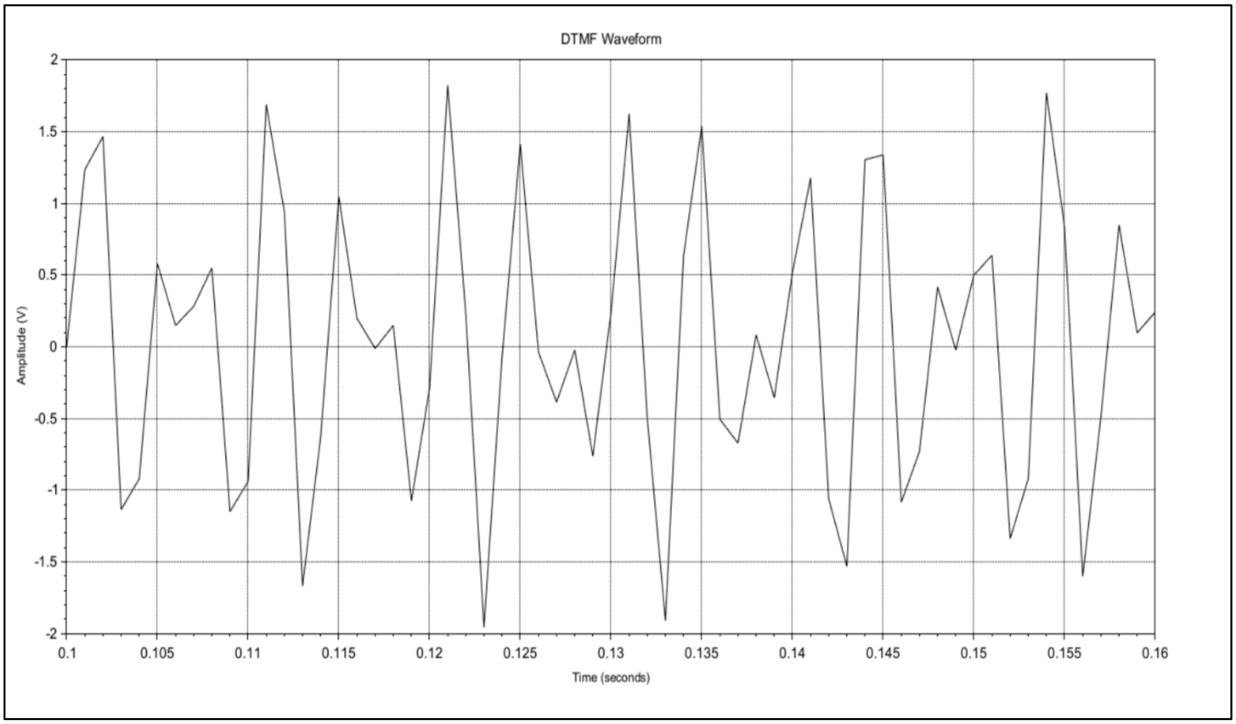


Figure 2: Digit '1'

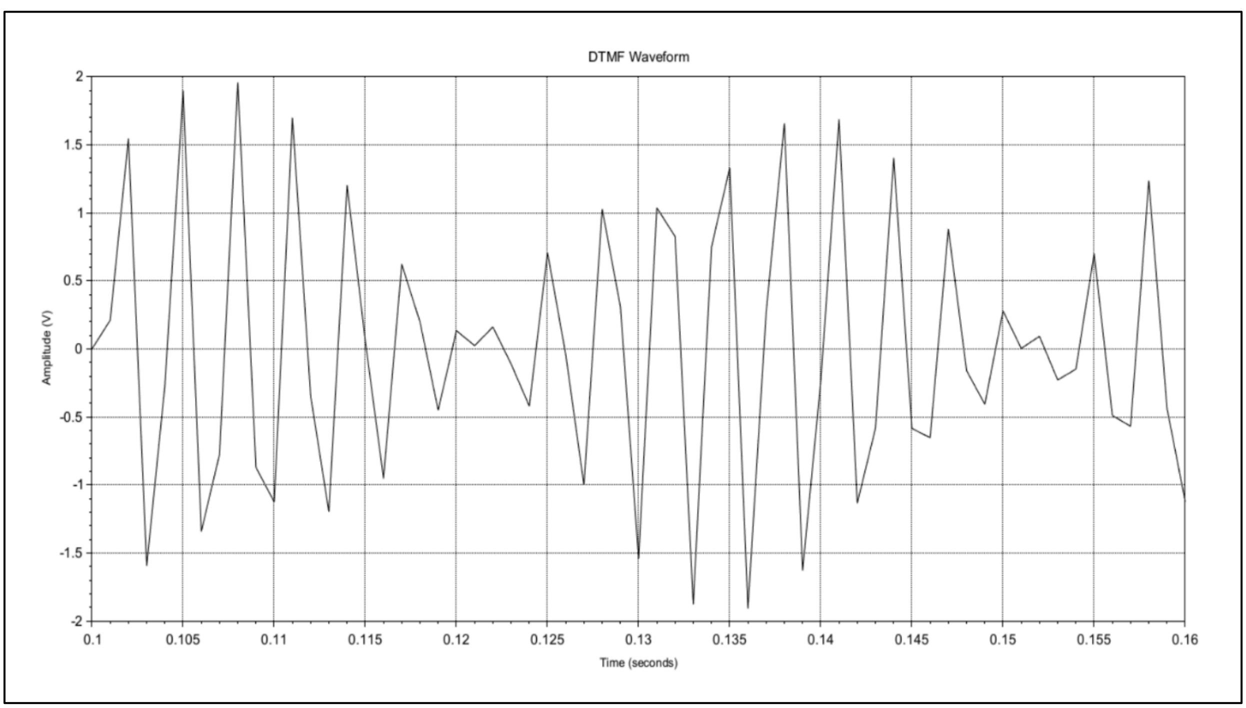


Figure 3: Digit '2'

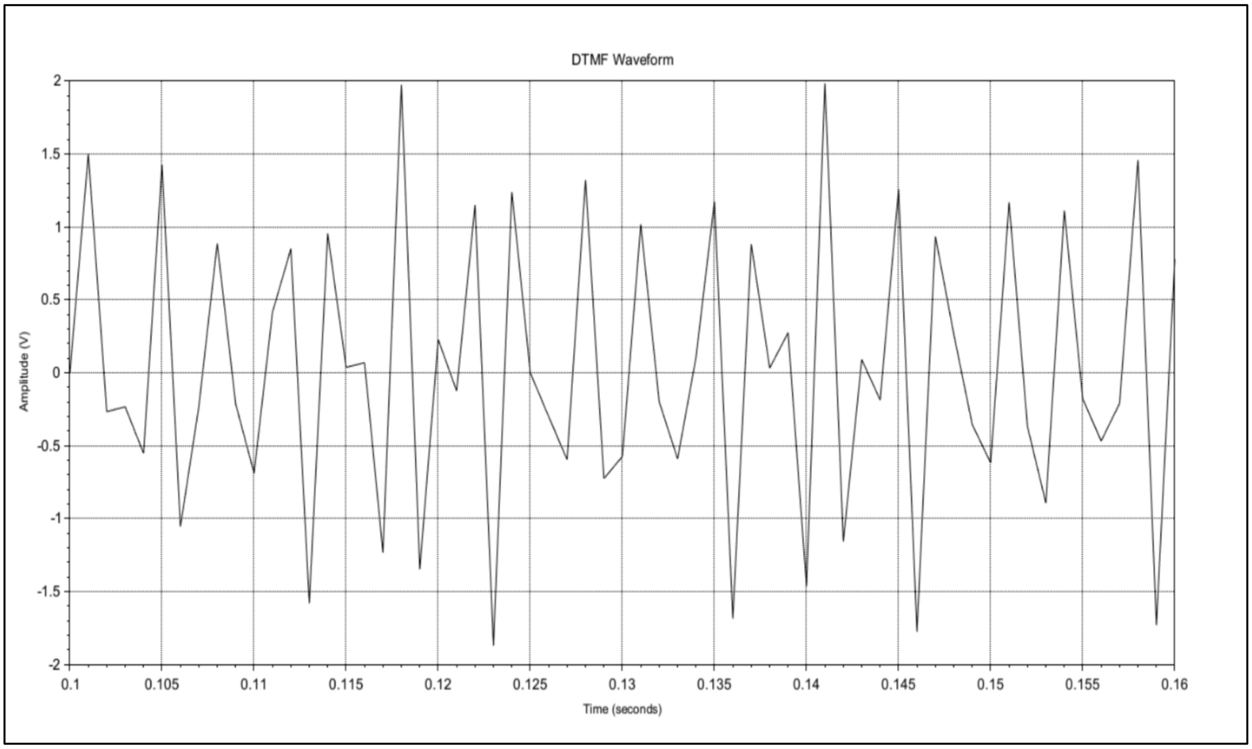


Figure 4: Digit '3'

