

# FPGA IMPLEMENTATION AND CO-SIMULATION OF ENERGY DETECTION BASED METHOD

**Karel Povalač**

Doctoral Degree Programme (3), FEEC BUT

E-mail: xpoval00@stud.feec.vutbr.cz

Supervised by: Roman Maršálek

E-mail: marsaler@feec.vutbr.cz

**Abstract:** This paper is focused on real time implementation of spectrum sensing method used for detection in TV bands. The most common method of spectrum sensing is based on the energy detection principle (using Periodogram, Bartlett and Welch methods). Intermediate frequency band signal of TV receiver was used in real-time implementation and co-simulation. The FPGA was chosen as a convenient solution for fast real-time implementation. Our results were compared with Matlab simulations based on the same input signals. The results show possibilities of implemented method and usage of the FPGA as energy detector in cognitive radio chain.

**Keywords:** Energy Detection, FPGA, Periodogram

## 1. INTRODUCTION

Cognitive radio (CR) has been introduced as a promising technology to spectrum utilization in wireless communication. All the cognitive radio users are divided into the primary (licensed) and secondary users. In a CR network secondary users scan the frequency spectrum (try to detect a spectrum holes in time or frequency domain) and adapt transmission parameters to actual available communication channel [1]. Our work has been focused to detect licensed users in TV bands. Digital Video (DVB-T) and analogue broadcasting belong to primary users. One TV channel uses 8 MHz frequency wide band. Obviously, the spectrum sensing is a critical point of CR networks. The main problem can be defined as follows. Two basics hypothesis are usually known in defined frequency bandwidth  $B$ :

$$\begin{aligned} H_0 : x(n) &= v(n) \\ H_1 : x(n) &= v(n) + s(n), \quad n = 1, 2, \dots, N \end{aligned} \tag{1}$$

where  $H_0$  denotes the absence of primary signal. It means the received signal  $x(n)$  represents only the additive white Gaussian noise  $v(n)$ . Hypothesis  $H_1$  denotes the presence of primary signal. The received signal contains primary signal  $s(n)$  with additive noise  $v(n)$ . The variable  $N$  denotes number of signal samples. The main detectors can be divided into several categories mentioned below.

## 2. ENERGY DETECTION

Energy detector is also known as radiometry or periodogram. It is the most common way of spectrum sensing because of low computational and implementation complexities [2]. The receivers do not need any knowledge about the primary users. The received signal is detected by comparing the output of the energy detector with a threshold. The threshold  $\lambda$  depends on the noise floor and is compared with test statistic  $T(x)$ . Various versions of energy detection can be employed. Three basic approaches are described below.

## 2.1. PERIODOGRAM METHOD

Calculation of energy detector is based on measuring the power of the signal on the output of band pass filter. Periodogram method uses power spectral estimation. The main objective of spectrum estimation is the determination of the power spectral density (PSD). According to the [3], periodogram can be obtained by first estimating the autocorrelation sequence from the observed samples  $x[0], x[1], \dots, x[N-1]$  and applying the Discrete Time Fourier Transform (DTFT) to these estimates. Usually the periodogram is calculated by applying the FFT. This property was used in the simulations and also real-time implementation. The periodogram can be expressed by:

$$P(f) = \frac{1}{N} \left| \sum_{n=0}^{N-1} x[n] e^{-j2\pi fn} \right|^2. \quad (2)$$

Every frequency corresponds to calculated power level. The periodogram has a problem with higher variance. The quality of estimation depends also on number of samples. One approach to reduce variance of the periodogram is dividing the data to several segments and use different than rectangular window.

## 2.2. THE BARTLETT METHOD

The method is based on subdividing of the observed data into the  $K$  segments (without overlapping) with the length  $L$ . Total number of data samples  $N$  is equal to  $K \cdot L$ . It is necessary to find the periodogram of each segment and then calculate the average value over all periodograms. The Bartlett method can be expressed by [3]:

$$P_B(f) = \frac{1}{K} \sum_{i=1}^K P^{(i)}(f) \quad (3)$$

where  $i$  denotes  $i$ -th segment and where  $i$  takes values  $i=1, 2, \dots, K$ . The variance of the Bartlett's method is smaller than variance of the periodogram. The reduction of variance leads to decrease of resolution. The method based on Bartlett estimation has  $K$  times smaller resolution than the method of periodogram [3].

## 2.3. THE WELCH METHOD

The Welch method is based also on the periodogram method with the similar idea as Bartlett's method. The segments are overlapped in this case. The overlaps are usually 50 % or 75 % large. Each data segment is also windowed. Total number of data samples  $N$  is defined as:

$$N = L + D(K-1) \quad (4)$$

where  $D$  denotes the offset of successive sequences samples. This approach to periodogram calculation can be described by the following formula:

$$P_M^{(i)}(f) = \frac{1}{L} \left| \sum_{n=0}^{L-1} w[n] x_i[n] e^{-j2\pi fn} \right|^2 \quad (5)$$

where data samples  $x_i[n]$  are weighted by nonrectangular window  $w[n]$ . Thus the Welch spectrum estimation is given by following equation:

$$P_W(f) = \frac{1}{K} \sum_{i=1}^K P_M^{(i)}(f). \quad (6)$$

The Welch method can be used for variance reduction and also to improve the resolution [3].

### 3. HARDWARE DESCRIPTION, IMPLEMENTATION AND CO-SIMULATION

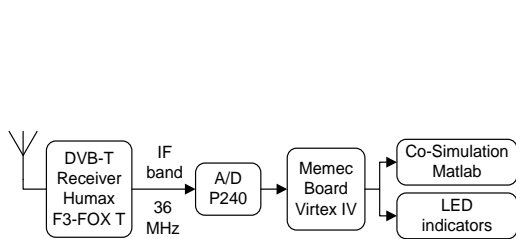
All the presented methods of Energy Detection were simulated in Matlab and method of periodogram was implemented on FPGA Virtex IV (device xc4vsx35). The implementation was done in the Xilinx System Generator environment. For the real time implementation the Memec Virtex IV MB Development Board with A/D (D/A) converters assembled on analogue module P240 was chosen. Humax F3-FOX T was chosen as a television receiver. System Generator provides hardware co-simulation, making it possible to incorporate a design running in an FPGA directly into a Simulink simulation. Hardware co-simulation compilation targets automatically create a bitstream and associate it to a block. When the design is simulated in Simulink, results for the compiled portion are calculated in hardware. This allows the compiled portion to be tested in actual hardware. Input data were uploaded from Matlab workspace then all the calculations were done in the FPGA and results were returned back to the Matlab environment. Real calculated data is possible to use for further processing. Hardware details are described in the following paragraph.

#### 3.1. BOARD DESCRIPTION

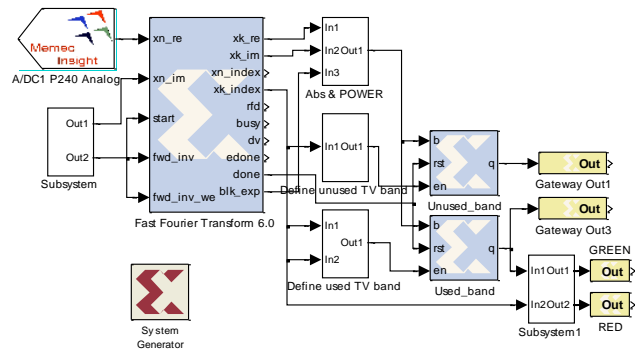
The Memec MB Development KIT provides development platform for design the digital signal processing applications. Software platform enables to use IP Cores. The main board includes many peripherals as 64 MB of DDR SDRAM, different clock oscillators, LCD panel, user LEDs, push button switches, P240 connectors (connection with analogue module) and etc [4]. The analogue module provides dual channel analogue inputs and outputs. The A/D converters are 14 – bits up to 125 MSPS and D/A converters are 16 – bits up to 500 MPSP [5]. As the main clock of the FPGA and A/D converter 125 MHz signal was used. The buttons and user LEDs were used for testing and evaluation of the received signals.

#### 3.2. BLOCK DIAGRAM

Intermediate frequency band signal from DVB-T receiver Humax F3-FOX T was chosen as an input signal for FPGA processing. The received signal was sampled by A/D converter with frequency of 125 MHz. The block of Memec board computes power frequency spectrum using the method of the periodogram. The algorithm computes energy in the band from 32 MHz to 40 MHz. It corresponds to one television band. Note that the intermediate frequency (IF) of the Humax receiver was 36 MHz.



**Fig. 1:** The block diagram of real-time implementation and co-simulation.



**Fig. 2:** Simplified block diagram of the FPGA implementation (Xilinx System Generator).

Two LED diodes were used as signal present/absent indicator. The situation described above is displayed in the figure 1. Simplified block diagram of the FPGA implementation is shown in the right hand side figure. There is a A/D converter block connected to FFT block. Behind the FFT block there are blocks of subsystems evaluated power and defined exact frequency samples. Calculated power in the TV band is compared with the threshold determined in order to guarantee desired false alarm probability. If the detected power is higher than threshold level it is signaled by

a green LED indicator inversely by a red LED indicator. Discussed block diagram was generated into the bit file and then uploaded to the Memec FPGA board.

