Analysis of FFT Based Spectrum Detection Model using Modified Periodogram Algorithm

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Abstract: ***Spectrum sensing technology is one of the most common requirements needed to solve the communication problems faced in today's wireless communication world. The modeling of proper spectrum detection method solves the problem of spectrum scarcity and also provides the means for wastage of spectrum. The detection of digital modulated signals has been carried out & verified using FFT based modified Period gram Algorithm applied for spectrum analysis. The performance of detection of digital signals & effectiveness in detection is upgraded by using spectrum analysis method. The proposed modified Periodogram algorithm based FFT approach is capable of superior in simplicity of computations which in turn used to sense the spectrum measurement in fast & precise manner so that detection of signals may be carried out without much problem in today's communication network. The other existing techniques are satisfied for high SNR range which is not always in reality in today's communication world. In this research paper, we have developed simulation model using Mat lab version of R-2014a by FFT based Techniques. The result of simulation indicates that it is possible to get nearly zero percentage missed detection when SNR is very low.***

Keywords: Fast Fourier Transform (FFT), Power Spectral Density (PSD), Signal to Noise Ratio (SNR), Total Harmonic Distortion (THD),Modified Periodogram Algorithm

1. Introduction

The wireless technology today adopts fixed Spectrum allocated policies. These spectral resources allocation has been done by governmental departments of every country. From the Federal Communication Commission (FCC) frequency Chart [1] it is clear that very poorly the spectrum is utilized .The spectrum utilization details [2][8] across various range of frequencies in GHz has been studied & shown in fig 1.

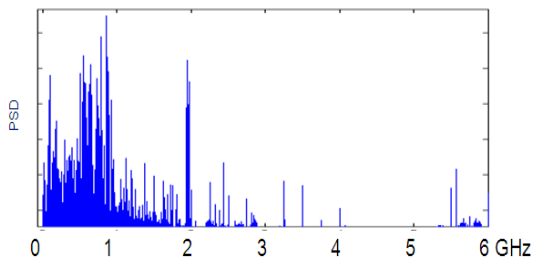

Figure 1: Spectrum utilization across 6 GHz

From the experimental observations conducted over various regions it is clear that between 0-1 GHz Spectrum is used very much for most of the applications, between 1-2 GHz is has been utilized moderately, various between 2-6 GHz the spectrum is utilized very poorly.nSpectrum utilization percentage is shown in table1.

Table 1: Percentage of Spectrum utilized

Freq in GHz	0-1	1-2	2-3	3-4	4-5	5-6
Utilization %	55	34	7	0.2	0.13	5

From the analysis of the table results, it is concluded that more than 50% of the allocated spectrum is utilized upto 1 GHz the remaining ranges of allocated Spectrum is simply wasted due to improper sensing technologies. Therefore there is necessary to adopt a proper sensing technique to detect the signal in fast and efficient manner. Generally there exist different techniques[3] to detect & analyze signals which include one dimensional Eye diagram technique[4] ,two dimensional Constellation scope technique[5],Trajectory boundary scope technique etc. The strength of all these existing techniques is that they work better at high SNR i.e., high influence of Signal dominance over Noise region, but their drawback is they work average and poor at medium and low SNR region .Signal detection in these kind of real time situation is very poor and suffers from low performance. To overcome this problem & increase the speed of processing, an FFT based spectrum measurement has been introduced to analyze the detection process fast & precisely using spectrum analysis. The proposed technique uses an algorithm called Modified Periodogram Algorithm to approximate the equivalent power spectrum waveform. Since the FFT based DFT Algorithm [6] has been used internally by the spectrum analyzer, it is shown the amount of CM & CA has been reduced compared to DFT Algorithm & how efficiently this data in frequency domain has been converted to spectrum display using Modified Periodogram Algorithm through computation graphs & speed graphs.

The FFT based Simulink models has been developed with spectrum Analyzer scope & it is compared with Simulink models developed with all other previous techniques. The signal analyses has been done for various SNR ranges. Finally it is concluded that the proposed FFT based technique is found to be faster & efficient in sensing digital signals. This paper is organized as follows. Section II describes the importance of FFT based DSP Algorithm & Modified Periodogram Algorithm in Spectrum Sensing. Section III describes the development of various Simulink models for detection of signals. Section IV gives the details of simulated results obtained at transmitter & receiver side of the communication, comparisons of computation reduction, analysis & discussion has been done in the same section. Finally in the end Section V gives the conclusions & Recommendations.

