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# Goertzel Algorithm based DTMF Detection

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***Abstract**: DTMF namely Dual Tone Multi frequency is a signaling standard in telecommunication applications that produces two tones simultaneously for each key press. DTMF signaling has many applications such as telephone dialing, data entry, credit checking, voice mail system control and many. The DTMF tone detection is a very crucial block in several telecom based systems. As the current generation systems are looking for key feature of the low power less area and more. The DTMF detection algorithm also must be implemented with the low power schemes.*

*The Dual Tone Multi Frequency detection can be done with FFT based technique but which is power consuming type and also it requires much more hardware. In this paper, FPGA based DTMF detection using VHDL with very low power and low area using Goertzel algorithm is done using Very High Speed Integrated Circuit Hardware Description Language.*

***Keywords**: DTMF detection, FFT, VHDL, Goertzel Algorithm*

## I. Introduction

Dual Tone Multi-Frequency famously known as 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. The DTMF dialing system traces its roots to a technique AT&T developed in the 1950s called Multi-Frequency, which was deployed within the AT&T telephone network to direct calls between switching facilities using in-band signaling. In the early 1960s, a derivative technique is offered by AT&T through its Bell System telephone companies as a "modern" way for network customers to place calls. In AT&Ts Compatibility Bulletin No. 105, AT&T described that, the product as "a method for pushbutton signaling from customer stations using the voice transmission path." The consumer product was marketed by AT&T under the registered trade name Touch-Tone. Other vendors of compatible telephone equipment called this same system "DTMF" or "Tone" dialing.

Dual Tone Multi-Frequency signaling has many applications such as telephone dialing, data entry, credit checking, and voice mail system control. A DTMF signal Consists superimposed of two sinusoidal waveforms with frequencies chosen from a set of eight standardized frequencies. These frequencies should be generated and detected according to the Consultative Committee for International Telegraph and Telephone (CCITT) Recommendation. The DTMF system uses eight different frequency signals transmitted in pairs to represent sixteen different numbers, symbols and letters.

## II. Architecture Design

The below figure can represents the general module of DTMF Detection.
The module DTMF detection consists of

- Hex key pad
- DTMF test signal generator
- Additive white Gaussian noise
- Frequency Detection block
- Magnitude / index estimator
- Frequency to digit look-up table

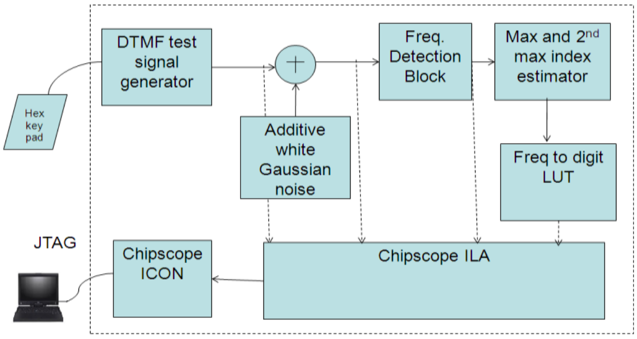

DTMF test signal generator
Freq. Detection Block
Max and 2nd max index estimator
Hex key pad
Additive white Gaussian noise
Freq to digit LUT
JTAG
Chipscope ICON
Chipscope ILA

**Fig.1: DTMF Detection (General Module)**

Hex Keypad gives input to the module. It is an external component. The signal from column is taken as input. Row and display are the output signals. By using PC we analyze the corresponding results. The below figure can represents the Goertzel Algorithm blocks as frequency detector.

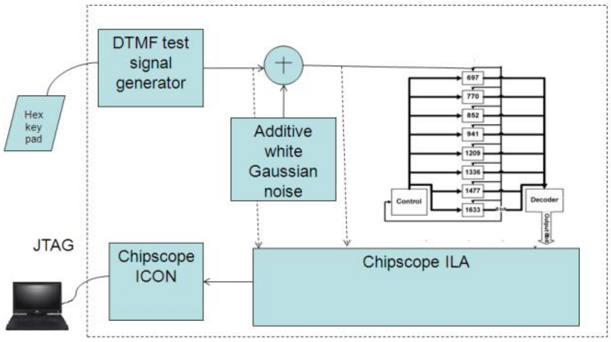


**Fig.2: Goertzel Algorithm Blocks as frequency detector**

***A. Hex keypad:***

The Hex Keypad gives input to the basic module. It is an external component. The signal from the column is taken as input. Row and display are the output signals.

