# Performance analysis of the DTMF detector based on the Goertzel's algorithm

Miloš S. Trajković
Menthor: Dušan Radović

***Abstract* — The subject of this paper is performance analysis of DTMF signal detector. There are many algorithms for DTMF detection, and among all of them the chosen one is Goertzel's algorithm. It is very often used in practical realizations and it is one of the simplest algorithms of all, which is very important fact when the microcontroller is programmed. The simulation environment of this algorithm is done in MATLAB and results from performance tests are given in this paper.**

***Keywords* — DTMF detection, Goertzel's algorithm**

## I. INTRODUCTION

Dual tone multi frequency (DTMF) is a method of representing digits with tones for transmission over communication channel. It is used by all touch tone phones to represent the digits on a touch tone keypad. A DTMF tone consists of two superimposed sinusoidal signals selected from two frequency groups. The frequency groups represent rows and columns on a touch tone keypad as shown in Fig. 1. Each DTMF tone must contain one sinusoid from the high-frequency group (1209, 1336, 1477 and 1633 Hz) and one sinusoid from the low-frequency group (697, 770, 852, 941 Hz). This allows a touch tone keypad to have up to 16 unique keys.

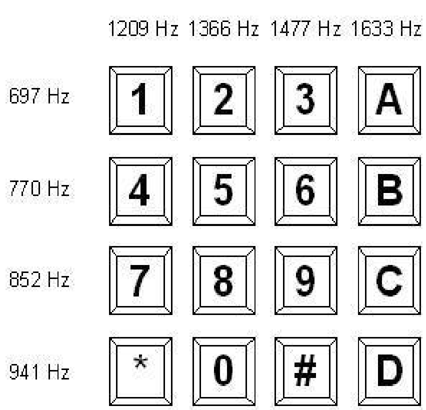


*Fig. 1. DTMF Keypad*

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Miloš. S. Trajković, Faculty of Electrical Engineering, Bulevar Kralja Aleksandra 73, 11000 Belgrade, Serbia (tel: +381641516555; e-mail: miloss.trajkovic@gmail.com)

Dušan Radović, ELSYS Eastern Europe, Vladimira Popovića 6, (Apart. B39), 11000 Belgrade, Serbia (tel: +381638215443 , e-mail: dusan.radovic@elsys-design.com)

The frequencies selected for the DTMF tones have some distinguishing characteristics and unique properties:

- All tones are in the audible frequency range allowing humans to detect when the key is pressed
- No frequency is multiple of another one
- The sum or difference of any two frequencies doesn't equal another selected frequency

These properties simplify DTMF decoding and reduce falsely detected DTMF tones. They also allow receivers to detect simultaneously pressed keys and to reject signals with harmonic energy such as speech or noise. In this way, the possibility of detecting speech or noise as a valid DTMF tone is minimized.

Because of the compatibility of the DTMF detectors world wide, DTMF tones should always be produced and decoded according to International Telecommunication Union (ITU) Recommendation Q.23 [1] and Q.24 [2].

## II. DETECTION ALGORITHM

The detection of the DTMF tones is a capability of distinguishing eight DTMF frequencies from the signal that is received from the line, and a capability of detecting and rejecting false tones produced by the noise. The signal always contains noise which can more or less affect the detection. False detection of DTMF tones is so called talk-off error and it is possible due to speech or any other form of noise. There are many methods for distinguishing between DTMF tones and speech such as detecting the presence of second harmonic or checking the energy of the detected samples. Frequency detection is typically accomplished by applying Discreet Fourier Transform (DFT) to a time domain input signal to extract frequency information. By analyzing the spectrum of the signal, one can realize if there are any DTMF frequencies and which they are. The most used algorithm for performing DFT, Fast Fourier Transform (FFT), could be used as a DTMF detector, but its complexity is a drawback. That is because FFT is generating the frequency information on entire range of frequencies from DC to half of the sampling rate. Performing it in real-time requires a lot of memory for calculations and storing the results and therefore it is not suitable for 8-bit or 16-bit microcontroller, where this algorithm is often implemented. Instead of FFT, the other way for performing the DFT is used, which is less complex. It is called Goerzel's algorithm [9] and its main feature is that it is performed on $N$ samples and not the entire DFT is done.

The veracity of the calculations is not changed because the number of frequencies is small (only eight) [9].

There are also other algorithms for DTMF detection, such as: Non-uniform DFT [5], MUSIC – Multiple Signal Classification [4], Full FFT algorithm [3], and Modified Goertzel's algorithm [7]. They are all more complex to understand than the one described in this paper, and they could be subjects on their own.