2. Spectrum Sensing based FFT and Modified Periodogram Algorithm

A. FFT based DSP Algorithm:

Several communication applications needs signal processing in frequency domain representation, where the periodicity, frequency content, symmetry, energy & power spectrum measurement can be clearly done & analyzed.FFT is the fast DSP Algorithm used to compute DFT in fast & efficient manner. There exist two main FFT Algorithm.

1. Discrete In Time (DIT) FFT Algorithm
2.Discrete In Frequency (DIF)FFT Algorithm.

Discrete In Time (DIT) FFT Algorithm is described by the following equations:

$$X(K) = \sum_{r=0}^{\frac{N}{2}-1} x(2r)\, w_{\frac{N}{2}}^{rk} + w_N^k \sum_{r=0}^{\frac{N}{2}-1} x(2r+1)\, w_{\frac{N}{2}}^{rk} \quad ---(1)$$

In this approach N-point DFT is broken into 2N/2 DFT, and then each N/2 into 2N/4 & then this process is continued until 2 point DFT's are formed. Using this Algorithm it requires only $N/2\log_2 N$ Arithmetic operations compared to N^2 operations of DFT Algorithm. It is further reduced by half the number of Arithmetic operation by Cooley Turkey Algorithm [7].Where the multiplication operations per butterfly are reduced by one.

In case of Discrete In Frequency (DIF) FFT Algorithm, a separate analysis for detection of odd and even sequence is being done & it is described by the equations is given as:

$$X(K) = \sum_{n=0}^{\frac{N}{2}-1} [x(n)+x(n+N/2)]\, w_{\frac{N}{2}}^{rn} \quad -- \quad (2)$$

Odd sample is defined by:

$$X(K) = \sum_{n=0}^{\frac{N}{2}-1} [x(n)-x(n+N/2)]\, w_N^{n} w_N^{2rn} \quad -(3)$$

In this Algorithm also, it requires $N/2 \log_2 N$ CM & $N \log_2 N$ CA instead of N^2 & N^2-1 computations of direct method like previous methods. The reduced Butterfly diagram used for detection inside the analyzer by using Cooley Turkey FFT Algorithm. This FFT based sensing really increases the speed of operations in detecting signals.

B. Modified Periodogram Algorithm:

It is Spectrum based Algorithm used in Spectrum Analyzer to compute & plot the Power Spectrum, PSD & Spectrogram of input signal. It is used to compute Spectrum updates and to average the windowed Periodograms for each and every data segments. Based on the number of Spectral Peaks available in the Spectrum Spectral information can be updated. Whenever this Algorithm finds the Spectral Peaks, it removes all the other adjacent information content which decreases monotonically from these Spectral Peaks. After the recording of these Spectral Peaks, it subsequently clears its contents .

Periodogram description:
Pxx = Periodogram (x): returns the Periodogram PSD estimation of input signal(x) using default rectangular window.Pxx is a one sided PSD estimate if 'x' is real valued input.

Pxx = Periodogram (x,window): returns the modified Periodogram PSD estimate of two sided input signal complex value using the window function.

Modified Periodogram Algorithm multiplies input time series by a window function which is positive and decreases to zero at the beginning & end points. Multiplying the time series by suitable window function tapers the data gradually on & off and helps to alleviate the spectral leakage in the Periodogram. Modified Algorithm is given by :

$$P^{\wedge}(t) = \frac{\Delta t}{N}\left|\sum_{n=0}^{N-1} h_n x_n e^{-i2\pi fn}\right|^2 - \frac{1}{2\Delta t} < f \le \frac{1}{2\Delta t} \quad ----(4)$$

Where h_n is the window function,
Δt is the sampling interval.

Frequency are expressed in terms of radians/sample, then Modified Periodogram Algorithm is given by:

$$P^{\wedge}(t) = \frac{1}{2\pi N}\left|\sum_{n=0}^{N-1} h_n x_n e^{-iwn}\right|^2 - \pi < w \le \pi \quad ----(5)$$

3. FFT Based Model Development for Detection of Digital Signal

Various Simulink models has developed for reliable and efficient detection of signals. The analysis has been carried out by using a filter called Raised Cosine Filter & also without using Filter. Various developed models has been shown in fig 2-5.

