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Goertzel DFT Estimation based Reduced Noise Decoding for DTMF Automation System

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Abstract

The need to automate industrial, residential, and commercial sectors has alleviated the need for Automation Systems, that are controlled by application-specific communication technologies. The communication protocols are considered for controlling loads situated remotely ranging from wired to wireless standards. Implementation of various wireless technologies such as ZigBee, GSM/GPRS, Bluetooth, Wi-Fi requires network establishment schemes, development of software, dedicated devices, etc. Hence, their deployment becomes protracted making the system costly. This paper illustrates the implementation of a more reliable Mobile Controlled Automated System based on the DTMF (Dual Tone Multiple Frequency) principles, which is highly efficient. The purpose of monitoring and controlling loads remotely by the user is accomplished by exploiting the existing PSTN infrastructure and mobile network. The connecting link which facilitates the exchange of commands for control action is highly susceptible to noise. Hence, efforts are taken to reduce the effect of noise by designing the system in two decoding modes. Goertzel DFT estimation mode eliminates the error in decoding and mitigates the noise in the system, whereas DTMF decoder IC MT8870D-1 mode is dedicated only for decoding. The comprehensive analysis studying both the modes is illustrated and results are presented.

Keywords: *Automation system, Communication standards, Protocols, Mobile, DTMF (Dual Tone Multiple Frequency), Goertzel DFT, Message decoding, Noise reduction*

1. Introduction

The advent of communication technologies and the introduction of the concept of network establishment have enabled the implementation of automation systems in an industrial and commercial environment, enabling devices can be controlled and managed from a remote location. This is achieved by implementing networks, along with the support of various wireless technologies viz. ZigBee, Bluetooth, and UWB etc. There has been a rapid expansion and

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potential development of automated systems since it facilitates the user to organize the appliances and devices at his convenience.

Such systems deal with establishing a network that links computers peripheral equipment, smart chip bearing appliances, and sub-systems. It promises to control electricity-operated devices cautiously in real-time, from a remote location. But again these implementations require either radio link communication or wired communication. Be it wired or radio link, each has its limitations such as complex wire deployment, maintenances, range restrictions, low data rate, high cost, software arrangements, etc.

Hence this paper introduces a system that provides identical operations of directing devices from a remote location but using the mobile-based DTMF principle. This mobile-controlled switching unit installed at a site is capable of controlling mains, powered loads, and devices with the aid of commands received via a telephone unit. Any (DTMF) telephone set or cell phone can be used to send commands to the switching unit. A wide range of applications in various fields such as household, Industrial, Offices, institutions, Telephone answering machines, Interactive voice response system applications (IVRS), etc is achievable. The major advantage of this system [1] is that it makes use of already established PSTN telephone infrastructure, and no additional investment is required.

Many systems have been proposed in this area such as low-cost GSM/GPRS-based wireless home security systems [2] [3]. The system is a wireless home network that contains a GSM/GPRS gateway and three kinds of wireless security sensor nodes that are door security nodes, infrared security nodes, and fire alarm nodes. But since it is based on GSM, the system falls short in a low network coverage situation. The paper proposing home automated systems based on Bluetooth technology enabling devices to be controlled is presented in paper [4]. But the limitation here is the short-range typically of 50 meters offered by Bluetooth technology. This neglects the purpose of remotely controlling the devices. Also, a system is implemented using ZigBee wireless personal area network [5] which facilitates intrusiveness of the respective system installation. Apart from this, ZigBee is also deployed in various automation scenarios such as Home automation, Industrial [6], [7], [8]. But the main constraint in ZigBee is the network span; which is eliminated in the case of the proposed DTMF-based automation system [1]. The wireless network mentioned in [9] implements a new high bandwidth home application using 802.11 technology. But again this system is very expensive reduces customer feasibility. All these papers suggest Automation systems have certain limitations since the nodes deployed can cause network congestion, the entire infrastructure has to be laid down from the initial stage which is time-consuming and is complex.

Our proposed system uses Mobile controlled DTMF-based technology which can be implemented in various applications such as in agricultural sectors, industrial locations, and domestic homes for controlling loads.

Mobile communication network coverage is bigger than that of Local Area Network (LANs), thus users can take benefit of portable phones to organize the system. The system presented is more relevant than the infrared remote controller since the range covered is more and it facilitates remote monitoring. Also, it surpasses any other wireless communication method, since it provides a solution that allows accessibility at a low cost and in a simpler way. The major advantages of this system are listed below:

- No distance (range) limitation
- Instant switching with minimum delay fewer hardware components
- Cost-effective and minimal call charges
- Less power consumption compared to other systems
- Already existing infrastructure of PSTN telephone net-work is exploited

- The switching unit is compatible with any kind of telephone sets
- Users can access and connect the desired number of loads.

The paper is organized as follows; the preliminaries of the DTMF working principle and Goertzel DFT estimation algorithm for reducing system noise are explained in Section 2. Section 3 describes the implemented system and highlights the advantages system. Section 4 provides the operational working of each unit with its circuit implementation and justifies the application of Goertzel DFT decoding. The reduced noise decoding of commands with the application of Goertzel DFT estimation is illustrated in Section 5. Section 6 summarizes the work and concludes the paper.

2. DTMF working principle and GOERTZEL DFT estimation

Dual-tone multi-frequency signaling (DTMF) [10] is used for telecommunication signaling over analog telephone lines, in the voice-frequency band. The frequencies used in the process of exchanging information are categorized into Low Band Frequencies and High Band Frequencies. The concept of DTMF that is used in push-button telephones for tone dialing is known as Touch-Tone. The DTMF system uses 8 different frequency signals transmitted in pairs and is represented as sine wave tones. They represent 16 unique numbers, symbols, and letters. In our system, each character (frequency pair signal) when pressed and transmitted over the network acts as a control command directing a load at the receiver end. A 12 key keypad, having a 3x4 matrix arrangement of keys is used. The keys for digits 0-9 symbols, * and # are arranged on the keypad in 4 rows and 3 columns rectangular matrix shown in Table 1.

Table 1. Frequency/key matrix for DTMF keypad

Frequency	1209 Hz	1336 Hz	1477 Hz	1633 Hz
697 Hz	1	2	3	A
770 Hz	4	5	6	B
852 Hz	7	8	9	C
941 Hz	*	0	#	D

When the key corresponding to a digit is pressed by the user to send commands for controlling a load, the tones equivalent to its row and column are generated. The technique of generating two separate tones that are not related harmonically to each other eliminates voices that accidentally get produced as a valid pair. In the system described here, these tones can be decoded using the DTMF decoder IC as well as by using the Goertzel DFT algorithm. [12] Using the Goertzel algorithm facilitates a reduction in noise interference with the signal. The noise gets eliminated since the analog signal is converted to a digital pulse. In Goertzel's estimation, digital tone detection can be achieved by measuring the energy present in the received signal. Each symbol can be separated by simply taking the component of maximum energy in the lower and upper-frequency groups shown in [Figure 1]. and can be converted back to analog signal form for further processing.

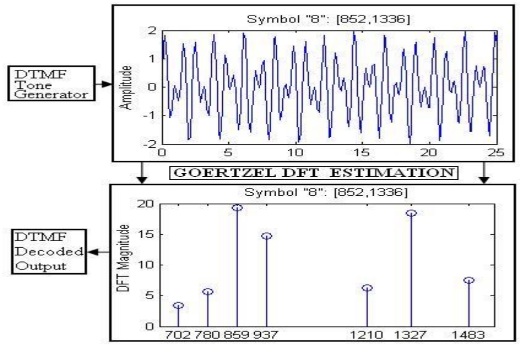

Figure 1. Goertzel DFT estimation for tone generated (Ex. 8-key)

3. System implementation

The implemented system consists of two main units namely; the User side (DTMF facilitated mobile phone) and the receiver side Application End Controller Unit (AECU) as shown in Figure 2 which is employed at the location where devices and loads need to be monitored and controlled. The AECU comprises six main circuit sections;

- Central Controller Unit (MCU)
- Relay Driver & Load Control Unit (RDCU)
- Ring Detector Unit (RDU)
- Automatic Line Pickup (LPU)
- Acknowledge Tone Unit(ATU)
- DTMF Decoder Unit (DDU)

One should notice that the system operates in two different modes for decoding received commands by the user; with the implementation of DTMF decoder MT8870D-1 and implementation of Goertzel DFT Algorithm.

