Sevastopol National Technical University

TI university program
technology for tomorrow's innovators

Texas Instruments

PROJECT TITLE: **Universal Kitchen Alarm System**

TEAM LEADER: Olexandr Slobodenuk; alexandrslobodeniuk@gmail.com

TEAM MEMBERS: Artyom Lysenko; lysenko.av@ukr.net
Eugene Novosyolov; eugnov@mail.ru
Alexander Grusha; alexander_grusha@bk.ru
Sergey Syomin; SyominSZ@yandex.ru

ADVISING PROFESSOR: Prof. Valeriy Vertegel; vertegel@bk.ru

UNIVERSITY: Sevastopol National Technical University, UKRAINE

DATE: 31/07/2013

TI's PARTS USED IN PROJECT:

Quantity	TI Part Number	Reference
2	OPA1642	http://www.ti.com/product/opa1642
1	OPA1641	http://www.ti.com/product/opa1641
1	TLV3491	http://www.ti.com/product/tlv3491
1	INA217	http://www.ti.com/product/ina217
1	PGA112	http://www.ti.com/product/pga112
1	PCM1802	http://www.ti.com/product/pcm1802
1	TPS7250	http://www.ti.com/product/tps7250
1	TPS7233	http://www.ti.com/product/tps7233
1	TPS63700	http://www.ti.com/product/tps63700
2	MSP430G2553	http://www.ti.com/product/msp430g2553
1	TPA2038d1	http://www.ti.com/product/tpa2038d1
1	TPS81256	http://www.ti.com/product/tps81256

ABSTRACT

The Universal Kitchen Alarm System (UKAS), which can be used as a component of the "Smart House" technology, is presented. A distinctive feature of a designed system in comparison with the traditional alarm systems is that it allows recognizing the sounds that produce kitchen appliances at the moments of stopping or shutdown of their operation (beeping and other sounds) and informing the consumer in other room about the occurred event. The system consists of two blocks. The first block (Acquisition and signal analysis) is located in the kitchen. The second block (Alarm) is placed to the room (for example, in the cabinet) near the user. Both blocks communicate with each other wirelessly. The usage of such system makes it possible to reduce the energy consumption, and to eliminate the re-start operation and a possible damage of kitchen appliances caused by their retarded shutdown.

INTRODUCTION

The "Smart House" is a very exquisite, advanced technology. The smart house usually consists of many devices combined into a system. The different types of the "Smart House" vary from simple systems such as lighting control automatic systems or security systems to mind blowing technologies. The newest "Smart House" appears "intelligent" because its computer can monitor many aspects of daily life. For example, when we are keen on working with computer in the cabinet or when we are busy with domestic work, we sometimes forget a kettle on an electric or gas stove. Many know what that leads to! It would be nice to have someone (or something) who like mommy say gently, "Darling, kettle has boiled, go drink tea!" Such function we propose to implement in new "Smart House" systems. We have not found in the Internet the existing "Smart House" systems which support the sound signal recognition of the kitchen appliances. We decided to implement this idea in the Universal Kitchen Alarm System, which (in addition to the traditional smoke detector, gas leak detector, and fire alarm) recognizes the sounds that emit kitchen appliances at the moments of their stopping or shutdown, and informs the user in another room about occurred events. The main reason for designing such universal alarm system is that nowadays the role of the "Smart House" technology is increasing. It also may have other various home and industry applications.

MOTIVATION FOR PROJECT

We are students of the Department of Radio-engineering and Telecommunications of the Sevastopol National Technical University. We are specialized in telecommunications and analog IC design. Our diploma projects are related to the analog signal processing, DSP, and wireless data transfer systems. Combination of our knowledge and interests in analog electronics, RF system design and DSP let us to create the devices that can be used in "Smart House" systems. Participation in TI's Analog Design Contest give us the opportunity to realize designed devises using TI's high-performance analog Integrated Circuits (ICs), evaluation modules, and software tools. This contest allows us to gain the experience in the analog devices design, digital signal processing and RF system design.

THEORETICAL BACKGROUND

Analysis of recognizable signals

The sounds recognition of the stopping or shutdown of kitchen appliances operation is one of the most important features of our system. Before designing the system architecture and choosing its block parameters, it was necessary to make analysis of sound signals characteristics which must be recognized.