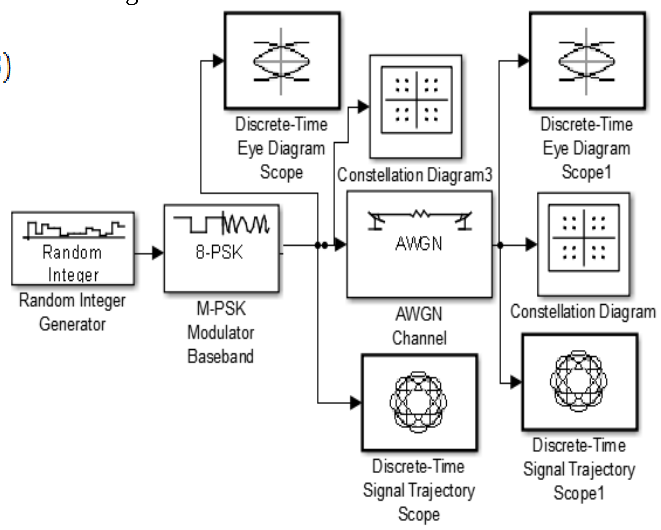

Figure 2: Detection model using Eye Diagram, Constellation Diagram & Trajectory scope

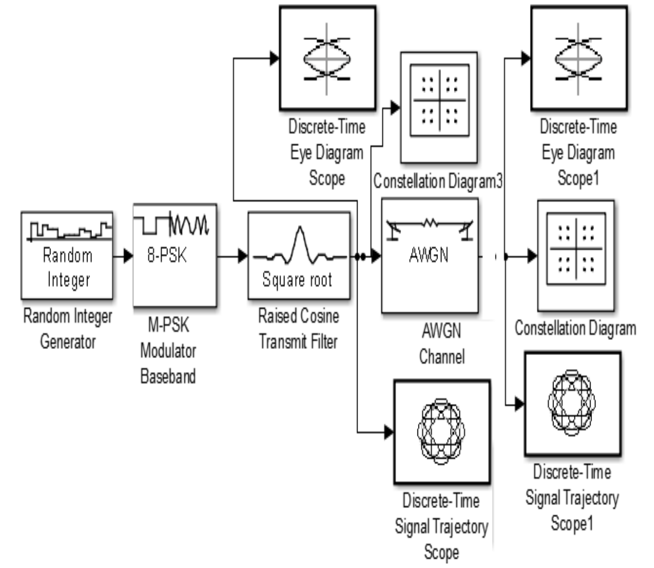

Figure 3: Model using Eye Diagram, Constellation Diagram & Trajectory scope with Filter.