The Goertzel's algorithm is based on the use of second-order IIR filter for each DTMF frequency. The filter has samples as input and gives DFT coefficients as output. Operations performed by Goertzel's algorithm can be described by the following difference equations:

$$Q_k[n] = x[n] + 2\cos(w_k)Q_k[n-1] - Q_k[n-2] \quad (1)$$

$$y_k = Q_k[n] - Q_k[n-1]\exp(-jw_k) \quad (2)$$

$$w_k = 2\pi f_k = 2\pi k f_s / N \quad (3)$$

$$X(w_k) = y_k[n = N] = y_k[N] \quad (4)$$

where $x[n]$ is the input sample, $N$ is length of the block which is used for calculation and $w_k$ is $k^{th}$ DFT sample. The block diagram of the Goertzel's algorithm is shown in the Fig. 2. Equation (1) represents the recursive part of the algorithm and it is performed for every sample ($N$ times). Equation (2) represents the non recursive part and it is executed only once, at the end of the recursive part, because of equation (4). Thus, the number of operations for the computation of one DFT sample is $N$+2 real multiplications and $2N+1$ addition.

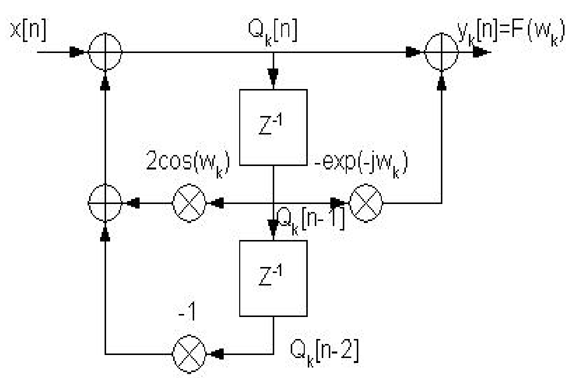


*Fig. 2. Block diagram of Goertzel's algorithm*

The effectiveness of the algorithm depends on the sampling rate and length of the block – $N$. If the sampling rate is fixed, usually 8 kHz, the block size determines frequency resolution and time required to capture $N$ samples. Frequency resolution is used for selection of the desired DTMF frequency in the IIR filter by calculating $k$ as given in equation (3), and DTMF frequencies do not coincide with frequencies at which DFT is computed. These differences can be made small by choosing large value of $N$. On the other hand, greater $N$ increases time necessary for capturing $N$ samples, and therefore the time needed for the detection, which is also important fact for the realization. That is why the selection of $N$ is very important, and a tradeoff must be done. Because of the properties of the DTMF frequencies, it is impossible to find $N$ when all calculating frequencies coincide with actual DTMF frequencies. Calculations were made, and minimum average absolute error for each frequency was obtained for $N$ = 205 ($f_s$=8kHz) [3]. These results are shown in Table 1. Having taken into consideration the results of calculations, $N$ was chosen to be 205 and the sample rate 8 kHz.

TABLE 1: CALCULATIONS FOR COEFFICIENT *K*.

| *tone in Hz* | ***N = 256, Δf = 31.25 Hz*** | ***N = 1024, Δf = 7.8125 Hz*** | ***N = 205, Δf = 39.0244 Hz*** |
|---|---|---|---|
| 697-1633 | Avg. abs. err = 0.265 | Avg. abs. err = 0.187 | Avg. abs. err = 0.1562 |

## III. MATLAB SIMULATION AND TESTS

Implementation of the Goertzel's algorithm was done in MATLAB. It consists of several parts:

- generation of the DTMF signal containing two sinusoids
- three different types of noise generation (random, sinusoidal and recorded speech)
- DTMF detection
- Probability of detection and error calculations
- Displaying sent and decoded keys

Simulation tests were developed in accordance with the ITU recommendations [1], [2] and therefore it has some additional features like inserting twist and frequency offset during the generation of the DTMF signal, specifying the tone and pause duration between the tones, specifying signal to noise ratio. DTMF detector is using eight Goertzel's filters (Fig. 2) to get the magnitude at all DTMF frequencies. The evaluation of those filter outputs is the most important part of the detection progress and it was done by checking the power of the whole system. Firstly, the maximum power of the low-group and high-group of frequencies is found, and then they are compared to the power of the whole received signal. If sum of two maximums is more than 75% of the whole received power, the detector will consider that valid DTMF tone is present. This number of 75% is taken as a result of many simulations with different parameters. It is found suitable for all DTMF tones and the detection is the most reliable. The other reason, why this type of evaluation was taken, is that it was completely immune to speech or any other form of noise which can produce false tone detection. Evaluating power of the second harmonics can produce more errors due to the noise present on the line, because there is no clear definition how much power of the first harmonic must be greater than the power of the second harmonic. At some references [6] it is 8-10 times greater, but it depends on the conditions and realizations.

The other type of evaluating power of the received signal was comparing it to a certain threshold value, but it has the same problem as evaluation of the $2^{nd}$ harmonics and therefore it hasn't been taken into consideration. The detector is also checking the twist of the received signal which is defined as difference in decibels between the maximum power from the low-group and high-group of frequencies. The forward twist is defined when the maximum power from the high-group is greater than the maximum power from the low-group. Reverse twist is defined vice-versa. Detector twist properties are in accordance with ITU recommendations which are 8dB for forward twist and 4dB for reverse twist. If the twist is greater than those limits, the detector will take no action and the error symbol will be displayed.

The testing of the algorithm [10] has been performed on 10000 successively generated DTMF tones with the tone duration of 40ms and pause duration of 15ms. Sampling frequency has been 8 kHz and $N = 205$ (except for the test where $N$ was variable parameter). The following tests have been done:

- Twist test – twist has been intentionally inserted in the generated signal and the probability of detection has been watched (Table 3)
- Signal to noise (S/N) ratio test – S/N has been changed from 0dB to 40dB, while there is no twist (Table 4).
- N test – $N$ was taking values from 160 to 250, and probability of detection was recorded

The ITU recommendations are given in the Table 2

TABLE 2: ITU RECOMMENDATIONS.

| ***Standard*** | ***Operational*** | ***Non-operational*** |
|---|---|---|
| Forward Twist | < 8 dB | > 8dB |
| Reverse Twist | < 4dB | > 4dB |
| Frequency offset | < 1.5% | > 3.5% |
| S/N ratio | < 15 dB | > 15 dB |

## IV. ANALYSIS OF THE RESULTS

Analyzing the results of the twist test, given in Table 3, it could be said that detector is not in accordance with ITU recommendations for boundary values of twist, 8dB for forward and 4dB for reverse. The probability of detection is around 0.5 at those values, which is very low.

TABLE 3: TWIST TEST.

| ***Twist test*** | | | |
|---|---|---|---|
| FRW twist | $P_d$ | REV twist | $P_d$ |
| 0 | 0.9866 | 0 | 0.9866 |
| 2 | 0.9823 | 1 | 0.9782 |
| 4 | 0.9761 | 2 | 0.9582 |
| 5 | 0.9691 | **3** | **0.8807** |
| **6** | **0.9391** | 3.5 | 0.7393 |
| 7 | 0.7675 | 4 | 0.5115 |
| 8 | 0.4689 | 5 | 0.1357 |
| 9 | 0.1279 | 6 | 0.0156 |
| 10 | 0.0266 | | |

On the other hand, S/N ratio has been on its minimum value and, if the S/N ratio was bigger, $P_d$ will be also bigger and this standard would have been fulfilled. For the veracity of the tests, the minimum value for S/N must be taken. In real situation, S/N will be much bigger or the transmission of the DTMF signals won't happen.

S/N test results from Table 4 are showing that this DTMF detector has completely passed the standard defined values for S/N ratio. As it can be seen from the Table 4, even for the values lower than 15dB (ITU recommendations threshold [1], [2]), probability of detection is very high, more than 0.95, and the transmission could held safely above 15dB, just like the ITU recommendations are preferring. For the S/N bigger than 25dB, probability of detection is 1 and there will be no errors during the transmission.

TABLE 4: S/N TEST.

| ***S/N ratio test*** | | | |
|---|---|---|---|
| S/N | $P_d$ | S/N | $P_d$ |
| 0 | 0.0016 | 14 | 0.9738 |
| 5 | 0.1009 | 15 | 0.9837 |
| 7 | 0.3102 | 16 | 0.9924 |
| 8 | 0.4698 | 17 | 0.9957 |
| 10 | 0.7844 | 18 | 0.9986 |
| **12** | **0.9143** | 20 | 0.9999 |
| 13 | 0.9488 | 40 | 1 |

The N test results shown in Fig. 3 can affirm the assumption that for N = 205, average absolute error for $k$ is the lowest and therefore the probability of detection will be very high. What can also be seen from the Fig. 3 is that there are other values for $N$ (186, 197, 210, 216, 227, 232, 238, 245), where the probability of detection is high enough, and even higher than the one for $N = 205$. Other values for $N$ can be used for DTMF detection, which is left to a programmer to choose.

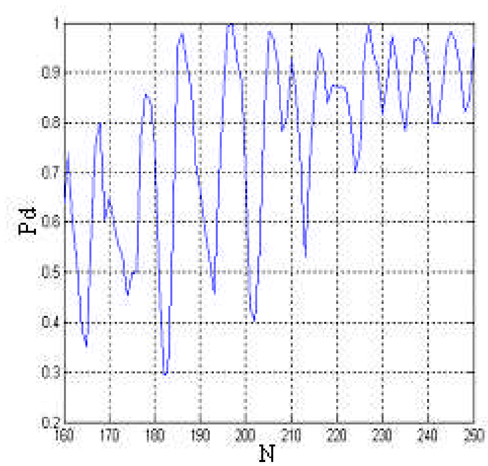


*Fig. 3. N test results*

The author of this paper has chosen $N = 205$ value because it is used in most applications he read about [3], [4], [8]. Some additional tests have also been performed for $N = 186$ (the lowest mentioned value). The results showed that at the boundary values defined by ITU recommendations, the probability of detection is lower than the one obtained in the tests performed with $N = 205$.

The results obtained from the tests performed in this paper showed that Goertzel's algorithm could be used in practical realizations of DTMF detectors on microcontrollers or DSPs. The most important part is choosing the type of power evaluation, and the type described in this document is only one of many. That is left to a programmer to choose in accordance to conditions of the transmission and other circumstances.

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