The main characteristic of a signal in frequency domain is power spectral density. In engineering, the Welch's method is commonly used for estimating the power of signals at different frequencies. This method is based on the concept of using periodogram spectrum estimates, which are the result of converting a signal from the time domain to the frequency domain. In practice, the periodogram is often computed from a finite-length digital sequence using the Fast Fourier Transform (FFT) according to the formula:

$$\tilde{P}_m = \frac{1}{F_s N U} \left| \sum_{n=0}^{N-1} X_n w_n \exp(-j \frac{2\pi}{N} nm) \right|^2 ;$$

$$U = \frac{1}{N} \sum_{n=0}^{N-1} w_n^2 ;$$

where F_s is the sampling frequency; X_n is the sequence of signal samples; N is the length of the samples segment; w_n is the windowed function; $n = 0, 1 \ldots, N - 1$.

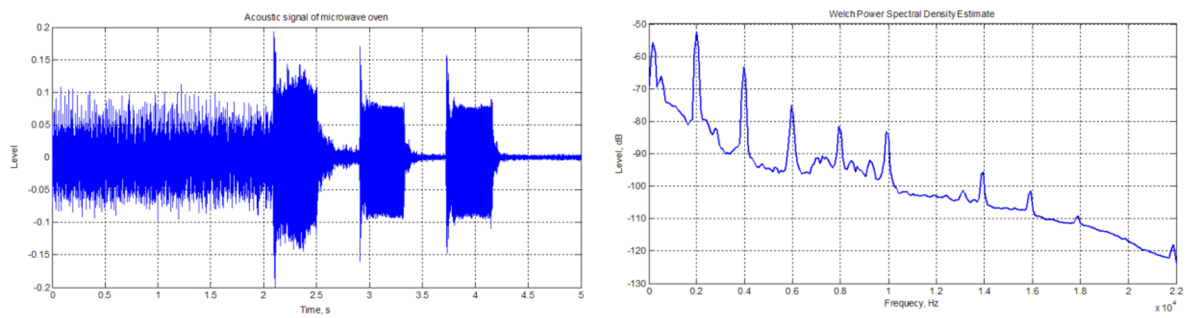
In Welch's method the signal is split up into overlapping segments. It reduces noise in the power spectral density in exchange for reducing the frequency resolution.

Using Welch's method, the signals that are produced at the moment of stopping or shutdown of their operation by following appliances were investigated:

- microwave oven DAEWOO KQG6C5R with beeper;
- dishwasher DELFA DDW-3201 with beeper;
- microwave oven LG MB3724-HL with jingle;
- kettle VINZER Shiny 69000 with steam whistle;
- electric kettle BRAUN WK 600 (without beeper).

The sound signals were recorded using external microphone connected to the microphone input of a laptop. To record the signals and calculate their power spectral density MATLAB was used. Standard 44,1 kHz sampling frequency and 16-bit ADC resolution were chosen.

As an example, Fig. 1 illustrates a waveform (a) and a power spectral density diagram (b) of the microwave oven DAEWOO KQG6C5R beep.



(a) (b)

Fig. 1: Waveform (a) and power spectral density diagram (b) of "beep" signal.

The beep of the DAEWOO KQG6C5R is represented by 3 pulses with 0,9 s period and tone frequency about 2 kHz (fig 1, a). The first harmonic which prevails in its spectrum has frequency about 2 kHz (fig 1, b). It exceeds the second harmonic by 12 dB and the third harmonic by more than 20 dB. Since low-frequency components of an electric motor acoustic noise are present in spectrum, it is advisable to select bandwidth from 1,8 kHz to 6,5 kHz for signal recognition.

We investigated characteristics of "beep" signals of other kitchen appliances. As a result of their analysis, it was determined that the beep of dishwasher DELFA DDW-3201 represents 9 pulses with 0,9 s period and tone frequency about 4 kHz. The first harmonic which prevails in its spectrum has frequency about 4 kHz and exceeds the second and third harmonics by more than 45 dB.

Sound signal of the microwave oven LG MB3724-HL shutdown represents the sound caused by mechanical vibrations of the jingle which damped over time. The shutdown sound of this microwave oven has maximums spectral density at 2885 Hz and 6847 Hz.

The analysis of the sound signal (whistling) characteristics of the VINZER Shiny kettle 69000, which has an actual whistle on a cover at the end of the spout, shows that it has a maximum power spectral density at 2900 Hz.

A special interest aroused the problem of recognizing the shutdown sound of an electric kettle. Most manufacturers of appliances do not provide such kettles with a special beep sound indicating their shutdown. Therefore, for determination of the kettle shutdown time, it was decided to use the acoustic signal (click) generated by the thermoswitch at the shutdown moment. The analysis shows that click's spectral density has several maximums in the frequency band from 500 Hz to 8 kHz.

The analysis of sound signals which should be recognized showed that the levels of these signals depend on the characteristics and position of the microphone, the type of kitchen appliance and have a dynamic range about 40 dB. In order to recognize the signals with different levels, the system should have Programmable-Gain Amplifier (PGA). To reduce the noise at the low and high frequencies the active bandpass filter with a bandwidth from 500 Hz to 8 kHz should be used. This frequency band is determined by the frequency range of information components of electric kettle thermoswitch sound. This band also covers informational components of all recognizable signal spectrums. Since the maximum frequency F_{max} of the sound signal spectrum content at the ADC's input is determined by the top cutoff frequency $F_{max} = F_{ct} = 8$ kHz of bandpass filter in accordance with the Nyquist sampling theorem the ADC's sampling frequency F_s is chosen by: $F_s \geq 2F_{max} = 16$ kHz. It is advisable to choose the standard sampling frequency $F_s = 44,1$ kHz or 96 kHz, since its enlarged value allows reducing the order of the filter and hence its complexity.

Method choice of signals recognition

Commonly used for speech/speaker recognition Dynamic Time Warping and Hidden Markov Models techniques cannot be used for non-speech sound recognition, because kitchen appliance sounds lack the phonetic structure that speech does. Therefore, for non-speech signals recognition the value of amplitude and frequency of harmonics are essential parameters.

For the recognition of non-stationary sounds in the frequency domain previously mentioned Welch's method and Short Time Fourier Transform (STFM) can be used. Discrete Wavelet Transform can be viewed as the projection of the signal into a set of basis functions named wavelets. Such basis functions offer localization in the frequency domain. Compare to STFT which has equally spaced time-frequency localization, Wavelet Transform provides high frequency resolution at low frequencies and high time resolution at high frequencies.

In order to recognize the sound it is necessary to have different sound templates and to evaluate the value of essential parameters of each template by comparing the values of their parameters with the values of recognizable signal.

Two approaches are commonly used for signals recognition. In the first a Correlation Function is a similarity metric of the essential parameters of the signal and a template. Calculation of the Correlation Function is possible in both the frequency and the time domains. For this approach the maximum of the correlation function is a criterion for selecting the template which should be identified as signal.

The second approach does not use the auxiliary functions, but simulates the process of recognition in biological systems. This approach uses the technology of the so-called neural networks. However, this method requires large computational resources.

Since some sounds produced by kitchen appliances (beep) are quasiharmonic with different frequencies, the Goertzel algorithm may be used for their recognition in the frequency domain. The Goertzel algorithm is a DSP technique that provides a means for efficient evaluation of individual terms of the Discrete Fourier Transform (DFT). For computing a small number of selected frequency components, it is more numerically efficient. The simple structure of the Goertzel algorithm makes it well suited to small processors and embedded applications.

IMPLEMENTATION

System Architecture

The Block diagram of the Universal Kitchen Alarm System (UKAS) is depicted in Fig. 2.

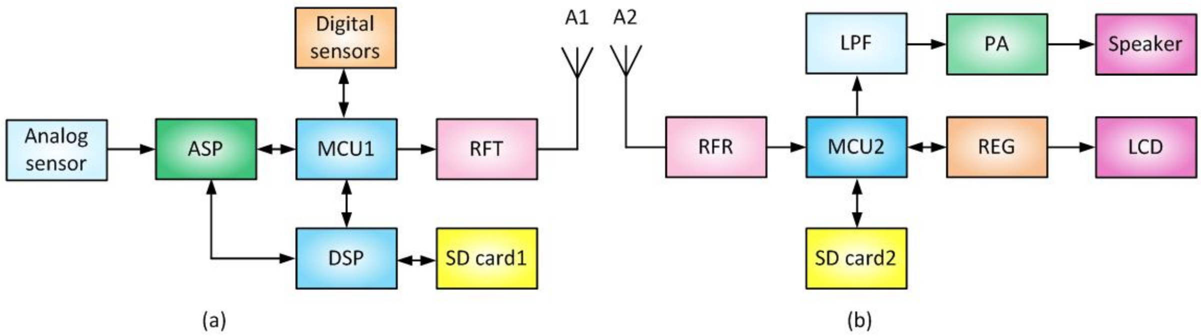


Fig. 2: Block diagram of the Universal Kitchen Alarm System: Acquisition and signal analysis (a); Alarm block (b).

The system consists of two blocks: the block of Acquisition and Signals Analysis (ASA) (fig. 2a), which is located in the kitchen and Alarm block (fig. 2b), that is placed in a room close to user. Both blocks communicate with each other wirelessly.

The digital sensors form the digital signals that are applied to the ports of a Microcontroller Unit 1 (MCU1). The using of standard digital sensors (smoke detector, gas leak detector, humidity and temperature sensor etc.) with serial I2C interface is provided in the system.

An analog signal formed by the Analog sensor (microphone) which is applied to the Analog Signal Processing block (ASP), which performs a primary signal processing: filtering, amplification, and analog-to-digital conversion of an audio signal into a sequence of digital samples. The samples are obtained by the Digital Signal Processing device (DSP). The DSP is intended for software implementation of the Goertzel recognition algorithm. The implementation of the correlation method of the signal recognition is also provided by the system. For this purpose, a SD card1 for storing preliminary recorded templates of recognizable signals is used. After definition recognizable signal, DSP sends the binary code of the kitchen appliance, that emits beep or shutdown signal to the MCU1. This code is applied to a RF transmitter (RFT). It performs the generation of the carrier, its frequency manipulation by binary code, power amplification of RF signal, and radiation by antenna A1.

Received by the Alarm block's antenna A2 the RF signal is applied to the input of RF receiver (RFR). It amplifies and filters the received RF signal, demodulates the code of the appliance and sends it to the Microcontroller Unit 2 (MCU2). MCU2 sends a text message about occurred event to the LCD by the serial interface using a shift register (REG). MCU2 also forms a voice message using software-based Pulse Width Modulator (PWM). LPF forms the voice signal from PWM signal which then enters to a power amplifier (PA). PA amplifies the power of voice message. The voice message is emitted by Speaker.

The ability to record user's recognizable signals is provided by the system. For this purpose it is necessary to record on SD card1 additional templates in the record mode of system operation, increasing the database of recognizable sounds. The recording of additional voice messages is also provided by the system.

Analog Signal Processing device

The Block diagram of the Analog Signal Processing device (ASP) is depicted in Fig. 3.

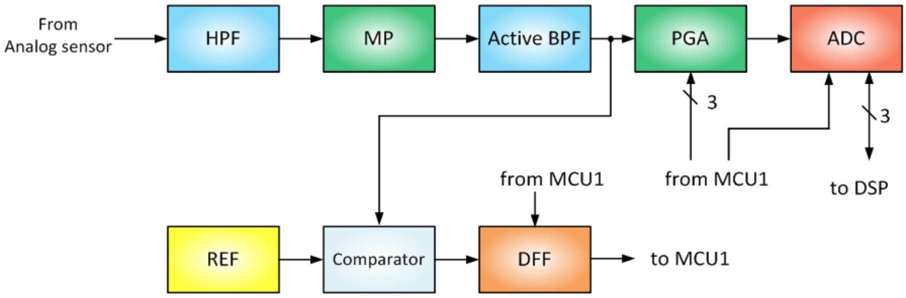


Fig. 3: Block diagram of Analog Signal Processing device (ASP).

In our system the omnidirectional electret microphone HMO0603B is used as an analog sensor. It has –65 dB sensitivity, 58 dB SNR, and low impedance. Its output signal is applied to a RC High-Pass Filter (HPF) that has 500 Hz cutoff frequency and 20 dB/dec attenuation. It is intended for attenuation of low-frequency noise (knocking of kitchen furniture and crockery, human speech, engine noise of appliances, hum etc.) at the input of the Microphone Preamplifier (MP).

The Microphone Preamplifier, which is implemented on the TI's IC INA217, performs main gain. The INA217 is ideal for low-level audio signal sources such as low-impedance microphones. The INA217 features differential input, low noise, and low distortion that provide superior performance in our application.

An active Band-Pas Filter (BPF) is implemented by the series connection of active HPF and active LPF. Active HPF intended for additional attenuation of low frequency noise in the band of (0 ... 500) Hz. Together with passive RC HPF it shall attenuate the low frequency noise by at least of 60 dB per decade. The inclusion of the active HPF after the MPF allows reducing of MPF's noise and thermal noise of input stage. Active LPF is used for attenuation of high frequency noise and aliasing.

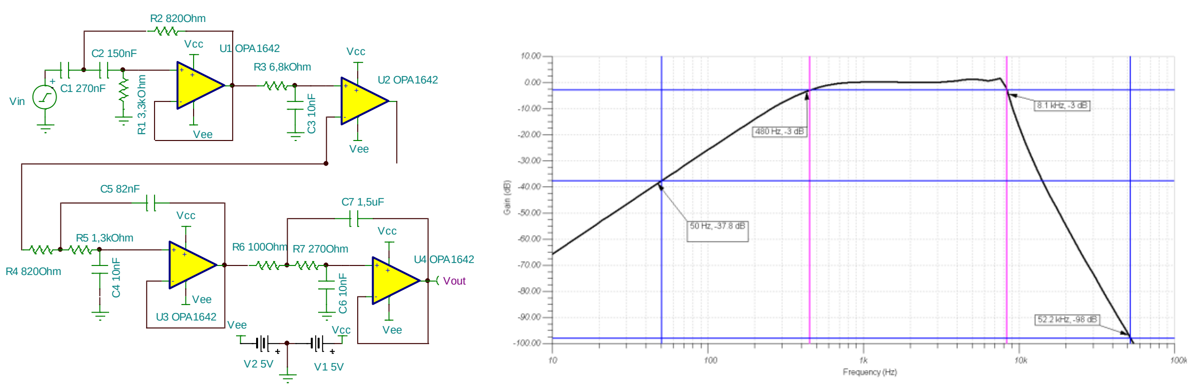
At the frequency $F_s – F_{max}$ the LPF has to ensure the attenuation of input signal level which should be less than the quantization noise of ADC. The Signal to Noise Ratio of quantization (SNR) for an N-bit ADC in the case of a harmonic input signal is given by: SNR = 6,02 N+1,76 (dB). For 16-bit ADC SNR = 6,02·16+1,76 = 98 (dB). Thus, the LPF should provide the attenuation at least of 98 dB at the frequency $F_s – F_{max}$.

The Chebyshev type filters are used in BPF, which have a steep slope of amplitude-frequency response in the transition bands. The oscillations of frequency response in the passband do not affect on the accuracy of signal recognition.

The Active BPF filter design was performed by the FilterPro v3.1 software from Texas Instruments. It was determined that the above mentioned requirements for frequency selection can be achieved by cascaded 2nd order HPF and 5th order LPF. The Sallen-Key topology of active BPF filter was chosen. To implement the active BPF the TI's IC OPA1642 was selected. The OPA1642 is ultralow distortion, low-noise operational amplifiers fully specified for audio applications. It benefits from a unity-gain stability and excellent dynamic behavior.

The simulation of the active BPF filter has been performed in TINA-TI 9 simulator from Texas Instruments. The schematic and the amplitude frequency response of active BPF filter are depicted in Fig. 4,a and Fig. 4,b respectively.

Fig. 4,b shows that the designed filter satisfies the previously specified requirements of frequency selection.



a) *b)*

Fig. 4: The schematic (a) and amplitude frequency response (b) of active BPF filter.

The comparator is intended to form an external interrupt signal for MCU1 when input signal exceeds certain threshold. This provides a sleep mode of ASP block for reducing the power consumption. Comparator is implemented on the TI's IC TLV3491 which features a high speed and low supply current. The D-Flip-Flop (DFF) is implemented on the IC 74HC74 and used for comparator's output signal storage. It stores a logical 1 until the reset signal from MCU1 applies.

In order to recognize the signal with different levels the Programmable Gain Amplifier (PGA) (TI's IC PGA112) is included in the ASP block. This amplifier together with MCU1 forms the Automatic Gain Control (AGC) that provides a constant average level of the signal at the input of ADC. The MCU1 controls the PGA gain and communicates by I2C interface with the DSP, which determines the average signal level.

The ADC is implemented on the TI's IC PCM1802. The PCM1802 is a high-performance, single-chip, stereo, 24-bit Delta-Sigma ADC with single-ended analog voltage input. It benefits from a low cost and supporting of sampling rate from 16 kHz to 96 kHz. For following signal processing only 16 high bits of digital signal are used in DSP. In order to increase the suppression of undesirable frequency components of recognizable signals outside of the first Nyquist zone the sampling frequency was chosen by Fs = 96 kHz.

Other devices of the Acquisition and Signals Analysis block are implemented on the IC's from Texas Instruments. As the microcontroller the MSP430G2553 was selected, ideally suitable for our application. It benefits from the ultra-low power consumption, built-in 16-bit timers, and built-in I2C and SPI interfaces. The RF transmitter is implemented on the base of CC110L RF transceiver. The main operating parameters of CC110L are controlled via SPI interface by microcontroller. In our project the CC110L RF BoosterPack kit containing TI's IC CC110L is used. The frequency band (868 ... 870) MHz was selected for our application.