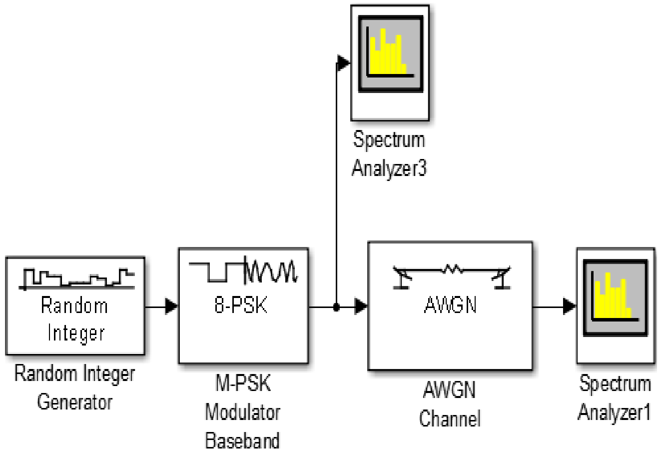

Figure 4: Spectrum Detection model without filter

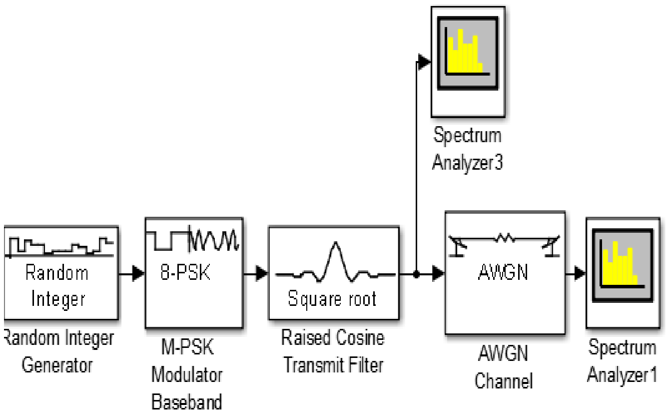

Figure 5: Spectrum Detection model with filter

The up gradation of detection performance can be improved by developing FFT based models using Spectrum Analyzer of Mat lab version R2014a. It is checked for various ranges of SNR regions by using spectrum measurement. The channel used here is Gaussian Channel. The model uses the filter called Raised Cosine Filter at transmitter side & receiver side which filters out the signal. The developed model is used to analyze the constelled output , Eye diagram output, Trajectory output & spectrum based output. Through our spectrum based model we can measure and analyze the spectral peaks, Power Spectral Density, Harmonic Distortion, Inter modulation Distortions, Channel capacity etc efficiently by using FFT Algorithm technique.

4. Simulation Results & Discussions

The simulations were carried out for different modulated digital signals passed through white Gaussian noise channel. The simulated results at transmitter & receiver are shown in fig 6-11. These figure shows simulated results when passed through constelled scope , trajectory scope, & eye diagram scope using simulink version Mat lab R2014a. Eye diagram scope gives detection beyond one dimensional time domain analysis for high speed digital signal. It helps to fastly analyze & detect the quality of digital signal. Constellation Diagram represents the modulated digital signal as two dimensional scattered diagram in the complex plane. Signal Trajectory technique displays the digital modulated signal in signal space by representing its own in phase component against quadrature components. It displays trajectory boundary for signal which in turn helps to detect the signal easily. Simulated output of FFT based spectrum using Modified Periodogram Algorithm is carried out .