Hence, two programmed IC's are used to analyze the system operation in the respective mode. The primary advantage of implementing the Goertzel DFT algorithm is that it eliminates the requirement of DTMF decoder IC. Only one mode is active at a time for decoding the commands received by the system. Out of the two supported modes, the software-based Goertzel DFT algorithm facilitates reduced noise decoding with precision.

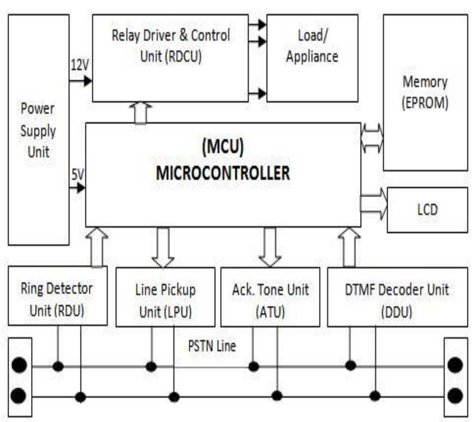

Figure 2. Block diagram of application end controller unit (AECU)

The AECU is connected in parallel with the PSTN telephone apparatus and does not interrupt the use of the telephone in any way. When the user dials the number using the cell phone from anywhere in the world, he can remotely turn on/off any of the 8 relays. The Aurdino board with ATmega328 microcontroller (MCU) on the interface senses telephone ring and an automatic telephone pick up gets enabled. It then provides the user with the available controlling options for the loads. The user can select the load and control the relay switching's accordingly.

The operation of the system is dependent on two modes stated above viz. the popular MT-8870 DTMF Decoder IC along with Aurdino MCU (for 1st mode of operation) and Goertzel algorithm implemented system (for 2nd mode of operation). The system is so programmed that after six rings the circuit lifts the receiver automatically sends an acknowledgment tone to the caller stating that a 6-digit password number needs to be entered. After entering a valid password, the system authenticates the user, and only then the user can enter the commands to control the loads. But if the password is entered incorrectly 4 times in a row, an error alarm sound is produced and the receiver gets disconnected. As a result, this function avoids any attempts by hackers to enter a large number of codes in succession and crack the password by brute force attack. The main component which governs the entire operation of the system is the Aurdino board which has the following duties:

- To count the pre-programmed number of ringing signals
- To enable the high-value resistance after counting the pulses
- To accept the decoded tones send by the tone decoder in 1st mode
- To accept the decoded tones generated using the Goertzel algorithm in 2nd mode
- To operate the corresponding relays according to the signal commands.

4. Hardware implementation and analysis

The entire system is deployed based on the idea of existing PSTN telephone infrastructure and therefore facilitates remote automation of loads enabling the user to switch them ON/OFF as per the requirement. The DTMF-enabled mobile and PSTN telephone act as a communication medium between the user and the system. When the system is initialized, the AECU side display is as shown in Figure 3. which indicates that the system is waiting for the user's input in the form of a call (ring). Figure 4 captures the signal when the user calls the system. The measured values are about +35V/-35V analog in nature.

Figure 3. System initialized

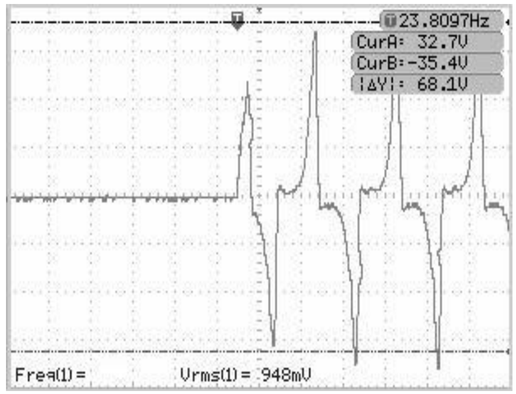

Figure 4. Ring captured (user calling the system)

4.1. Ring detector unit (RDU)

When the user calls the system, a signal is transmitted to the circuit via a bridge rectifier. The operation of the ring detector circuit (RDU) shown in [Figure 5] is to detect the occurrence of any incoming ring and to pick up the call automatically, thereby allowing an acknowledgment to be sent to the user so that further commands can be received.