The DSP is built on the base of the C5535 eZdsp USB Stick Development Kit. It includes TI's IC TMS320C5535. This IC is ultra-low power 16-bit fixed-point DSP. The main feature of this chip is FFT hardware accelerator which is used for recognition algorithm realization in our application.

The Data Acquisition and Signal Analysis block is powered by a standard AC/DC adapter with input voltages (100 … 240) V AC and output voltage +6 V DC (500 mA). All necessary voltages for supplying the block cascades are formed by TI's ICs:
+5 V by TPS7250; –5 V by TPS63700; +3,3 V by TPS7233.
The circuit level schematic of the Analog Signal Processing device is shown in Fig. 5

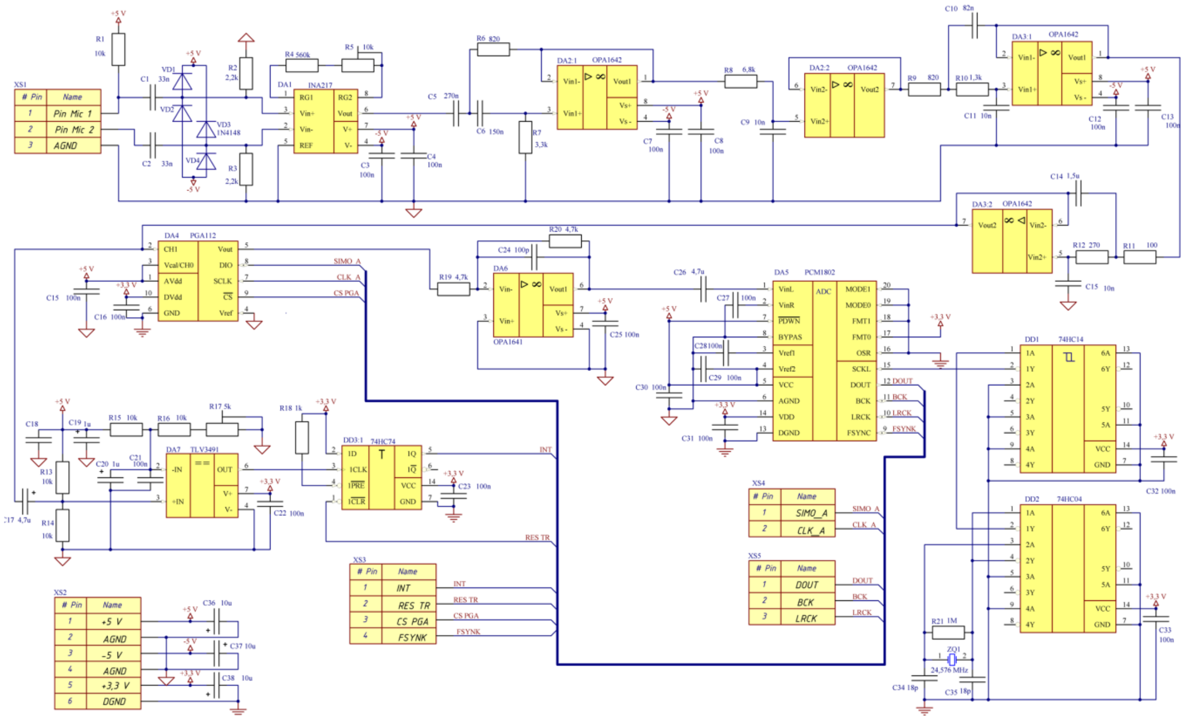
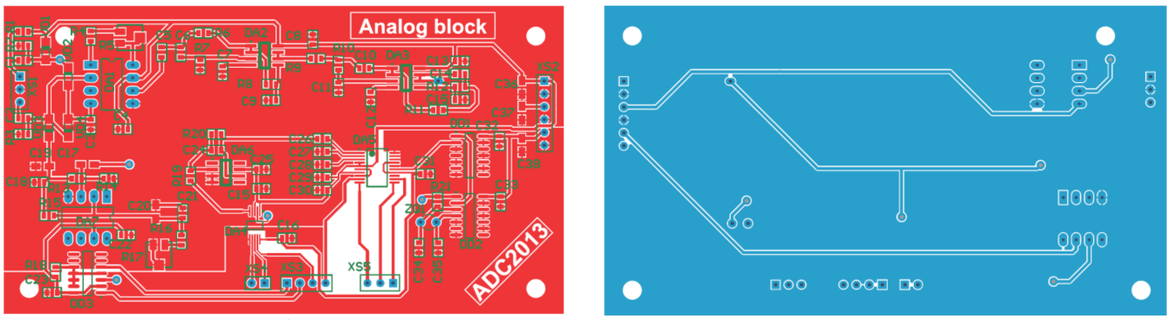


Fig. 5: Schematic of Analog Signal Processing device.