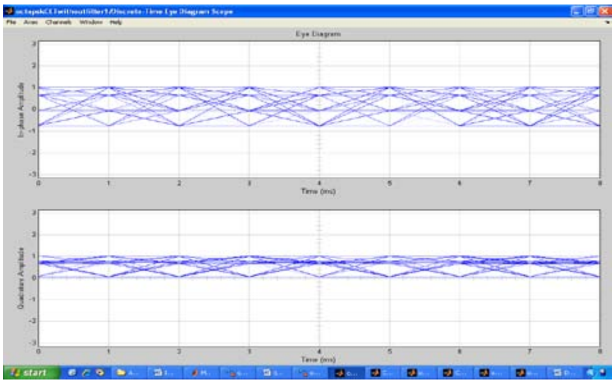

Figure 6: Eye diagram at the input

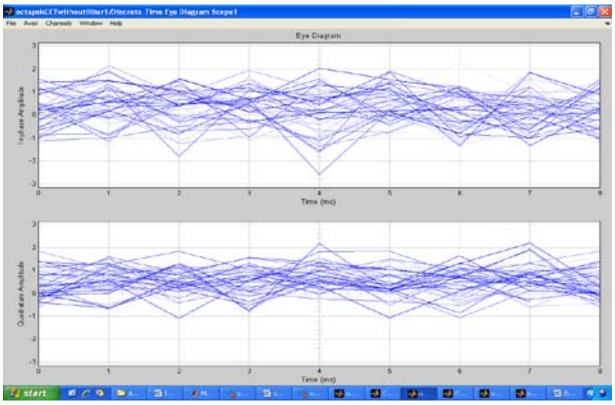

Figure 7: Eye diagram at the output

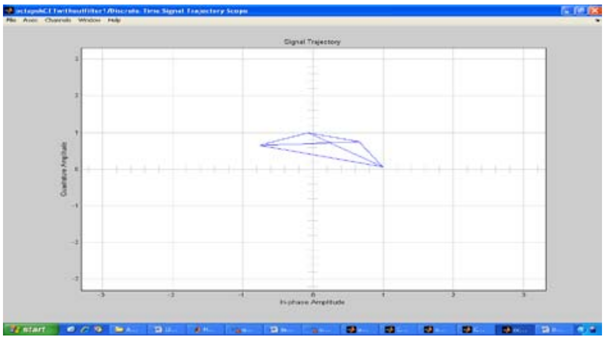

Figure 8: Trajectory diagram at the input

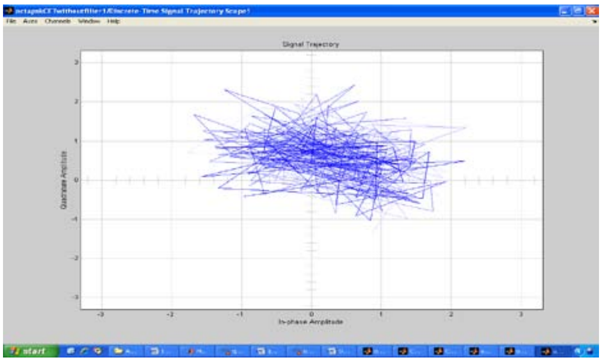

Figure 9: Trajectory diagram at the output

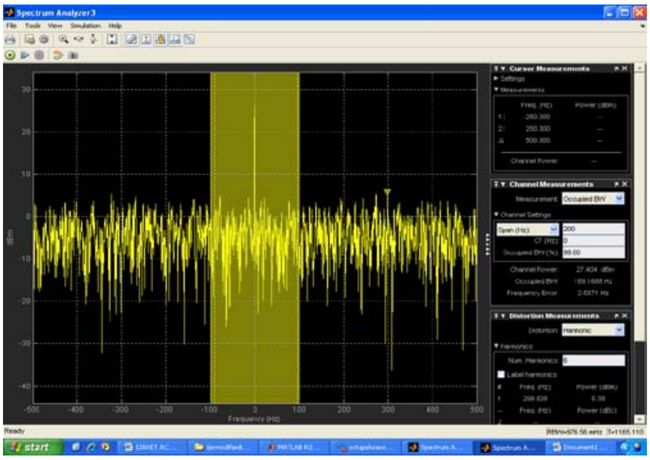

Figure 10: Spectrum measurement at input

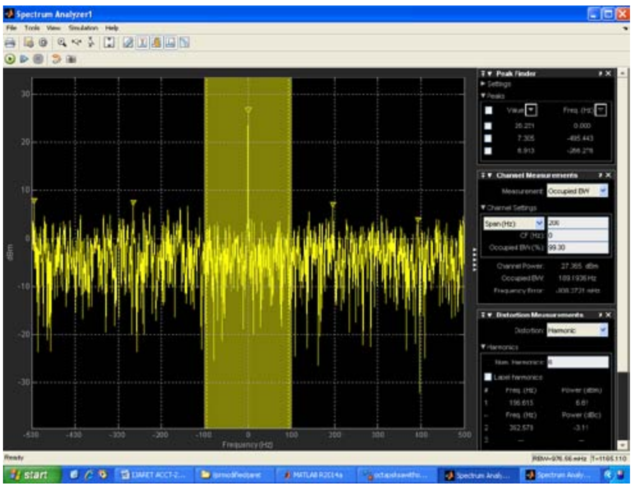

Figure 11: Spectrum measurement at output

It clearly shows the measurement of PSD, Spectral Peaks, Channel capacity, Harmonic Distortion & Intermodulated distortion SINAD etc at transmitter & receiver. Using these information the Percentage missed detection can be largely reduced.

A. Computational Reduction using FFT based Spectrum:

Computational complexity has been reduced large amount compared to DFT & it is shown in table 2

Table2: CM Reduction of FFT used in spectrum measurement

No of Points N	DFT Complex Multiplication N^2	FFT Complex Multiplication $N/2 \log_2 N$
8	64	12
16	256	32
32	1024	80
64	4096	192
128	16384	448
256	65536	1024
1024	1048276	5120

To process 8 point DFT signal using FFT CM has been reduced from 64 to 12 operations internally in spectrum analyzer which saves a lot of time in detection of modulated signal.

B. Processing of speed improvement using FFT in spectrum detection

Significant improvement of speed has been taken place by using FFT. Table 3 shows speed improvement of FFT over DFT for CM Spectral measurement.

Table 3: Speed improvement for CM

No of Points N	DFT Complex Multiplication N^2	FFT Complex Multiplication $N/2 \log_2 N$	Speed improvement for CM $2\,N^2/N \log_2 N$
8	64	12	5.3 times
16	256	32	8 times
32	1024	80	12.8 times
64	4096	192	21.33 times
128	16384	448	36.57 times
256	65536	1024	64 times
1024	1048276	5120	204.8 times
2048	4194304	11264	372.36 times

For an 8 point resolution the processing speed improvement is 5.3 times faster. For N= 2048 point resolution of signal analysis, the speed is increased to large amount i.e. 372 times the previous. This is the actual strength of DSP Algorithm used in Spectrum Analyzer internally to convert signal into frequency domain to measure the spectrum.In this way the FFT based detection helps to analyze the different modulated signals fastly & efficiently in today's communication world.

5. