WIDEBAND DIGITAL CHANNELIZER BASED ON SPECTRUM SENSING

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Abstract - *A Software Defined Radio has advanced significantly in all fields including military and mobile communications. In this paper, main requirement of a Software Defined Radio system is to effectively channelize the wideband input signal into sub-band. A channelizer extracts independent channels from wideband signal it is one of the most computationally expensive component in a communication receiver. Cognitive Radio is made to overcome the scarcity due to rapid development in wireless networks. It helps in utilizing the spectrum effectively. Spectrum sensing in cognitive radio is used to detect the presence of signal in each sub-band.*

This paper presents an extensive study on different of channelizing and spectrum sensing for Cognitive radio. A digital channelizer structure is proposed combining the polyphase FFT structure with Eigen value based spectrum sensing method. This work uses an IFFT block with increased number of channels. The results of work completed so far has been discussed.

***Key Words*: Channelizing, Spectrum sensing, Software defined radio(SDR), Cognitive radio(CR).**

1. INTRODUCTION

The concept of software defined radio implies that a system which can be controlled by software with re-usable hardware. **A Software Defined Radio system employs the re-usable hardware which can be configured using software.** It is also called as flexible architecture radio [4]. SDR is emerging as promising technology to provide general purpose hardware that can support different existing and future air interface standards [5]. In SDR all components of receiver like mixer, modulator, filter, amplifier, demodulator are implemented through software on a personal computer or embedded system..

The SDR receiver mainly contains an antenna, hardware (analog front end) ADC/DAC, channelizer and other base band processing blocks. The channelizer corresponds to digital front-end. The channelizer performs extraction of signals based on frequency present in wideband signal. A channelizer is a critical part in a receiver system. It filters out unwanted component of signal from original and reduce the sampling rate to minimum required signal of interest. Main requirement of channelizer is efficiency, less complexity, high speed and reconfigurability.

A cognitive radio dynamically and autonomously adapts to environmental parameters from earlier experience. Based on SDR, it provides flexibility and offers efficient spectrum management. The key technique is spectrum sensing. It provides awareness about frequency band usage [1]. In radio frequency spectrum, there are two types of users Primary users (PU) and Secondary users (SU). Both the users coexist in the spectrum based on specific policy. The Secondary user uses the spectrum without disturbing the Primary user in the spectrum. The ability to detect the presence of PU in the frequency band.

2. CHANNELIZATION TECHNIQUES

A channelizer is an important block in Digital signal processing, it seperates a wideband input signal into multiple narrow subbands. A channelizer in a receiver is always placed next to ADC , hence it must be able work at high speed. This section presents different channelization techniques [7].

2.1 Per-Channel Approach

Per-channel approach is one of the oldest and upfront method of designing a channelizer. In this approach each channel is designed based on the requirement. The channels are designed based on frequency choice and bandwidth. The channels can be designed with uniform and non-uniform bandwidths.

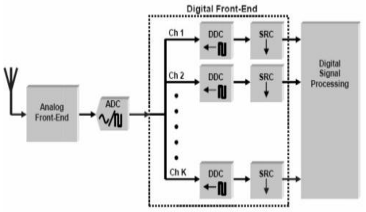

Fig-1 Per-channel Approach

A Digital down converter (DDC) mixes the wideband input signal with near carrier frequency of required bandwidth to baseband channel. The output of this is decimated through sample rate converter (SRC) reduce sampling rate. [4]

This type of channelizer architecture is rigid for alteration. Although it is easy to implement for few number of channels, the complexity in hardware increases when the number of channels increase. The silicon cost and power consumption also increases when implementing both narrowband and wideband signals.

2.2 Pipelined Frequency Transform

Pipelined Frequency Transform (PFT) is another channelization technology used in wideband receivers. The PFT architecture looks like a binary tree with DDC and a number of SRC. The PFT divides the incoming signal into high frequency part and low frequency part in every level of tree until the required signal of interest is achieved.

It takes half band filter symmetry and restricts the output sample rate to be quarter of input sample rate. It is advantageous compared to per-channel approach in terms of harware usage and power consumption. It is disadvantageous in terms of flexibilty as all the signals are divided in equal bandwidth.

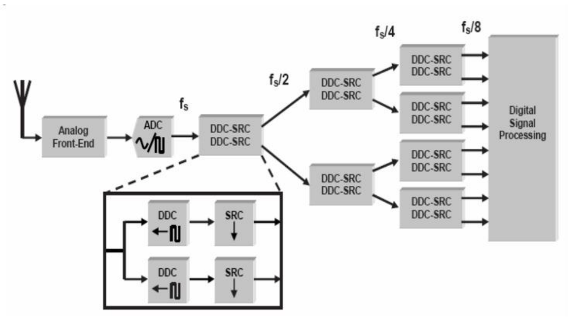

Fig-2 Pipelined Frequency Transform[7]

2.3 Frequency Domain Filtering

The frequency domain filtering exploits the properties of Fast Fourier Transform (FFT) [8]. The FFT computes the Discrete Fourier Transform (DFT) or the inverse FFT. It converts the signal from time domain to frequency domain and vice versa. The baseband filtering, conversion, decimation are performed using FFT. [9,10].

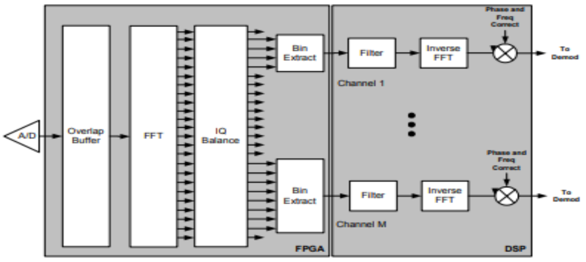

Fig-2 Frequency Domain Filtering

The architecture of frequency domain filtering is shown Fig 3. The input signal from ADC is buffered into the overlapping blocks. The FFT is performed on each block of data [8]. The FFT bins representing the frequency components for each channel of interest [11]. Each bin in the signal is multiplied with filter coefficient which represents baseband filtering process. It is done by "overlap-and-add" or "overlap-and-save"[11]. Secondary mixing after inverse FFT is to fully baseband the channel of interest. This method has improved flexibility and higher channel density than per channel approach. Since there exists a phase offset if the sample rate of ADC is not integer multiple of block size, an additional phase rotation is applied to output with different rotation to each IFFT[8]. The reconfigurable architecture of decimation filter have been discussed in [22][23] which can be used for higher frequency and bandwidth. It is advantageous because both wideband and narrowband signal operations can be made in single chaannelizer structure. The hardware used must be able to support all components effectively.

2.4 Polyphase FFT Channelizer

The polyphase filter bank structure improves the efficiency of channelizer with using FFT. This structure make use a bank of filters with different band of frequencies. A single filter is designed which is called as prototype filter. The remaining filters in the bank are obtained by modulating the prototype filter. The filter bank has analysis and synthesis section. The number of channels in this channelizer must be equal to decimation rate, sampling rate must be twice the baseband bandwidth [8].

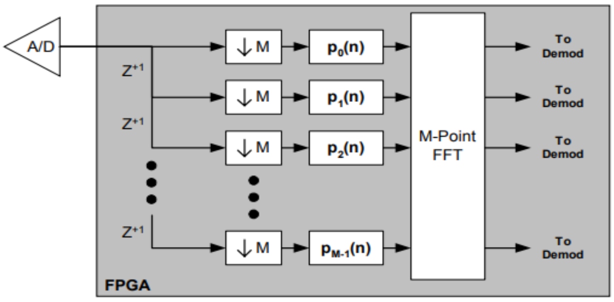

Fig- 4 Polyphase FFT channelizer[8]

Only channels with equal spacing can be implemented [12]. This channelizer is efficient since it requires only single filter design and FFT design. The entire structure can be implemented on FPGA.