Using Altium Designer tool, the printed-circuit board of the ASP device was designed. The PCB's Top and Bottom sides are shown in Fig. 6.



a) b)

Fig. 6: The PSB of ASP device: Top side (a); Bottom side (b).

Alarm block

According to the block diagram of the Alarm block (Fig.2,b) its circuit level schematic was designed on the base of TI's IC. It is depicted in Fig. 7.

As the MCU2 the TI's IC MSP430G2553 was selected. The RF Receiver (RFR) and SD card2 are connected to the MCU2 via SPI interface. Due to few number of microcontroller's ports the SPI interface is used for the connection LCD to the MCU2 via shift register (REG). The TI's IC CD74HC164 was selected for this purpose. The RF Receiver is implemented on the base of TI's IC CC110L. The CC110L RF BoosterPack kit containing CC110L is used as well as the block of Acquisition and signal analysis. Two CC110L transceivers together enable a low cost bidirectional RF link.

The MSP430G2553 microcontroller has not contained the DAC, which is necessary for the voice messages generation. The use of an external DAC is not appropriate for this purpose, because it increases the device complexity and its dimensions.

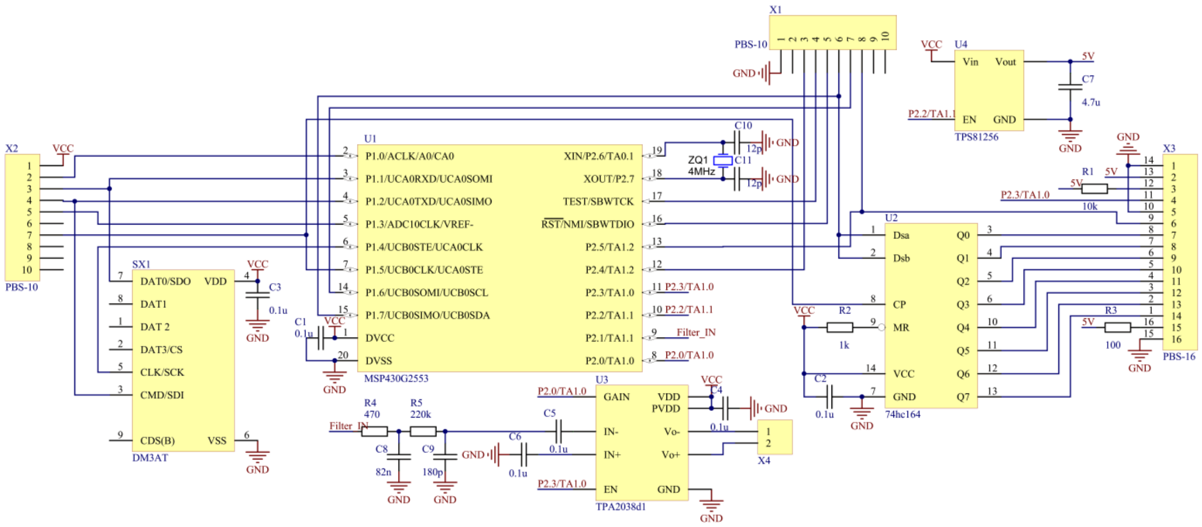
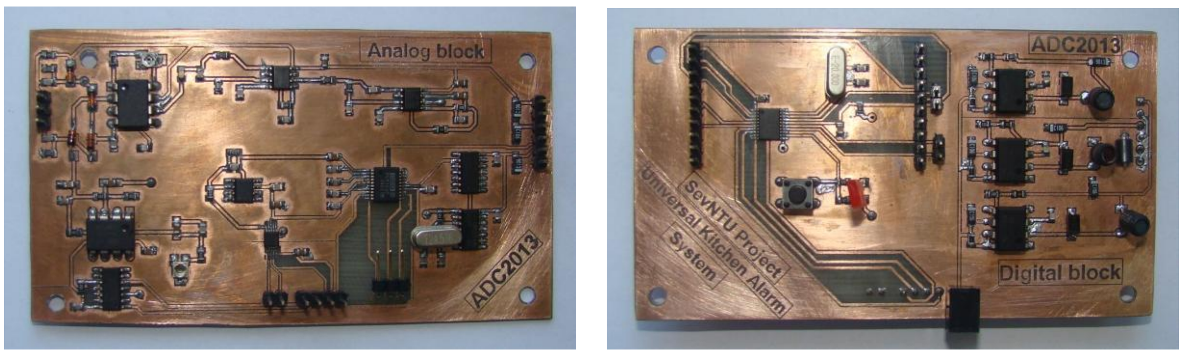