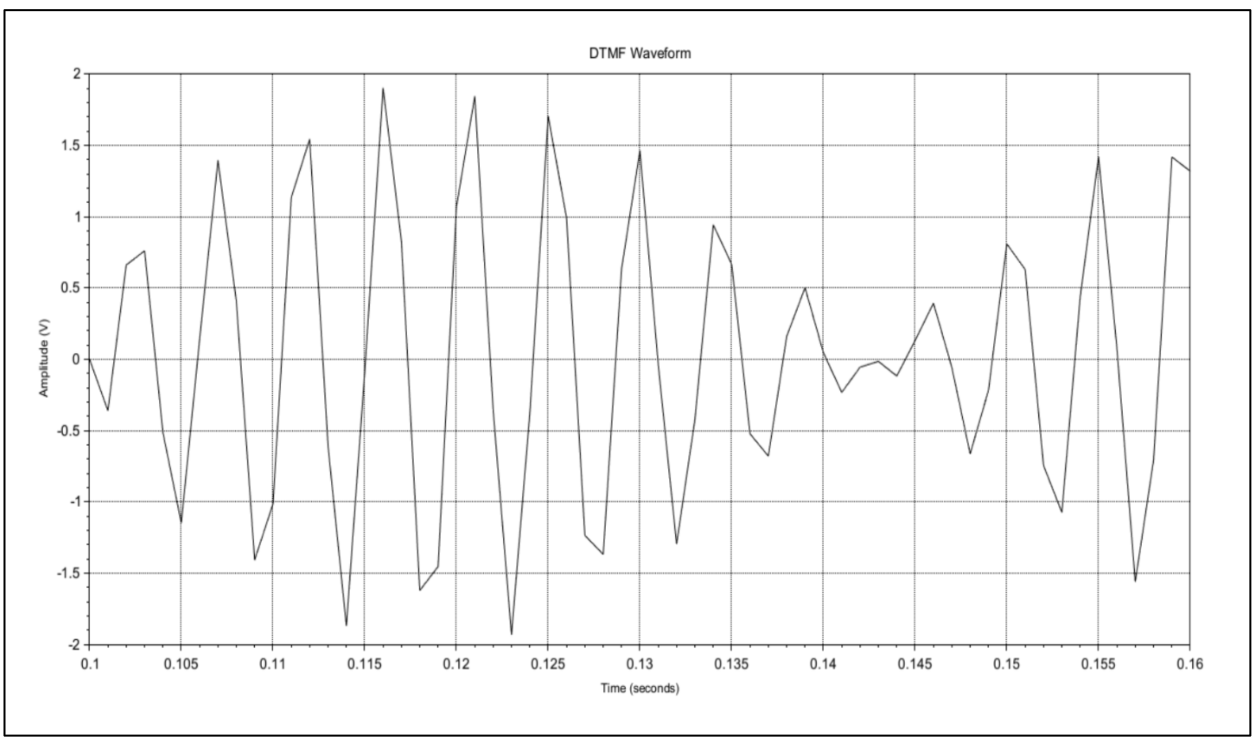


Figure 5: Digit '4'

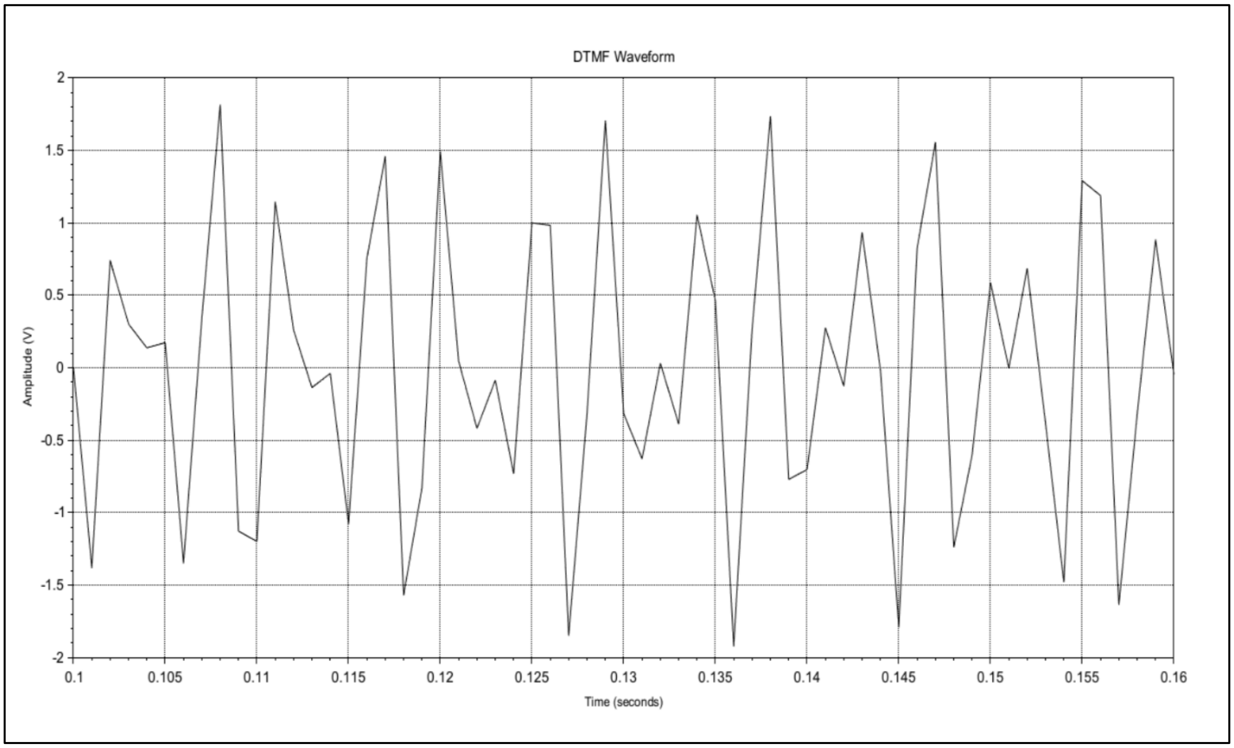


Figure 6: Digit ‘5’

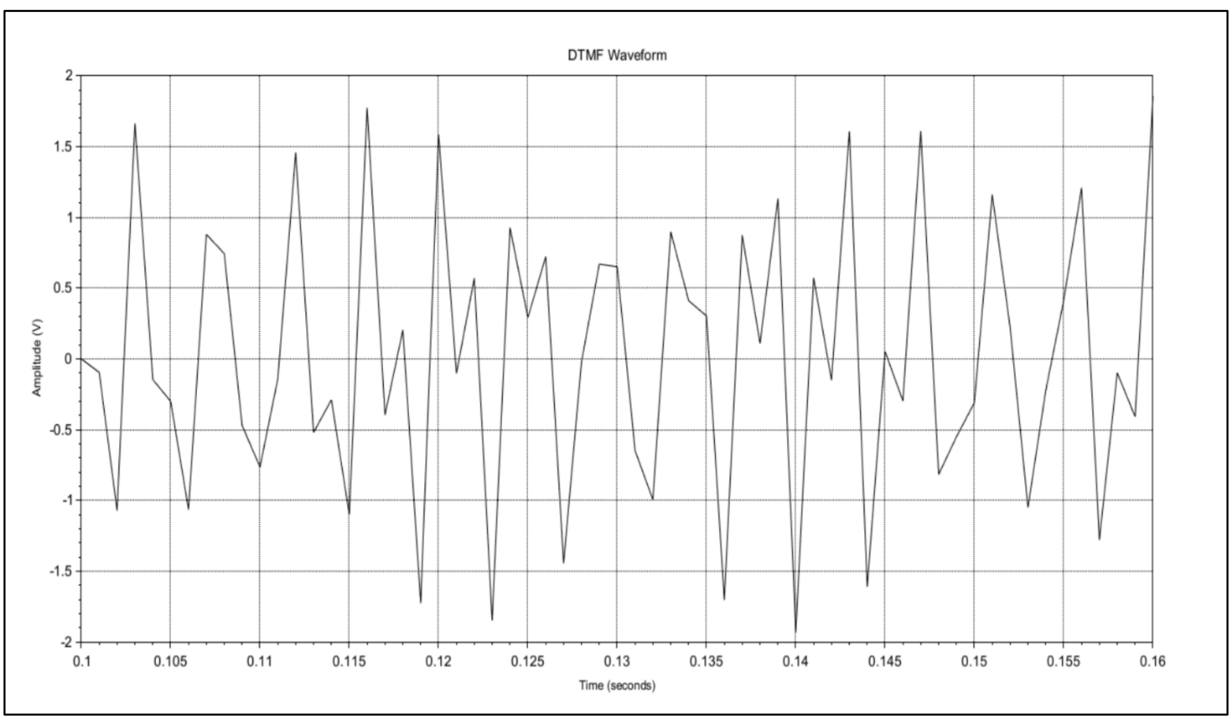


Figure 7: Digit ‘6’

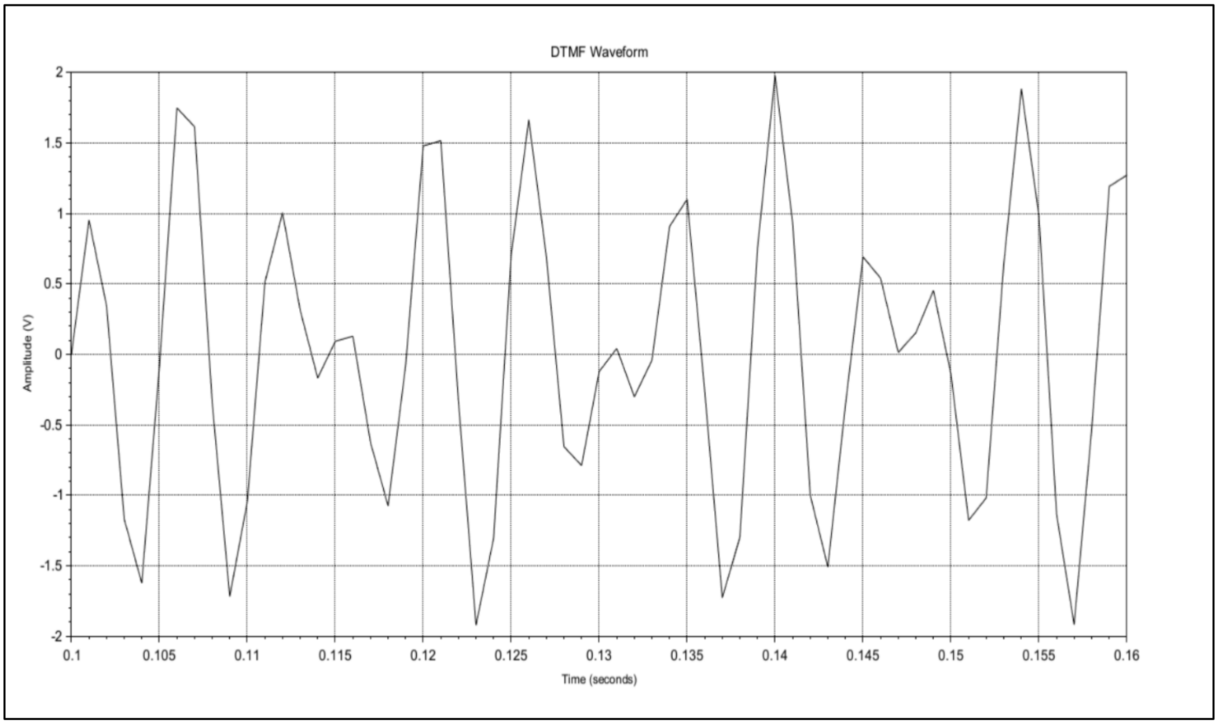


Figure 8: Digit '7'

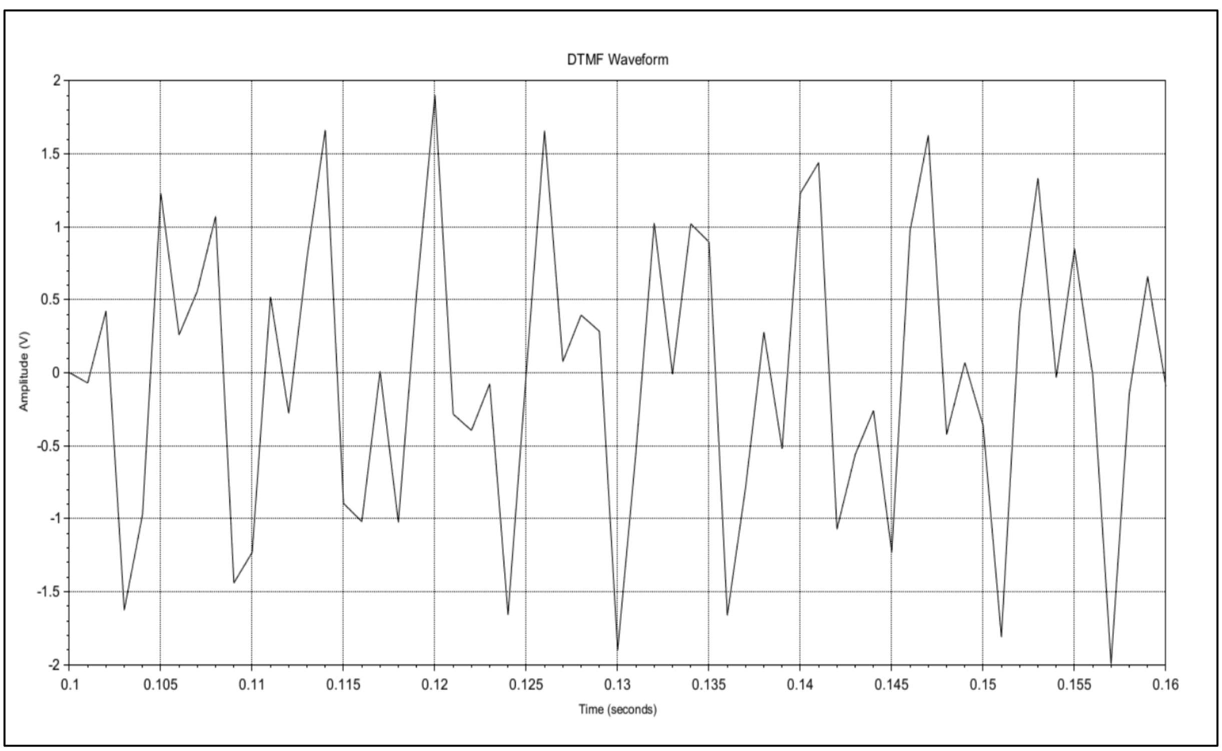


Figure 9: Digit '8'

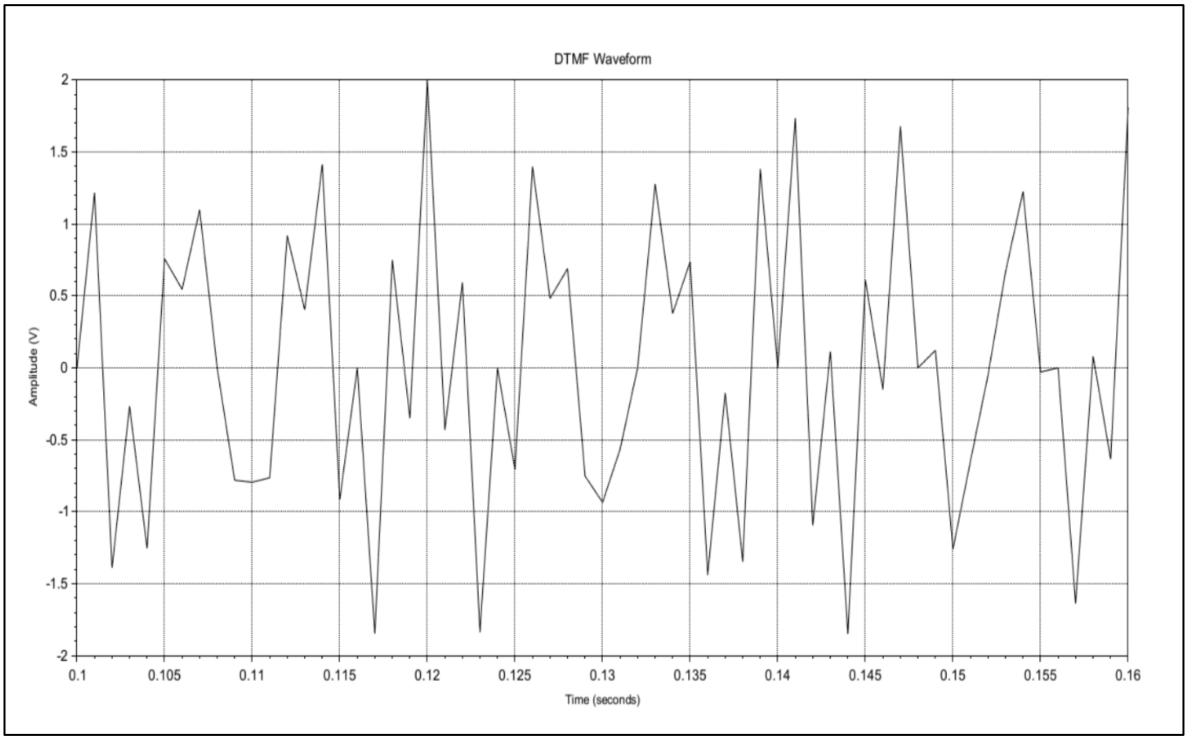


Figure 10: Digit '9'

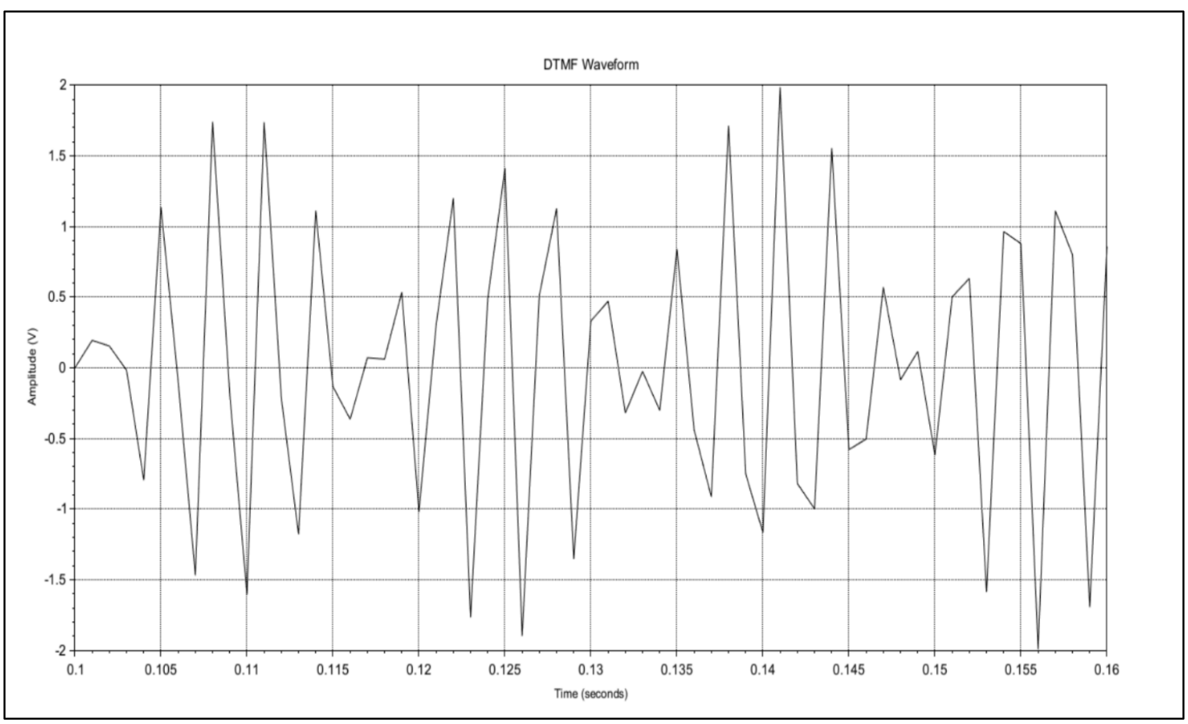


Figure 11: Digit 'A'

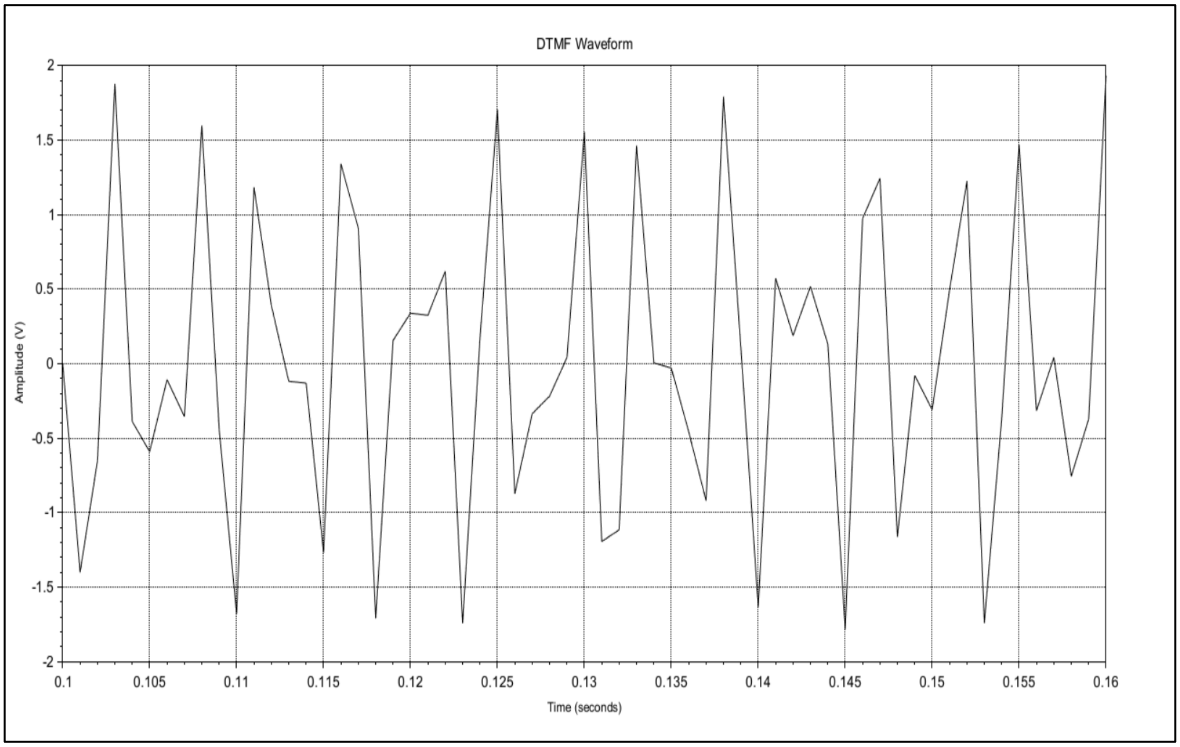


Figure 12: Digit 'B'

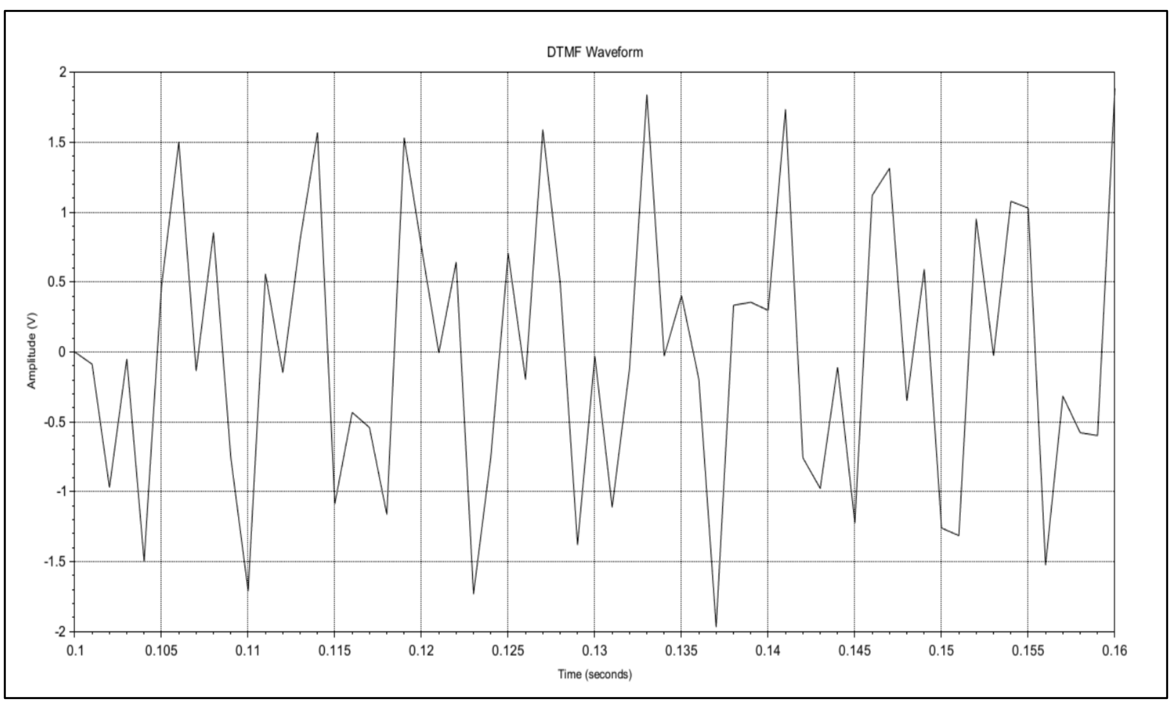


Figure 13: Digit 'C'

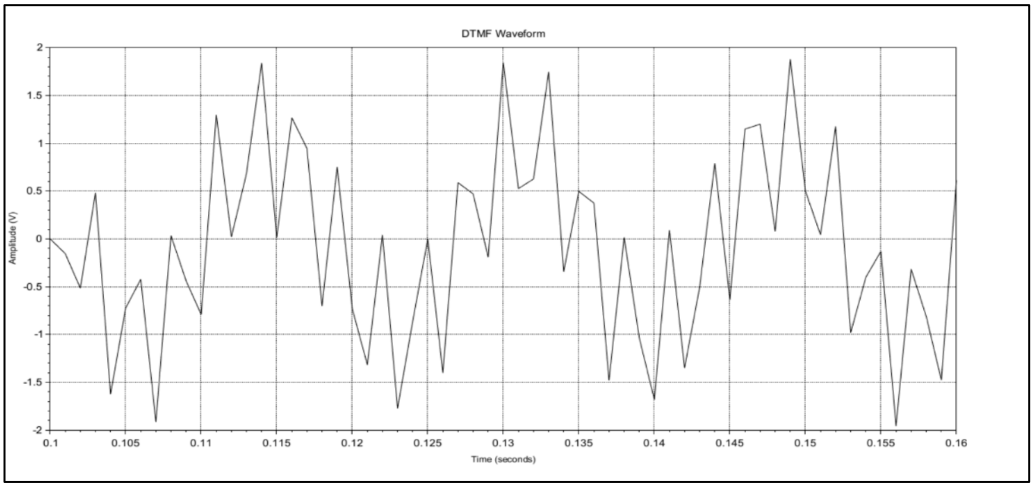


Figure 14: Digit ‘D’

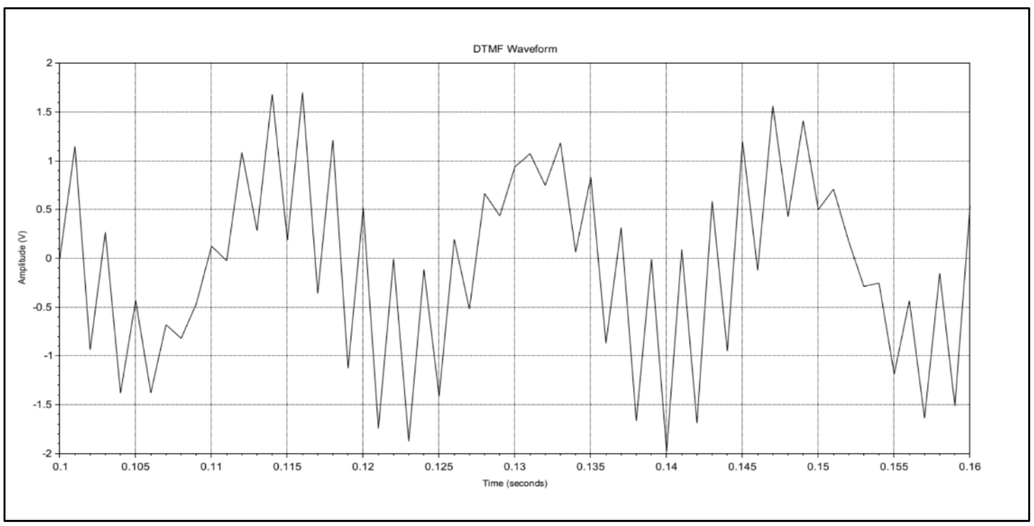


Figure 16: Digit ‘#’

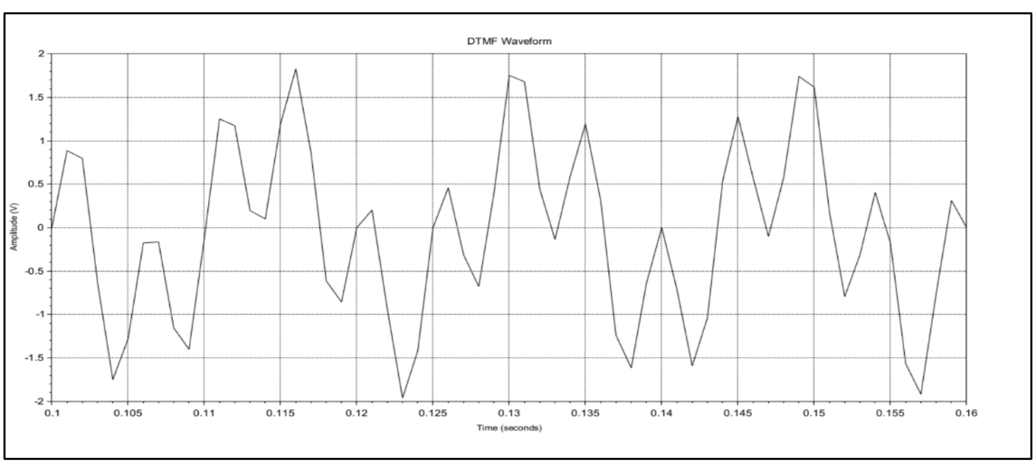


Figure 15: Digit ‘

Inferences

Two Sine wave generators are used to generate a low frequency signal and high frequency signal. The two signals are then added to produce the DTMF Signal. To make sure the signal only fires for 40 milliseconds, a pulse signal generated from pulse generator of width 40 milliseconds is multiplied with the DTMF signal.

When the user updates the digit variable, the digit is mapped is mapped to the corresponding low frequency and high frequency of the signal. These frequencies are saved in low_freq and high_freq variables which are fed to the Sine Wave generator.

7.4 Energy Output Graphs of Goertzel Detector

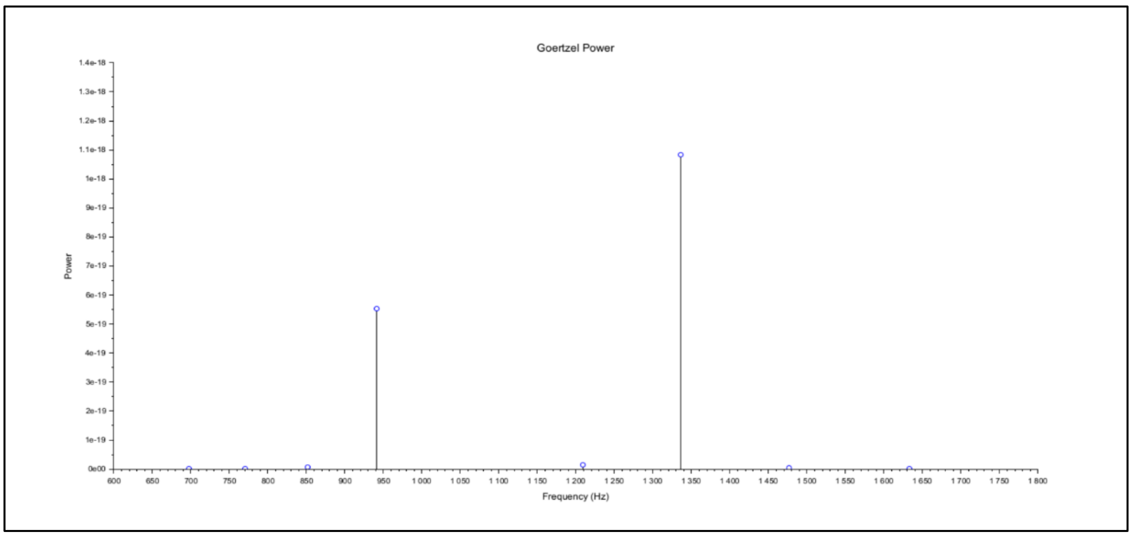


Figure 17: Output Energy for Digit ‘0

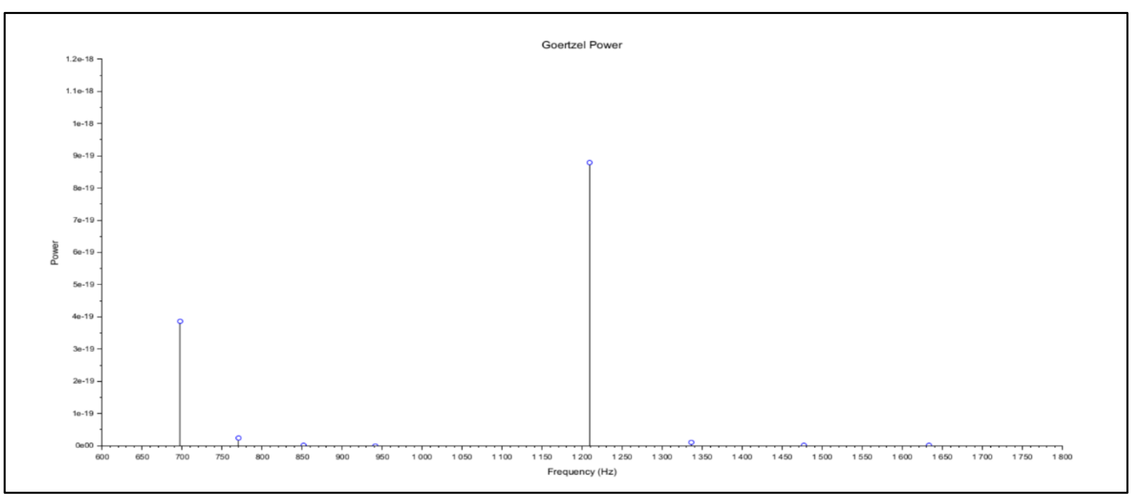


Figure 18: Output Energy for Digit ‘1’

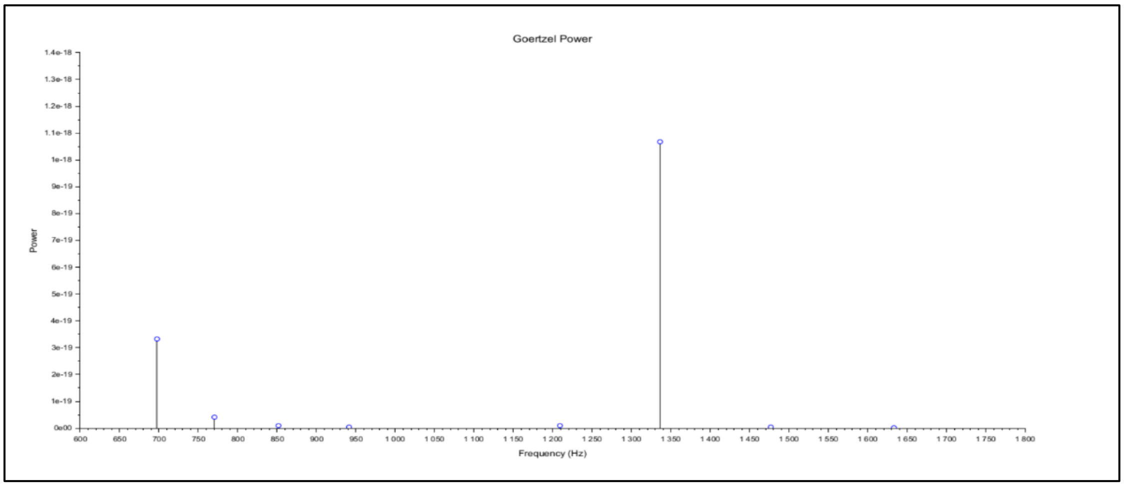


Figure 19: Output Energy for Digit '2'

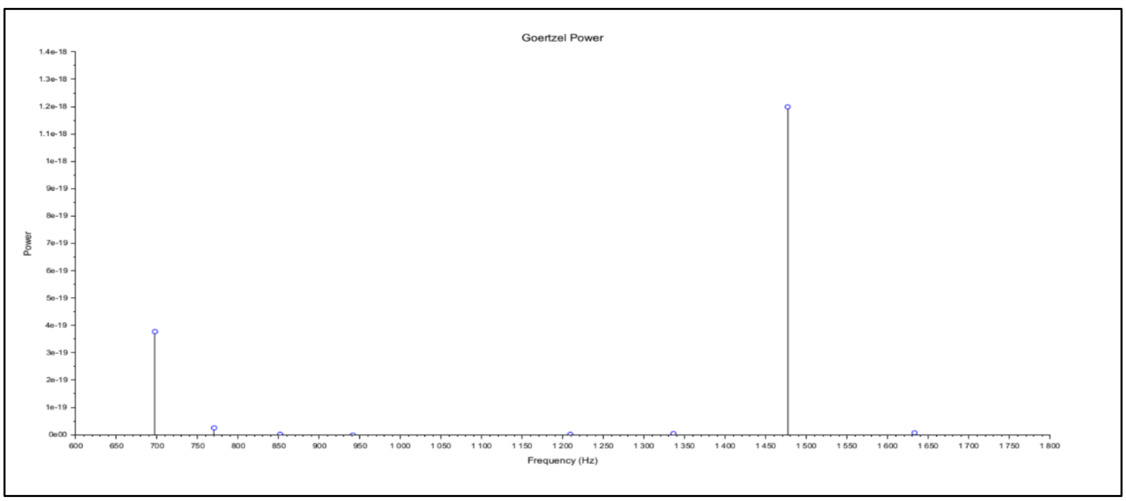


Figure 20: Output Energy for Digit '3'

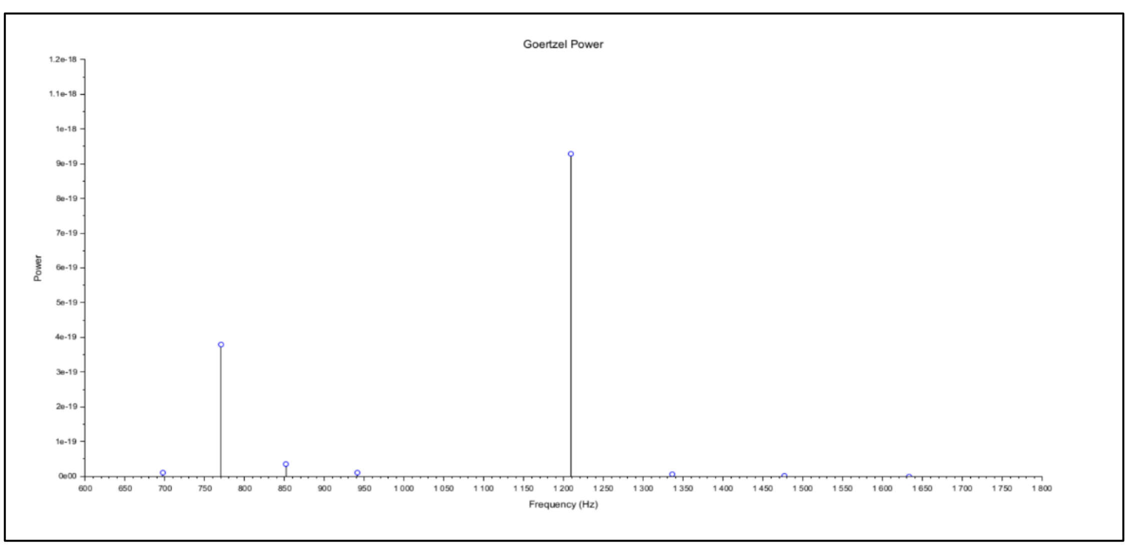


Figure 21: Output Energy for Digit '4'

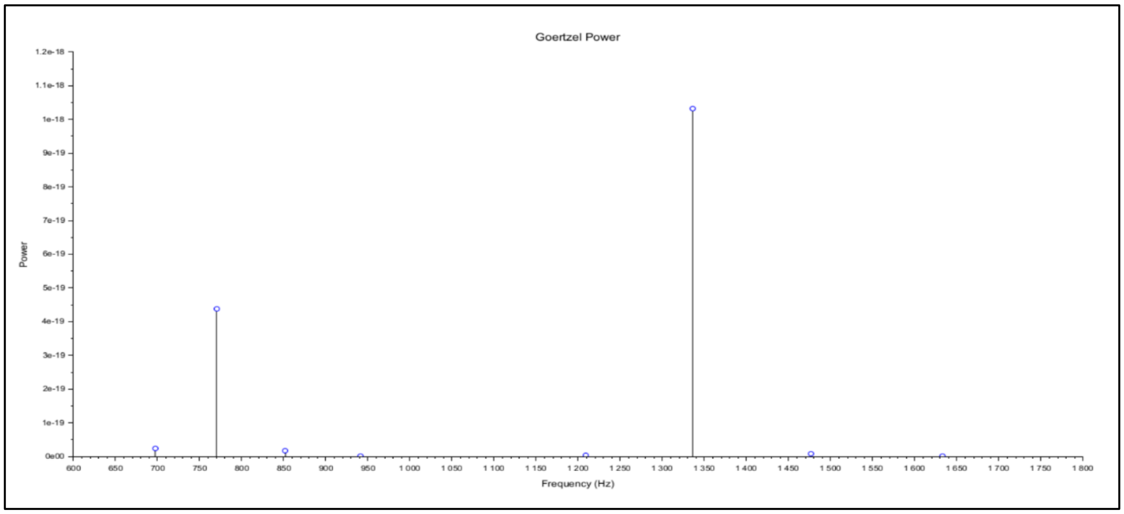


Figure 22: Output Energy for Digit '5'

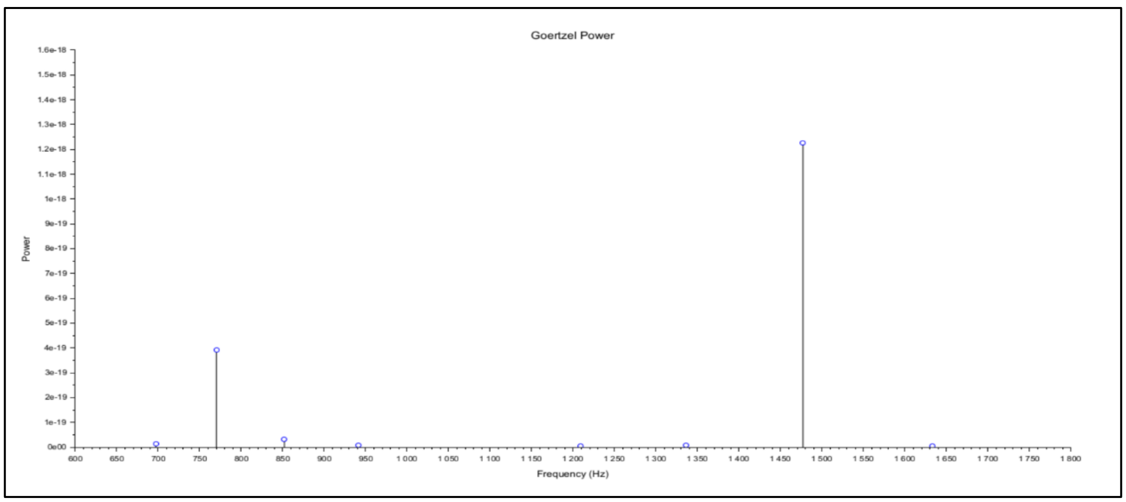


Figure 23: Output Energy for Digit '6'

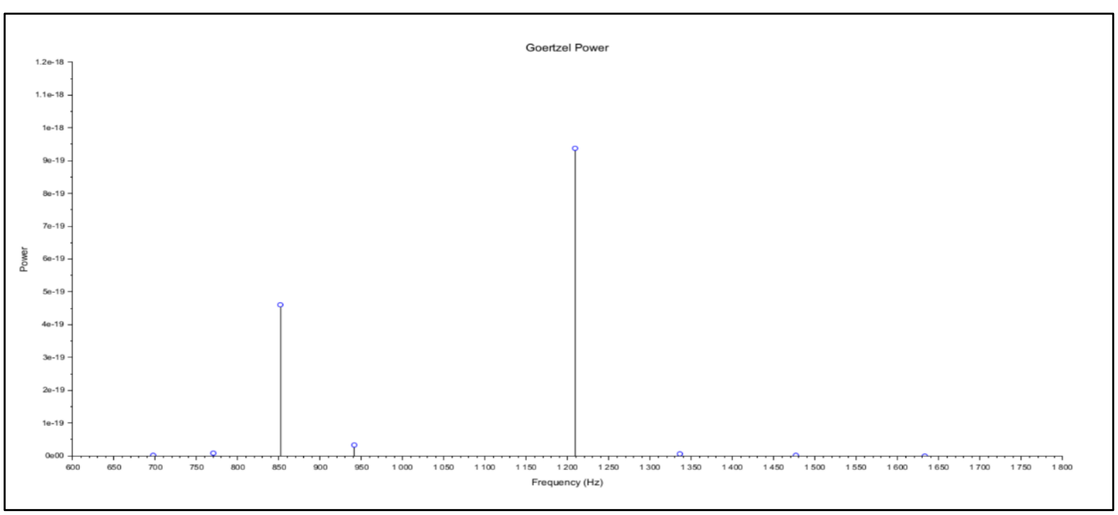


Figure 24: Output Energy for Digit '7'

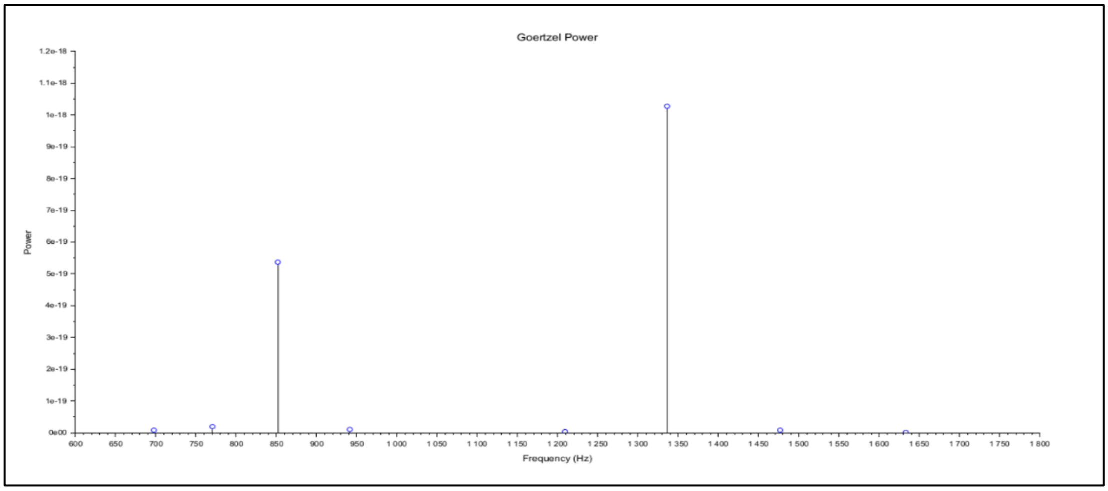


Figure 25: Output Energy for Digit ‘8’

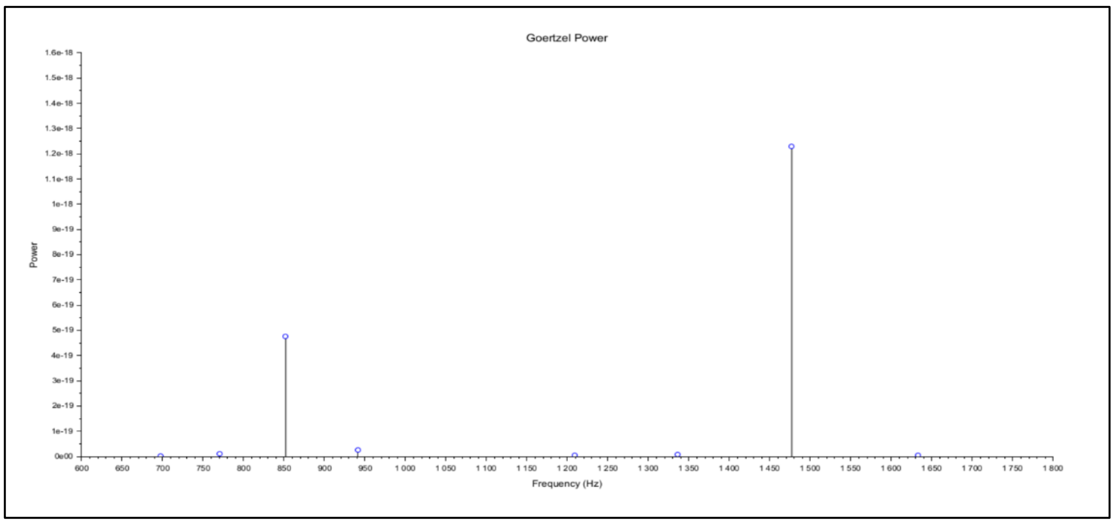


Figure 26: Output Energy for Digit ‘9’

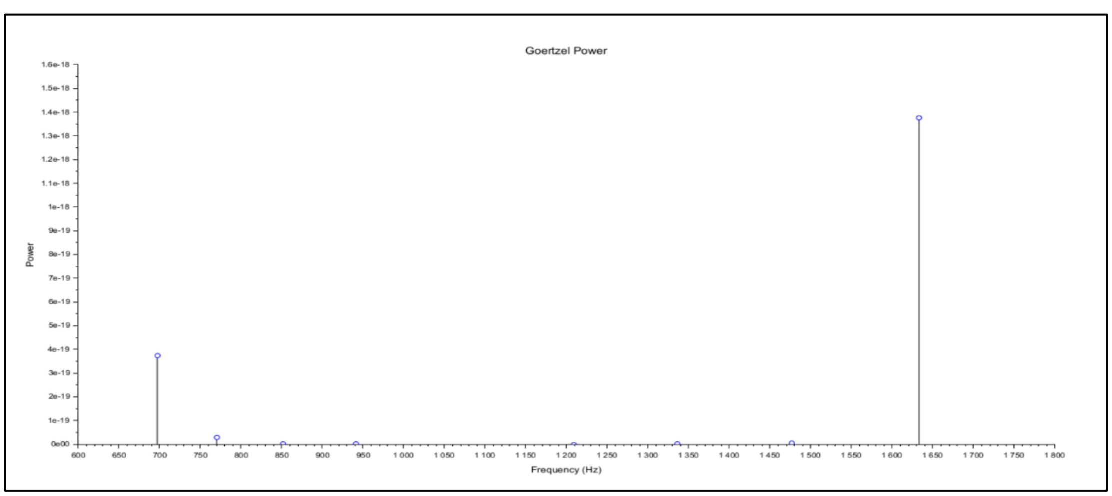


Figure 27: Output Energy for Digit ‘A’

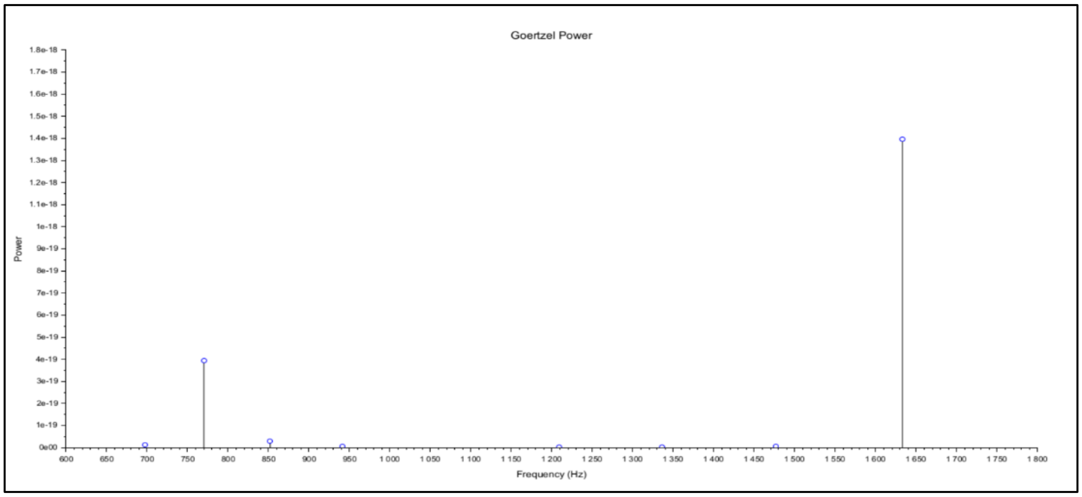


Figure 28: Output Energy for Digit ‘B’

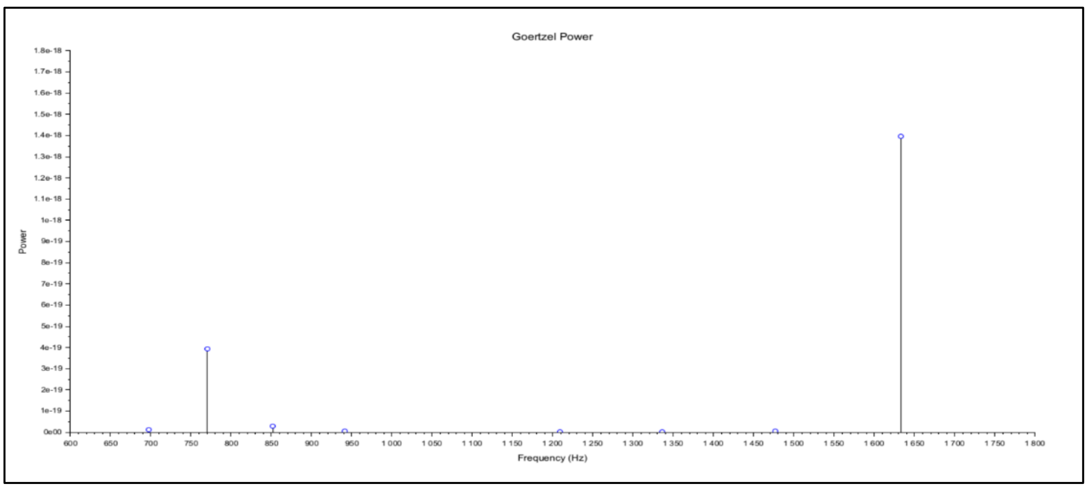


Figure 29: Output Energy for Digit ‘C’

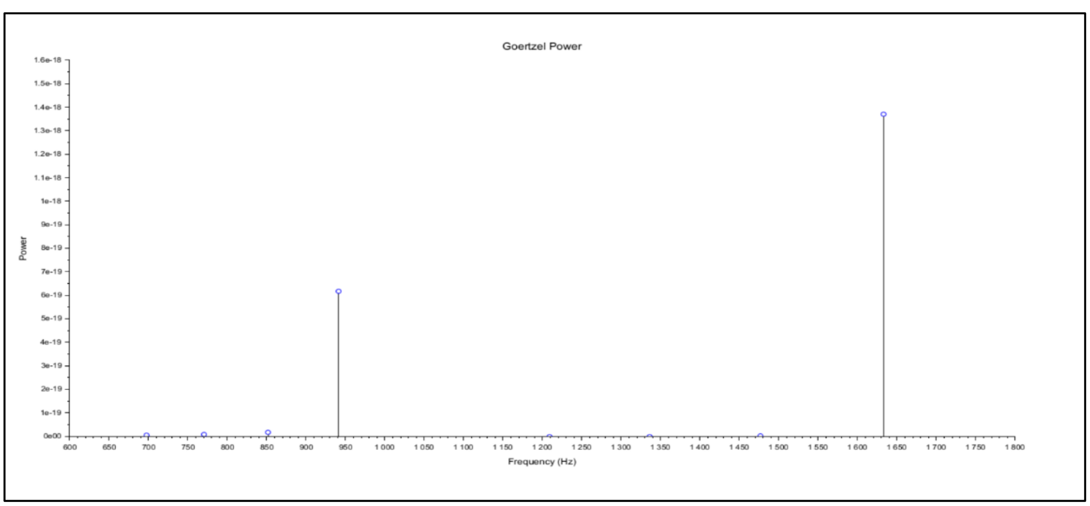


Figure 30: Output Energy for Digit ‘D’