4.1.1. Ring detector circuit

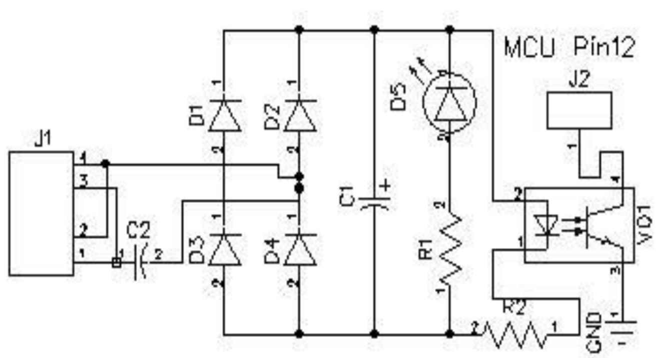

Figure 5. Ring detector circuit

MCT2E Optocoupler (VO1) is used since due to the bridge rectifier the polarity of the signal can be made relevant for a longer period. The ring signal is an AC voltage, which passes through capacitor C2 to the bridge rectifier. Since this voltage is as high as 60 volts, an optocoupler is used before the input of the central micro-controller. C1 ensures that only the ring signal, and not the DC offsets reach the optocoupler, thereby providing isolation. This protects the system from damage.

The system counts the number of rings and decrements the counter by one after each ring (ring=ring-1). For automatic picking up the call, the system waits for 6 rings and then justifies its core purpose of automatic pick up of the incoming call seen in Figure 6.

Figure 6. Automatic line pick up

After the call is connected and the system is activated, the security norms programmed in it ensure that only legitimate users gain access to the system. The system is hence designed with a security password in the initial step itself thereby securing and authenticating valid user access. More sophisticated security techniques can be implemented, but for user feasibility and ease of access, password authentication is deployed.

4.2. DTMF decoder unit (DDU)

1) DTMF Decoding mode1: When DTMF decoder IC-MT8870D-1 is implemented instead of the Goertzel algorithm, the system is said to be operated in mode1. In this mode, the commands entered by the user to control the loads are decoded by DDU decoder IC. The system is implemented with the MT8870D-1 [10] which is a comprehensive DTMF receiver. It uses a digital counting technique to detect and decode all 16 DTMF tone-pairs into a 4-bit code. The frequency decoder accepts the user command and decodes the input data stream, which is further processed by the Aurdino MCU. The circuit for DTMF Decoder Unit (DDU) is illustrated as shown in Figure 7.

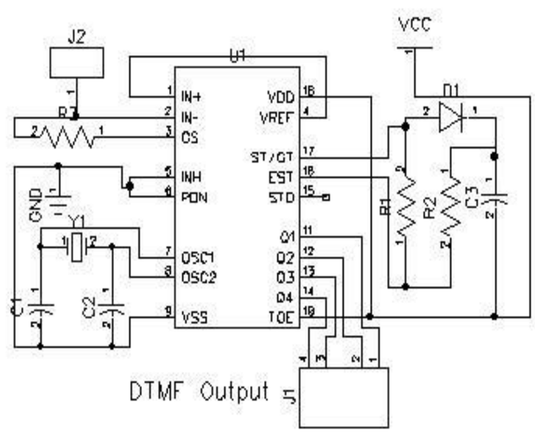

Figure 7. DTMF decoder interface

2) DTMF Decoding mode2: When the AECU is operated by bypassing the DTMF decoder IC with the implementation of the Goertzel DFT algorithm, the system is said to be operated in mode2. The implementation of Goertzel DFT estimation is shown in [11].

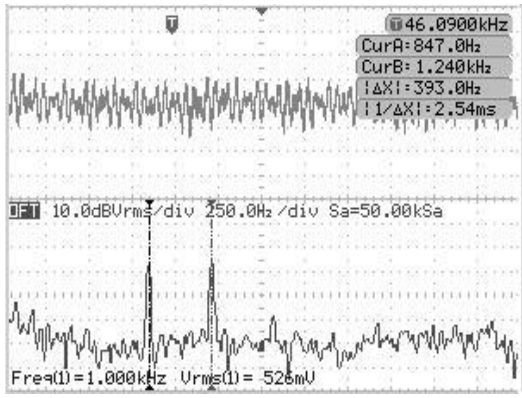

Figure 8. DTMF signal for key-7 and its corresponding Goertzel DFT decoded

In this mode, the commands entered by the user to control the loads are decoded by central micro-controller MCU as per the Goertzel DFT signal received. The component of the maximum energy in the lower and upper-frequency groups is considered the desired outcome.