Fig. 7: The schematic of Alarm Block.

Therefore, it was decided to implement the DAC using software-based PWM. In this case the sound quality is enough for warning voice messages recorded on the microSD card. PWM signal from the microcontroller’s P2.1/TA1.1 output is entered to the passive LPF with cutoff frequency by 8 kHz. As a power amplifier the TI's IC TPA2038d1 was selected. The TPA2038d1 is mono class-D speaker amplifier, ideal for our application due to its high efficiency. Power supply is provided by 2 AA batteries with total voltage 3 V. Since+5 V voltage supply is necessary for the LCD powered, the TI's IC TPS81256 was selected as step-up converter.

EXPERIMENTAL RESULTS

For the experimental study of UKAS, the prototypes of its devices were made in the laboratory without special expensive equipment. PSB of Analog Signal Processing device is shown in Fig 8,a. The PCB of digital section of Acquisition and signal analysis block is shown in Fig 8,b.

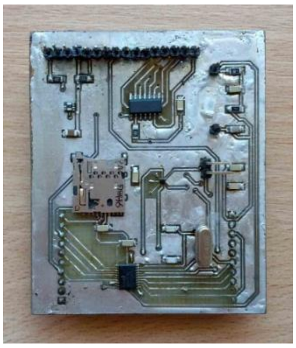


(a) (b)

Fig. 8: The ASA Block: PSB of ASP device (a); PSB of digital section (b)

The PCB of Alarm block is shown in Fig 9,a, all components of Alarm block in plastic enclosure are shown in Fig 9,b, and its top view is shown in Fig 9,c.

Software debugging of recognition algorithms was performed in the Code Composer Studio v 4.1 using the C5535 eZdsp USB Stick Development Kit.



(a)

(b)

(c)

Fig. 9: The PSB of Alarm block (a); all components in plastic enclosure (b); top view (c)

The experiments for the signals recognition and the data transmission by RF channel were carried out in the University's hostel (SevNTU). The signals are wirelessly transmitted inside the (868 ... 870) MHz band between the rooms.

The results show that UKAS recognizes different quasi-harmonic signals (beeps of the kitchen appliances) and whistling kettle with high confidence. The recognitions of click sounds of electric kettles occurred with variable success. Sometimes the system recognized the other sounds (for example claps and shouts) as a kettle's thermoswitch click. From our point of view it is caused by using of Goertzel algorithm, which is not intended for such signal recognition. However, recognition errors can be eliminated by using of Wavelet Transform, which provides high frequency resolution in the recognition algorithm. So the software development of this transform is a task of future work.

CONCLUSION & SUMMARY

The Universal Kitchen Alarm System that is capable of recognizing sounds was successfully implemented in this project. Special attention was paid to the careful development of the analog part of our system. During the designing, the software design and simulation tools from TI were used. For the system implementation, the best analog IC’s from Texas Instruments had been chosen, that allowed achieving the superior performance and low cost of devices. Experimental tests confirmed the possibility of sound signals recognition that can be used in the newly developed systems of "Smart House" technology, which is becoming increasingly sophisticated. The system's ability to recognize the sounds is a newer addition to the "intelligent" house to help conserve energy, which would help the planet!

FUTURE PLANS

Future work will be emphasized towards the on-board DSP device design on the base of TI’s TMS320C5535 DSP and the software enhancement of the signal recognition algorithms that may increase the data base of recognizable signals.

In following work, we will focus on an expansion of the system's possibility to recognize not only the sound of kitchen appliances but also other industrial and live sound sources. The ability of sounds recognizing can be used, for example, in the new hearing aids to determine the truck reversing with backing beeps, or other sounds to inform a weak hearing person about the dangers by voice messages.