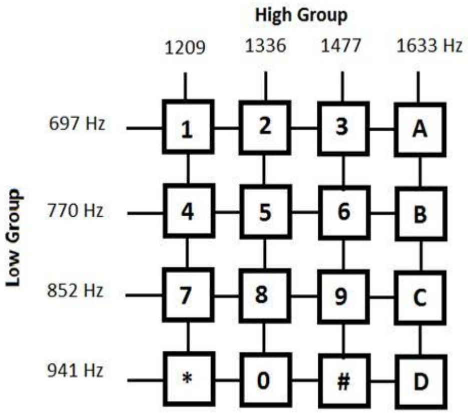


**Fig.3: Hex Keypad**

***B. Frequency test signal generator:***

Block generates the carrier frequencies necessary. It consists of 2 blocks one is frequency word selector and another one is DDS core unit.

***C. Frequency word selector****:*

In this block the carrier waves are generated according to the key pressed '0'

For example: If key 9 is being press the frequencies that are generated are 852 Hz (Low frequency group) and 1477 Hz (High frequency group).

These frequency waves are generated by a DDS core.

***D. DDS Core:***

The Logic ORE™ IP Direct Digital Synthesizer (DDS) Compiler core sources sinusoidal waveforms for used in many applications. A DDS consists of, a Phase Generator and a SINE/COS Lookup Table. These parts are available individually or combined via DDS core.

DDS is a method of producing an analog waveform, usually a sine wave by generating, time-varying signal in digital form and then it performing a digital-to-analog conversion.

***E. Additive white Gaussian Noise:***

Coming to the Additive white Gaussian noise, the tone out, which is the output from tones generator is mixed with noise in this module. The output is named as the noise bits. Wideband Gaussian noise comes from many natural sources, such as, thermal vibrations of atoms in conductors, black body radiation from the earth and other warm objects, shot noise, and from the celestial sources such as the Sun.

***F. Frequency Detector:***

The Input to this module is noise bits, which is the output from additive white Gaussian noise. Output of the block is indices and magnitudes. As per the scope of the project, there are three variants of frequency detector block. Those are FFT-128 core, Goertzel algorithm and Resource sharing

***G. FFT- 128 core:***

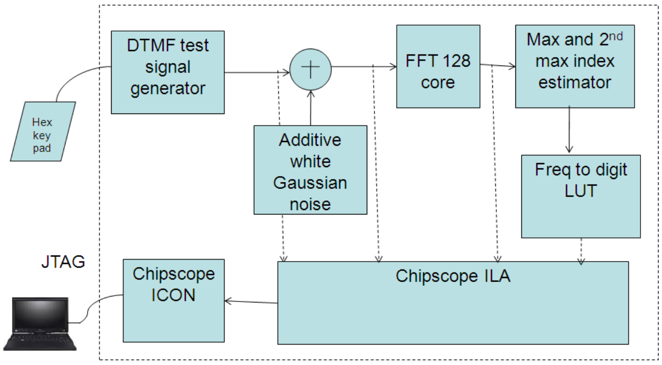
The Xilinx ISE LogicP Fast Fourier Transform (FFT) implements the Cooley-Tukey FFT algorithm, a computationally efficient method for calculating the Discrete Fourier Transform (DFT).

A Fast Fourier transform is an efficient algorithm to compute the discrete Fourier transform and it's inverse also. There are many distinct Fast Fourier Transform algorithms involving a wide range of mathematics, from simple complex-number arithmetic to group theory and also number theory.

A Discrete Fourier Transform decomposes a sequence of values into components of the different frequencies. This operation is very useful in many fields but computing it directly from the definition is often too slow to be practical. An FFT is a way to compute the same result more quickly: computing a DFT of $N$ points in the naive way, using definition, takes $O(N^2)$ arithmetical operations, while an Fast Fourier Transform can compute that, the same result in only $O(N \log N)$ operations. This improvement made many DFT-based algorithms practical; FFTs are of great importance to a wide variety of various applications, from digital signal processing and solving partial differential equations to algorithms for quick multiplication of large integers. The most well known FFT algorithms depends upon factorization of $N$, but there are FFTs with O ($N \log N$) complexity for all $N$, even for prime $N$. Many FFT algorithms only depend on the fact that $e^{-\frac{2\pi i}{N}}$ is an $N$ primitive root of unity, and thus can be applied to analogous transforms over any finite field, such as the number-theoretic transforms.