The power associated with the corresponding frequency pairs is taken to be the generated frequency. An example of the DTMF command signal sent over the network and its Goertzel DFT equivalent signal detected at the receiver side is depicted in Figure 8.

The working principle behind the Goertzel algorithm is the fact that it identifies the maximum power associated with frequencies. Since DTMF signals are a combination of two frequencies viz. Low band (697 Hz, 770 Hz, 852 Hz, 941 Hz) and High band (1209 Hz, 1336 Hz, 1477 Hz), applying Goertzel DFT algorithm produces power spectrum plot relative to the key pressed and frequency produced. A spike exactly corresponding to the frequency transmitted is observed in the power plot output, after the signal is subjected to Goertzel DFT estimation. The algorithm snippet for decoding the DTMF signals viz. commands and thereby identifying power spikes is given below:

Decoding DTMF signal via Goertzel DFT Algorithm
Initialization;

```
Originalfrequency = [697; 770; 852; 941; 1209; 1336; 1477];
L = round(Originalfrequency/8000*205);

estimatedf = round(L*8000/205); array = [CommandReceived]; digitIndex = find(array);

for

k = 1:length(digitIndex)-1
if

digitIndex(k) = digitIndex(k+1) - 1 &&
```

```
digitIndex(k-2) = digitIndex(k+1) - 4

k == length(digitIndex) - 1 TONE = abs(goertzel(tone,L+1)); vert = TONE(1:4) 50;
horz = TONE(5:7)   50;

PhoneNum = cat(2,phoneNum,buttonArray(vert,horz));
end if

end for
```

The reception and decoding of commands in noise prone environment and algorithm implemented scenario is illustrated in Figure 9. In our system, the list of valid commands decoded by both the modes (Mode-1 and Mode-2) are listed in Table 2.

Table 2. The key combination used for controlling loads

Key	Task Executed
(1-8)	Operates one of the four relays 1 to 8
#(1-8)#	Releases one of the four relays 1 to 8
123	Read EPROM
456	Change Password
789	Read Relay Status
*0#	Line disconnected

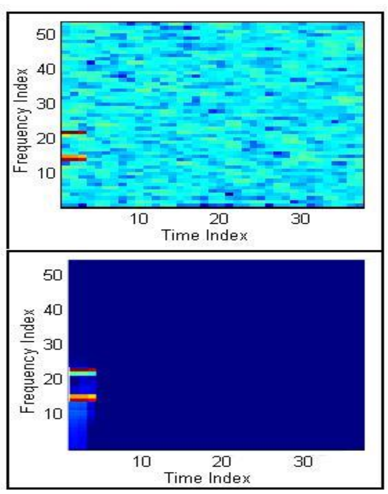

Figure 9. Comparison of noise v/s noise-free transmission of DTMF signal

4.3. Acknowledgment tone unit (ATU)

After the successful execution of managing the loads, the user receives an acknowledgment. An Acknowledgment Tone Unit (ATU) shown in Figure 10 is designed and implemented to intimate the user about the successful execution of the operation. More devices can be managed further on by sending desired commands. When the execution is completed the system auto hangs up the line to terminate the process.

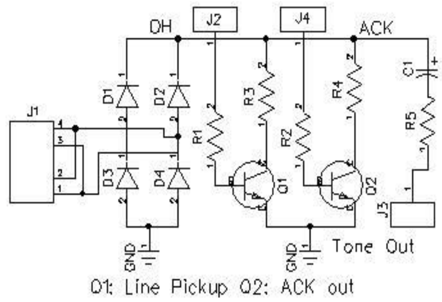

Figure 10. Auto pickup/hangup line acknowledgment circuit

When the Q1 transistor is driven by the Aurdino MCU, it is switched on and off at a frequency of 325 Hz and adds an extra alternating current of 2mA. This causes the user to hear a tone. This tone is used to acknowledge the user when the commands have been completed or if there are any command errors. It also facilitates auto line pick up since signal output to the PSTN telephone line is via two transistors viz. Q1 and Q2. The system is so designed that Q1 produces a line current of approximately 20mA, which corresponds to lifting the receiver.