### 3.3. HARDWARE CO-SIMULATION

The configuration bitstream contains the hardware associated with created model, and also contains additional interfacing logic that allows System Generator to communicate with the design using a physical interface between the board and the PC. This logic includes a memory map interface over which System Generator can read and write values to the input and output ports of the design. The hardware co-simulation block assumes the external interface of the model or subsystem from which it is derived. The port names on the hardware co-simulation block match the ports names on the original subsystem. The port types and rates also match the original design.

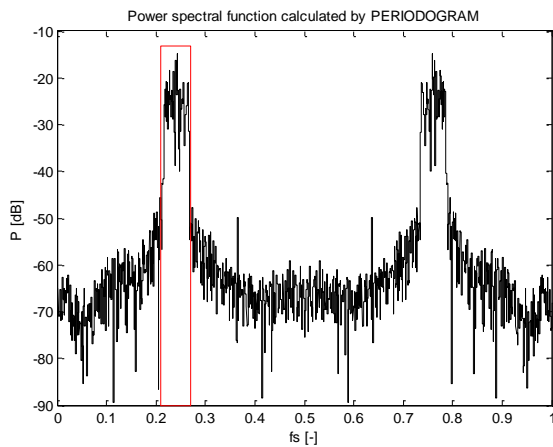
## 4. RESULTS

Simulation results of all energy detection methods with different input signals are shown in the table 1 (Matlab simulations only). Energy in the tested (used) band was compared with energy in the free channel. The tested channel was defined as the channel of 8 MHz width. Note that in this first (MATLAB) part of experiments the input signals have been captured from the above mentioned receiver using the CompuScope 12400 A/D card. The highest difference between the energy in the used and free band is given by the Welch method. The length of FFT was set up to 1024 samples. The three above presented methods for energy detection have been further evaluated using the same input signals containing DVB-T transmitting, analogue TV signal and channel noise. The results are shown in Tab.1.

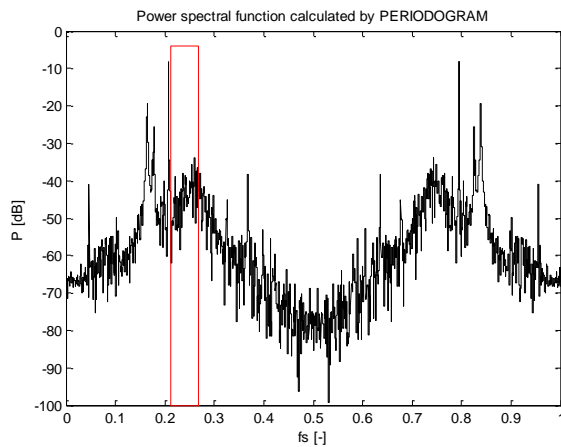
	DVB-T OFDM		Analogue TV		Noise	
	P used [dB]	P free [dB]	P used [dB]	P free [dB]	P used [dB]	P free [dB]
Periodogram	12.64	-12.22	17.13	2.41	-1.43	13.55
Bartlett	12.85	-8.54	16.29	2.23	1.37	16.03
Welch	8.92	-20	13.01	-2.15	-6.78	11.71

**Tab. 1:** Comparison of the Matlab simulation results.

Next experiment describes energy detector implemented on FPGA. All the following results have been obtained from the measurement (co-simulation) according to figure 1. Television channels were tuned on the Humax receiver and the FPGA device computed the energy in the used band. Power spectrum of the DVB-T occupied channel is displayed in the figure 3 for illustration.



**Fig. 3:** Power frequency spectrum calculated by FPGA (DVB-T transmitting in the channel).



**Fig. 4:** Power frequency spectrum calculated by FPGA (noise in the channel).

Frequency spectrum corresponds to television channel C40 in Brno's location. Red rectangle shows the 8MHz wide used channel. The independent axis denotes normalized sampling frequency. The power frequency spectrum is symmetric according to the half of sampling frequency. The power in the occupied band was computed as -20.85 dB and the power in the free band was evaluated as -47.36 dB. Power spectrum of the analogue television transmitting occupied channel was calculated as -21,95 dB and the power in free band achieved -40.53 dB. Number of occupied channel was C49. The channel number C48 was free – i.e. occupied by a noise only. Power spectrum of the channel is displayed in the figure 4. The power in used band was -41.32 dB (-28.52 dB in free band).

## 5. CONCLUSION

Different energy detectors based on the periodogram method were described in the presented work. Three detectors (periodogram, Bartlett and Welch) were simulated and results were compared. The best simulation result was given by the Welch estimation. Real time implementation was based on the periodogram method that yielded satisfactory results compared with simulations. Hardware co-simulation has been used as the purpose of better processing results of energy detector. Analogue and DVB-T television transmissions were detected by the FPGA. This energy based detector can be used as a part of the cooperative cognitive radio chain.

## ACKNOWLEDGEMENT

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