3. SPECTRUM SENSING

The rate at which the data is transmitted is increasing day by day due to growth in multimedia technology. Cognitive radio comes as a rescue to solve the problems of spectrum usage which dynamically learns the environmental parameters and changes accordingly [13].

The most important components of cognitive radio are to measure, sense, learn and check the unused spectrum. It has primary users and secondary users. Spectrum sensing is key technique in cognitive radio [1]. It helps in efficient utilization of spectrum by allocating them to primary and secondary users. Primary users have higher priority over spectrum whereas the secondary users have lower priority and must exploit the spectrum without affecting the primary user. A spectrum sensing for cognitive radio applications require high sampling rate, high resolution ADC and high speed processors [13]. There are different methods for identifying the presence of signal transmission [13]. Some of the common spectrums sensing methods are explained [12, 13, 14, 16, 17, 18, 19]

3.1 Energy Detection

Energy detection is a blind detection method and a simple method in terms of complexity and implementation [21]. In energy detection method a prior knowledge of signal is not known. A threshold value is calculated through known statistics of noise. A signal received is passed through band pass filter to band limit. The energy from received samples determine the existence of signal. After band limiting the signal is sampled in ADC. A squaring device and integrator is used to compute the energy density. The value is compared with threshold and decision is made.

Energy detection method is widely used since it does not require any knowledge of signal and ease of implementation. Energy detection is however influenced by noise uncertainity [1]. It has issues with selection of threshold for primary users [15].

3.2 Matched Filtering

Matched filter method is one of the optimal methods of signal detection [16]. It maximizes the SNR ratio. In matched filter technique the filter is required to be designed based on prior knowledge of primary user. The secondary use must have knowledge of primary user. The sampled signal is sent to match filter which convolves the input signal with the impulse response matched to shape of signal being sought [16]. The filter output is compared with predefined threshold. Depending on the threshold, decision is made on presence of signal.

Since, it is impractical to have matched filter for every frequency band in a cognitive spectrum this method is not widely used.

3.3 Cyclostationary Detection

Cyclostationary based detection is another method of signal detection. This method exploits the cyclostationarity features of received signal. Cyclostationary signals exhibit second order periodicity defining Cyclic Autocorrelation Function (CAF) [21]. Cyclostationary property, help in signal detection at low SNR level. This is inherent property of digital modulated signals whereas in Orthogonal Frequency Division Multiplexing (OFDM) and Code-Division Multiple Access (CDMA) techniques this property is induced. In this CAF is calculated after sampling, the Discrete Fourier Transform (DFT) of CAF is calculated which is known as Spectral Correlation Function (SCF). Using SCF the unique cyclic frequency is found.

This method does not require initial knowledge of signal. But has higher complexity and requires longer sensing time.

3.4 Eigen Value Based Detection

Eigen value based detection is semi blind detection scheme which does not require any prior knowledge of signal. This detection scheme is said to have overcome the short coming of energy detection [1]. This method is based on property of covariance matrix of received signals. In this method a covariance matrix of received signal from frequency band is calculated. Then the maximum and minimum Eigen values of covariance matrix are calculated. The ratio of maximum and minimum Eigen value is compared to predetermined threshold which decide the presence of signal.

4. PROPOSED STRUCTURE OF CHANNELIZER

Various research works have been proposed on designing an efficient channelizer [1-5]. From reviewing the works polyphase FFT channelizer seems to be advantageous compared to other structures. Eigen value based detection is an optimal method of spectrum sensing since it does not require any prior knowledge of signal [1].

The proposed structure of channelizer is shown in Fig 5. This design combines a polyphase filter bank structure with spectrum sensing block. The similar architecture is shown in [1]. It consists of a cosine modulated filter bank (CMFB), IFFT and Eigen value based Spectrum sensing block.

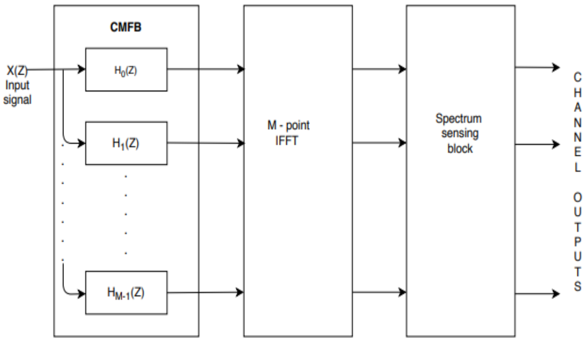

Fig-5 The proposed structure of digital channelizer.

4.1 Cosine Modulated Filter Bank

CMFB is a popular method of designing filter bank due to their real-valued nature and efficient implementation of poly phase structure [20]. A CMFB is designed from a low pass filter. A low pass filter is modulated to obtain band pass filters with different frequency bands. This filter is called prototype filter. Using which a uniform filter bank is designed. The prototype filter is linear phase filter whose magnitude is found by Park-McClellan algorithm. CMFB is implemented by modulating PF with linear phase using cosine modulation equation given by, [20]

$$h_k(n) = 2.h(n).\cos\left[(2k+1)\frac{\pi}{2M}\left(n-\frac{N}{2}\right)+(-1)^k\frac{\pi}{4}\right]$$
$$0 \le n \le N-1$$
$$0 \le k \le M-1 \quad \text{-------(1)}$$

$h_k(n)$ represents the analysis filters, $h(n)$ is the coefficients of PF, M is number of channels, N is filter length. Then CMFB of M bands will be formed.

4.2 Inverse Fast Fourier Transform

IFFT is designed using Cooley-Tukey algorithm, which breaks the DFT into smaller DFT's. Algorithm is written in radix-2 FFT. The code for IFFT is written in a modular way by using smaller IFFT's.

4.3 Eigen Value based Spectrum Sensing

A spectrum sensing block is designed based Eigen value sensing which generates covariance matrix. Using this matrix maximum and minimum Eigen values are computed. The ratios of maximum and minimum Eigen values are compared with predefined threshold to decide the presence of signal in a particular frequency band.

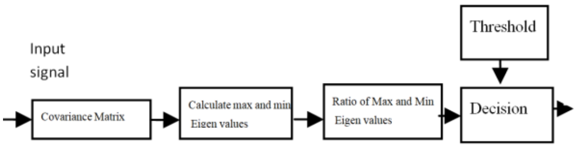

Fig-6 Eigen value based spectrum sensing

The received signal is defined as [1]

$$x[n] = s[n] + w[n] \quad \text{----------} \quad (2)$$

where, $s[n]$ is received signal and $w[n]$ is the AWGN with sample index n. If the signal is absent in spectrum then $s[n] = 0$.

Therefore Hypothesis can be given as

$$H_0 \;\; x[n] = w[n] \qquad \lambda max/\lambda min \le \propto$$
$$H_1 \;\; x[n] = s[n] + w[n] \qquad \lambda max/\lambda min > \propto \text{-- (3)}$$

$\lambda max, \lambda min$ are the maximum and minimum Eigen values. $\propto$ is defined threshold to decide if signal is present.

Threshold is calculated by equation [1]

$$\propto = \frac{(\sqrt{N}+\sqrt{M})^2}{(\sqrt{N}-\sqrt{M})^2}\cdot\left(1+\frac{(\sqrt{N}+\sqrt{M})^{\frac{-2}{3}}}{(NM)^{\frac{1}{6}}}F_1^{-1}(1-P_f)\right) \text{--- (4)}$$

Pf is the probability of false alarm, F1 is cumulative distribution function of Tracy-widow distribution [1].

Ratio is calculated as:

$$\text{Ratio} = \frac{\lambda max}{\lambda min} \quad \text{----------------------------- (5)}$$

5. RESULTS AND DISCUSSION

This section presents the results of work completed till now.