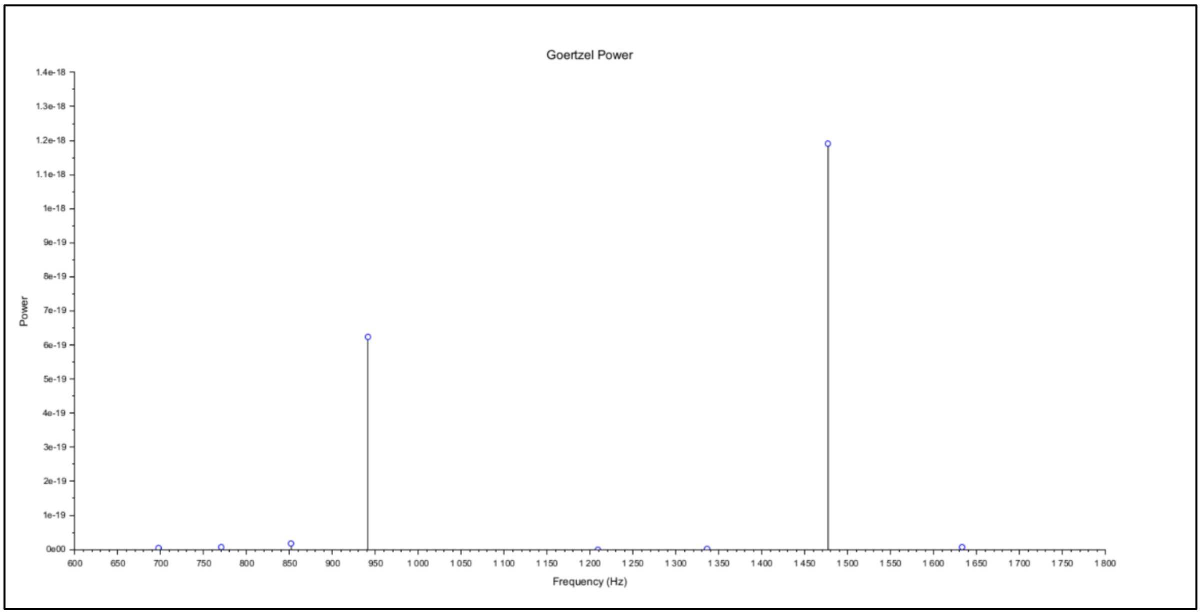


Figure 31: Output Energy for Digit '#'

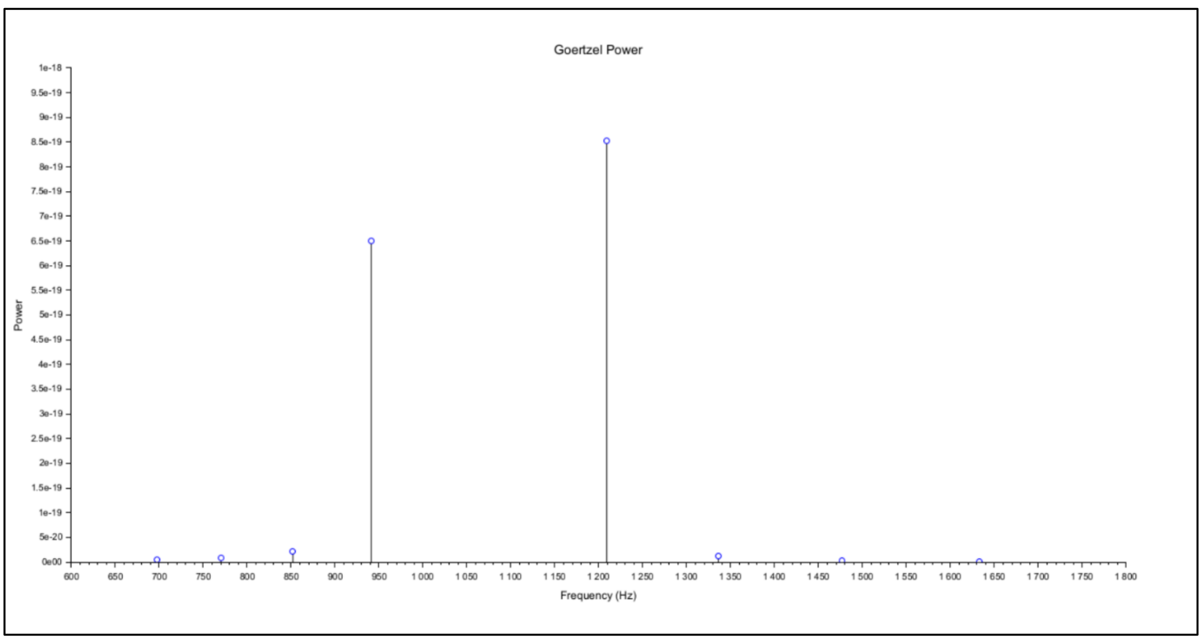


Figure 31: Output Energy for Digit '*'

Inferences

The energy output graphs validate the working of the Goertzel detector. In every case, the two dominant energy peaks match the standard DTMF frequency pair of the selected digit. The lower energy values at other frequencies indicate that unwanted frequency components are rejected successfully. Therefore, the detector correctly identifies the transmitted DTMF digit based on maximum energy selection in the low and high frequency groups.

7.5 Validation Tests Output

```
--> exec('C:\Users\vaidy\OneDrive\Desktop\dtmf.sce', -1)
 "1. Energy Threshold Test : T"
 "2. Twist Test: T [2.1975835 dB, Reverse Twist (High > Low)]"
 "3. Relative Peaks Test: T"
 "Dominant Low Frequency: 941 Hz"
 "Dominant High Frequency: 1477 Hz"
 "Detected Digit:#"
```

Figure 33: Validation tests for Digit '#'

7.6 Result Comparison of Internally Generated Signals VS WAV File Generated

Internally generating the DTMF signals within Scilab/Xcos produces the same Goertzel detection results as importing external .wav files. Both methods use the same mathematical formula to create the dual-frequency sine waves. Because both methods have sampling rate of Fs = 8000 Hz, the discrete-time numerical data points entering the frame buffer are identical. The Goertzel algorithm processes these numbers deterministically; therefore, whether the values stream from an Xcos block or a file header, the calculated power outputs, twist ratios and ITU validation metrics remain completely identical.

Inferences

- **Energy Threshold Test**: The peak magnitudes of both target frequencies exceed the minimum operational threshold parameter. This confirms that the incoming signal possesses sufficient power density to be categorized as a genuine keypad press rather than transmission line idle noise.

- **Twist Test:** The script calculates a twist value of 2.1975835 dB, meaning that the high-frequency component (1477 Hz) possesses more energy than the low-frequency component (941 Hz). This is known as Reverse Twist. Because the absolute value 2.198 dB falls below the maximum ITU-T standard allowance of 4 dB for reverse twist conditions, the signal passes compliance.
- **Relative Peaks Test:** The dominant frequencies stand out against secondary frequency bins within their respective low and high groups. Passing this test proves that the recorded energy belongs to discrete pure sine waves, rejecting broadband disruptions and background voice signals.

8. Scope of the Project

8.1 Elements Implemented from the Reference Paper

- **Dual-Tone Matrix Structure:** Incorporates the exact two-group frequency layout (697 Hz, 770 Hz, 852 Hz, 941 Hz for rows; 1209 Hz, 1336 Hz, 1477 Hz, 1633 Hz for columns).
- **Telephony Sampling Rate:** Sets the master clock simulation to a standard telephony sampling frequency of s = 8000 to comply with the Nyquist criteria.
- **Parallel IIR Filter Banks:** Replaces a full-spectrum Discrete Fourier Transform with 8 Infinite Impulse Response (IIR) Goertzel filters used for the individual DTMF frequencies.
- **Recursive State Difference Engine:** Implemented the time-domain recursive algorithm to update intermediate feedback states sample-by-sample
- **Dual-Threshold Twist Test**: Computes log-power ratios and strictly enforces ITU constraints to reject signals exceeding 8 dB for a normal twist or 4 dB for a reverse twist.
- **Relative Peaks Noise Rejection**: Measures the peak filter energy against the secondary non-target bins within the same frequency group to filter out speech or line noises.
- **Signal Energy Threshold Check**: Implements an amplitude detection threshold to distinguish actual, deliberate button presses from transmission line idle background noise.

8.2 Elements not Implemented from the Research Paper

- **Cool Edit Pro**: The paper generates its DTMF signals externally using third-party Cool Edit Pro software.
- **WAV File Audio Importing**: The reference model saves tones as .wav files and reads them into their workspace using the wavread command; the Scilab project passes the simulated continuous signals directly from Xcos to the Scilabworkspace.
- **Gain Control (AGC)**: The paper implements an AGC algorithm block before the Goertzel stage to adjust variable input signal amplitudes to a normalized feedback baseline.
- **Time Duration Check**: The paper talks about an ITU validation check ensuring that incoming DTMF signals maintain an active duration of at least 40 milliseconds.
- **Consecutive Multi-Digit String Decoding**: The reference project runs continuous buffer windows of length N=128 over a 5-cycle playback loop to parse multi-digit strings like "1234567890*#ABCD"
- **Frequency Deviation**: The project was stimulated in an ideal environment, so the sine wave generators have zero tolerance errors, zero thermal drift and zero voltage instability. Therefore, there is no frequency deviation.

8.3 Difference Table

Feature	Reference Paper	Scilab Project
Signal Source	Generates using Cool Edit Pro	Generates by two Sine Wave Generators in Xcos
Data Ingestion	Imported to workspace using .wav files	Transmitted directly from Xcos to Scilab workspace using TOWS block
Amplitude Control	Implemented an Automatic Gain Control (AGC) circuit.	Did not Implement Automatic Gain Control (AGC) circuit.

Time Duration Check	Evaluates minimum signal duration of 40 milliseconds.	Not implemented. Using a pulse wave of width 40 milliseconds ensure that the DTMF is of 40 milliseconds only.
Processing Capacity	Loops continuously to decode sequential strings (e.g., "1234...ABCD").	Designed as a single-key matrix to verify one target digit at a time.
Frequency Deviation	Implements Frequency Deviation	Does not implement Frequency Deviation

9. References

1) Pamuk, N., & Pamuk, Z. (2015). Dual Tone Multi Frequency (DTMF) signal generation and detection using MATLAB software.

   https://knowledgecenter.ubt-uni.net/cgi/viewcontent.cgi?article=2140&context=conference

2) W. Yuan, "A DTMF Signal Generation, Transmission and Detection System based on DSP and MATLAB," ISCTT 2021; 6th International Conference on Information Science, Computer Technology and Transportation, Xishuangbanna, China, 2021, pp. 1-5.
3) Ravishankar, M.K., Hari, K.V.S.: Performance Analysis of Goertzel Algorithm Based Dual Tone Multifrequency (DTMF) Detection Schemes, Departmental Technical Report (2004)