The Fast Fourier Transform (FFT) core computes an N-point forward DFT or inverse DFT. where N can be 2m, m = 3–16. For fixed-point inputs, the input data is a vector of N complex values represented as the dual $b_x$ -bit two's-complement numbers, that is, $b_x$ bits for each of the real and imaginary components of the data sample, where $b_x$ is in the range of 8 to 34 bits inclusive. Similarly, the phase factor $b_w$ can be 8 to 34 bits wide.

Three arithmetic options are available for computing the FFT is Full-precision unscasled arithmetic, Scaled fixed-point, where the user provides the scaling schedule, Block floating-point. The point size N, is the choice of forward or inverse transform, the scaling schedule and the cyclic prefix length are run-time configurable. Transform type (either forward or inverse), scaling schedule and cyclic prefix length can be changed on, a frame-by-frame basis. Changing the point size resets the core. Four architecture options are available: Pipelined, Streaming I/O, Radix-4, Burst I/O, Radix-2, Burst I/O, and Radix-2 Lite, Burst I/O.


DTMF test signal generator
Hex key pad
+
Additive white Gaussian noise
FFT 128 core
Max and 2nd max index estimator
Freq to digit LUT
JTAG
Chipscope ICON
Chipscope ILA

Block diagram with FFT 128 core as frequency detection module

**Fig. 4: Goertzel Algorithm Blocks as frequency detector**

### *H. Theory of Operation:*

The Fast Fourier Transform (FFT) is a computationally efficient algorithm for computing a Discrete Fourier Transform (DFT) of sample sizes that are, positive integer power of 2.

The DFT $X(k),\ k=0,\ldots,N-1$ of a sequence $x(n),\ n=0,\ldots,N-1$ is defined as

$$X(k)=\sum_{n=0}^{N-1}x(n)e^{-jnk2\pi/N}\quad k=0,\ldots,N-1$$

Where N is the transform size and. $j=\sqrt{-1}$ the IDFT is given by,

$$x(n)=\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{jnk2\pi/N}\quad n=0,\ldots,N-1$$

### *I. Algorithm:*

Coming to the Algorithm, The FFT core uses the Radix-4 and Radix-2 decompositions for , computing the DFT. For Burst I/O architectures, the decimation-in-time (DIT) method is used, while the decimation in frequency (DIF) method is used for the Pipelined, Streaming I/O architecture.

When using Radix-4 decomposition, the N-point FFT consists of log4 (N) stages, with each stage containing that, N/4 Radix-4 butterflies. Point sizes that are not a power of 4 needs an extra Radix-2 stage for, combining data. An N-point FFT using Radix-2 decomposition has log2 (N) stages with each stage containing N/2 Radix-2 butterflies.

### *J. Pipelined, Streaming I/O:*

The Pipelined, Streaming Input/Output solution pipelines several Radix-2 butterfly processing engines to offer, continuous data processing. Each processing engine has its own memory banks to store the input and intermediate data (Shown in Figure). The core has the ability to simultaneously performs the transform calculations on the current frame of data, load input data for the next frame of data and unload the results of the previous frame of the data. The user can continuously streams in data and after the calculation latency can continuously unloads the results. If preferred, this design can also calculate one frame by itself or frames with gaps in between.

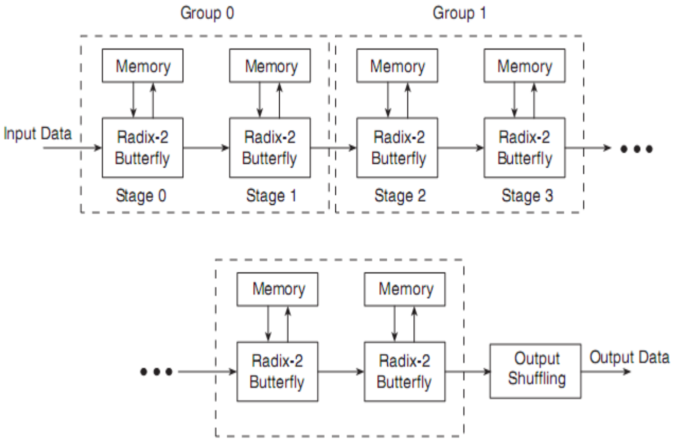
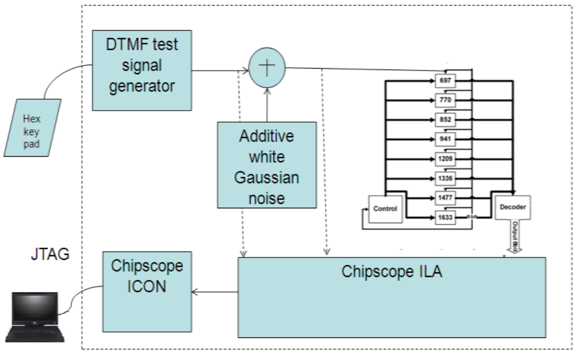


**Fig.5: Figure Pipelined, Streaming I/O**

## III. Goertzel Algorithm



Goertzel algorithm blocks as frequency detector

**Fig. 6: Goertzel Algorithm blocks as frequency detector**

The Goertzel algorithm is a DSP technique for identifying the frequency components of a signal, published by Dr. Gerald Goertzel in 1958. While the general Fast Fourier transform algorithm computes evenly across the bandwidth of the incoming signal, the Goertzel algorithm looks at the specific, predetermined frequencies. Some applications require only a few DFT frequencies. One example is the frequency shift keying demodulation, in which typically, two frequencies are used to transmit binary data; and another example is DTMF or touch-tone telephone dialing, in which a detection circuit must constantly monitor the line for two simultaneous frequencies indicating that, a telephone button is depressed. Goertzel algorithm reduces the number of real valued multiplications by almost a factor of that, two relative to direct computation via the Discrete Fourier Transform (DFT) equation. For a length of N, the Goertzel's series is:

$$H_k(z) = \frac{1 - W_N^k z^{-1}}{1 - 2\cos(\frac{2\pi k}{N})z^{-1} + z^{-2}}$$

Where,

$$k = 0,1,\ldots,\ N - 1$$

## IV. Simulation Results

***Hex Keypad Module:***

**Logic Symbol:**

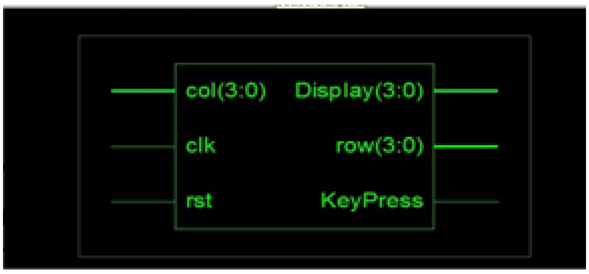


**Fig. 7: Goertzel Algorithm blocks as frequency detector**

**RTL Schematic:**

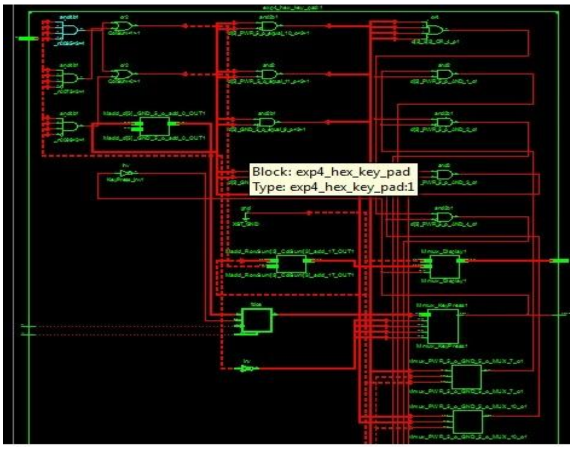
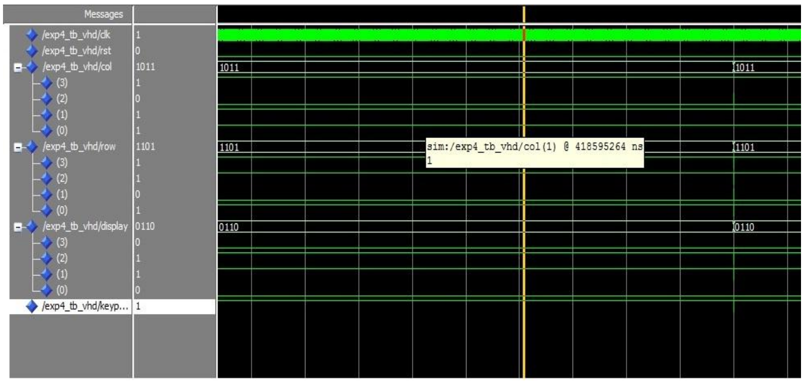