5.1 Prototype filter

A PF is designed as lowpass filter, equiripple, N(filter length) = 712, pass band : 90KHz, stop band: 100khz.

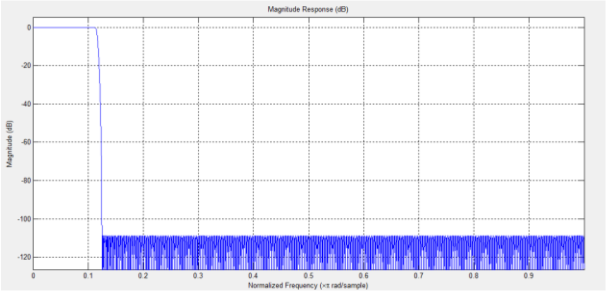

Fig-7 Magnitude Response of PF

5.2 CMFB

The CMFB is designed according to the equations mentioned in section 4. M(Number of channels): 32, Order: 712, Value of Beta : 7.853 which is calculated from [5].

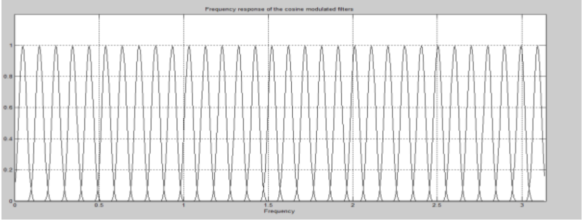

Fig-8 CMFB Filter banks

5.3 IFFT

The IFFT block was simulated and the 32 channel outputs are divided as real and imaginary.

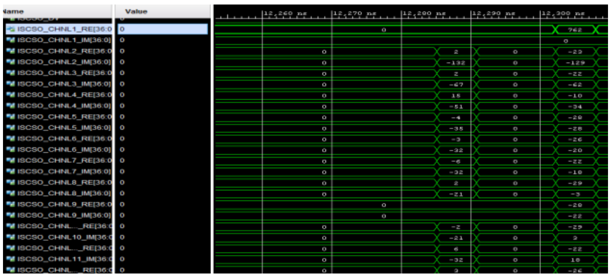

Fig 9 Outputs from channel 1 to 11

Similarly outputs from channel 12 to 32 were simulated. The waveforms show the output values from filter and IFFT block.

5.4 Eigen Value Based Spectrum Sensing

The measurements for Eigen values were carried out using Matlab. The Table 1 shows the ratio of maximum and minimum Eigen values. The threshold is calculated from equation (4) with the probabilty of false alarm Pf = 0.1, the threshold is found to be α = 1.0607.

Table 1: Ratio of maximum-minimum Eigen values os sub-bands

SUB-BAND	*Ratio of Maximum and Minimum Eigen values*
1	9.3996
2	9.1414
3	9.5455
4	10.6278
5	21.3630
6	11.0356
7	18.0069
8	21.1649
9	9.5105
10	10.8799
11	1.0008
12	9.2257
13	20.9437
14	13.8667
15	19.3637
16	11.4032
17	16.5141
18	14.7289
19	10.9237
20	21.8142
21	21.6667
22	14.1690
23	28.4179
24	11.2967
25	9.1322
26	13.3917
27	20.703
28	10.8907
29	13.6552
30	28.6782
31	21.8189
32	17.1715

From table we see that sub-band 11 is found to be having ratio lesser than threshold. Hence we can say that, signal is absent in the sub-band.

6. CONCLUSION

A study has been carried out on different channelization designs and spectrum sensing algorithms. It can be observed from the survey that polyphase FFT is an efficient design due to its less hardware complexity. In spectrum sensing . Eigen value based detection comes out as an optimal method of sensing since it does not require any knowledge of signal. A digital channelizer structure is proposed combining polyphase FFT and spectrum sensing. The work completed till now is presented with the experimentally observed results. The signals are efficiently channelized with increased number of channels. The spectrum sensing block is designed with predetermined threshold as explained in section IV and results are presented.The tools used for simulation are matlab and Xilinx Vivado.

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