4.4. Relay driver and control unit (RDCU)

The Relay Driver and Control Unit (RDCU) contains eight identical switched relay positions to handle the loads, power input, and data positions to drive the relays via a 10 pin SIP connector. Figure 11 depicts the single relay unit of RDCU for controlling one load. The BC547 NPN transistor Q1 acts as a relay driver. The diodes in the circuit protect the transistors from the back-emf which occurs when the relay is turned off and its magnetic field collapses.

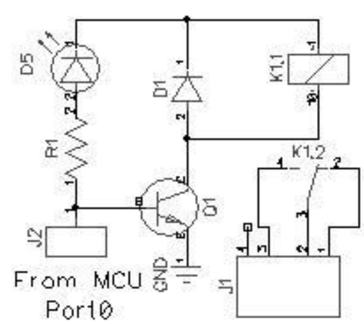

Figure 11. Relay circuitry for controlling loads

For simplification, the entire operation executed by the system can be summarized step-by-step in the above flowchart [Figure 12]. It can be recapitulated as follow:

- User initializes the system by calling on the PSTN telephone number from his mobile
- For authentication purposes system demands user pass-word
- For incorrect password line gets disconnected
- Hence, the only legitimate user can proceed further after auto line pick up
- The user can then enter the appropriate command to perform the switching operation
- After successful completion of the operation, the line gets disconnected

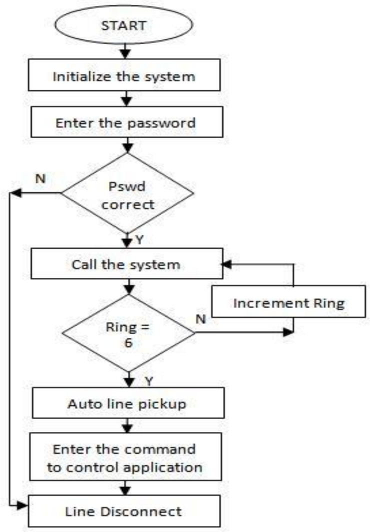

Figure 12. Flowchart for the system operation

The switching ON of the load when the user enters the command from his mobile is demonstrated in Figure 13.

Figure 13. Load switched ON via user command

5. Result analysis - GOERTZEL DFT estimated decoding

The model for remotely monitoring and controlling loads is implemented. The mobile and PSTN telephone network fabricate the backbone of the communication link in the system. Since the real-time exchange of commands & acknowledgment is crucial for the precise functioning of the system, the transmission should be error-free. Moreover, the probability of noise corrupting the data transmitted over the link should be minimum. Hence, efforts are taken to mitigate the effect of noise and decode the commands sent by the user efficiently. The application of Goertzel DFT estimation for decoding DTMF signals proves its supremacy over DTMF decoder IC. Since DTMF signals are a combination of two frequencies viz. Low band and High band, after applying Goertzel DFT on these DTMF signals, the power spectrum plot indicates two spikes each corresponding to each frequency band. Hence, converting the signals from the time domain to the frequency domain reduces the effect of noise. Working on these lines, the decoding of commands given in Table II is illustrated below.

5.1. 789 - Read relay status

When the user presses the keys 789 to read the relay status of the load controlling side AECU system, 4 frequencies are generated viz. low band frequency 852 Hz and high band frequencies 1209 Hz, 1336 Hz, and 1477 Hz. When the signal is subjected to the programmed Goertzel algorithm, the energy contained in the signal produces spikes indicating the corresponding frequencies. Hence, Figure 14 illustrates spikes near frequencies that the user generates.

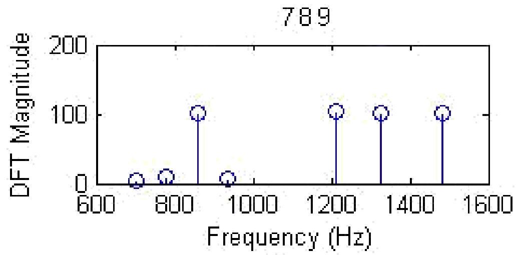

Figure 14. Goertzel DFT Estimation for reading relay status

5.2. *(1-8)* - Operates one of the four relays

When the user presses the keys *(1-8)* (ex.*1*) to operate the relays 3 frequencies are generated viz. low band frequencies 941 Hz, 697 Hz, and high band frequency 1209 Hz. Hence, Figure 15 illustrates spikes near frequencies that the user generates.

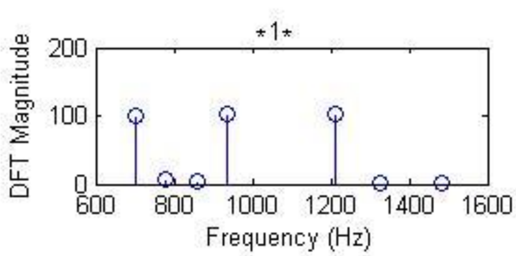

Figure 15. Goertzel DFT estimation for operating relays

5.3. *0# - Line Disconnected

When the user presses the keys *0# to disconnect the line after successful execution of the operation of commands 4 frequencies are generated viz. low band frequency 941 Hz and high band frequencies 1209 Hz, 1336 Hz, and 1477 Hz. When the signal is subjected to the programmed Goertzel algorithm, the energy contained in the signal produces spikes indicating the corresponding frequencies. Hence, Figure 16 illustrates spikes near frequencies that the user generates.

A. Advantage of implementing Goertzel DFT

The advantages of using Goertzel DFT Estimation for decoding DTMF signals are listed below. The major advantage of using Goertzel DFT estimation is that the need for additional hardware like encoder and decoder chips (like MT8870 and TP5089) or crystals is eliminated since the software is implemented. The noise affecting the system is eliminated as seen in Figure 9 since Goertzel's estimation is in the form of digital pulses that suppress unwanted signals. FFT is used for longer sequences, but since DTMF comprises only 8 frequencies, Goertzel is used. As in the case of DTMF where only 8 frequencies need to be detected, the computational capability is more competent and the time required is less by the Goertzel algorithm, than the FFT when an N-point DFT is less than 2 log2 N DFT coefficients.

To detect the strongest energy pulse as seen in Figure 1, the first harmonics of the 8 possible frequencies need to be detected, which is done by this algorithm efficiently.

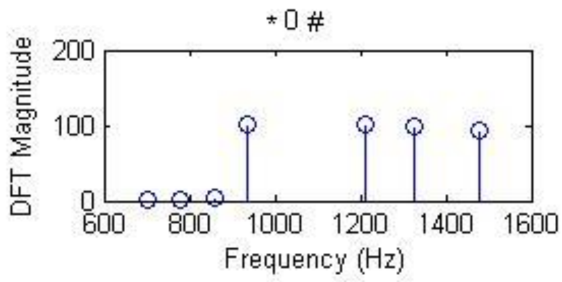

Figure 16. Goertzel DFT estimation for disconnecting the line

6. Conclusion

The system implemented exploits the public switched telephone network (PSTN) exclusively, which comprehends distant controlling of devices using a DTMF tone-based system. It supports full-duplex communication between the user and the Application End Controller without disrupting regular communication on the PSTN Line. It is achievable to do so since the system is designed and linked to the line using the parallel connection. Also, the accepted range for exchanging the signals is not limited since it utilizes the already deployed widespread PSTN infrastructure.

Overall this paper presents a secured technique to manage loads/devices using the DTMF principle which is cost-effective over other wireless technologies. This method has been realized using a 2G mobile communication network and since there is no need to deploy an entirely new base, but exploit the fundamental telephone network, the system becomes highly competent. Two modes of the system operation viz mode1: with DTMF decoder IC and mode2: with Goertzel DFT algorithm, for decoding the received encoded signals are described. It is then demonstrated that by implementing the Goertzel DFT algorithm, the noise affecting DTMF signals has been suppressed efficiently. All these factors make this technology a better option for sending control signals and receiving updates from a remote location.

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