**Fig. 8: RTL Schematic**

**Simulation Waveform:**



```
Messages
/exp4_tb_vhd/clk       1
/exp4_tb_vhd/rst       0
/exp4_tb_vhd/col       1011
  (3)                  1
  (2)                  0
  (1)                  1
  (0)                  1
/exp4_tb_vhd/row       1101
  (3)                  1
  (2)                  1
  (1)                  0
  (0)                  1
/exp4_tb_vhd/display   0110
  (3)                  0
  (2)                  1
  (1)                  1
  (0)                  0
/exp4_tb_vhd/keyp...   1
```

**Fig. 9: Simulation Waveform for Hexkeypad**

***Frequency Word Selector:***

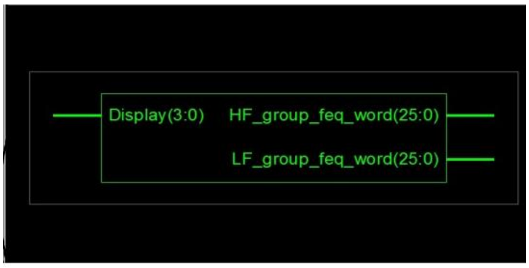


**Fig. 10: Frequency Wordf Selector Logic Symbol**

**RTL Schematic:**

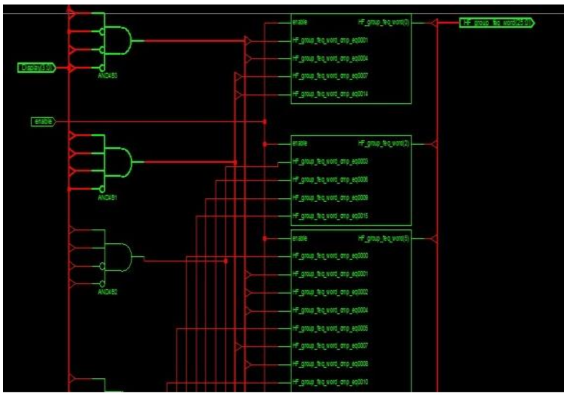


**Fig. 11: RTL Schematic for Frequency Word Selector**

**Simulation Waveform:**

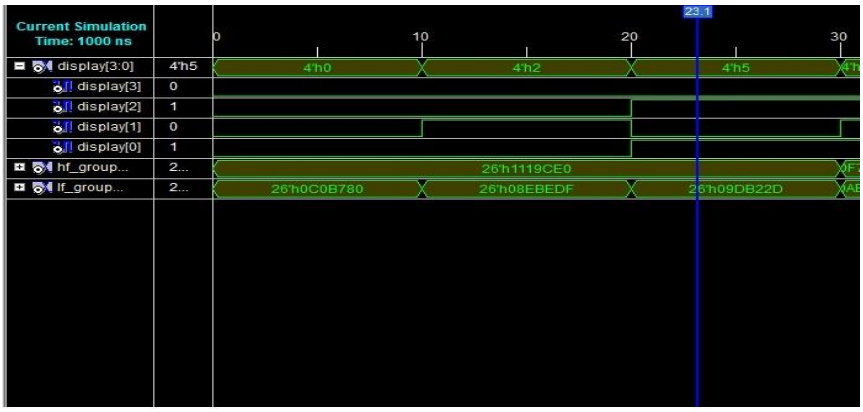


**Fig. 12: Simulation Waveform for Frequency Word Selector**

## V. Conclusion

Here we are implemented up to Hex Keypad and Frequency Word Selector and corresponding simulation results are shown. The Goertzel algorithm can detect the incoming frequency within a ±1.5% offset range. This algorithm does not check for overflow problems, nor is it a complete detection algorithm. To ensure complete detection, further evaluation of the detected tone in the form of many tests is required. These tests could include twist tests, dynamic tests, guard time tests, signal-to-noise ratio tests, and talk off tests.

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## VIII. Acknowledgments

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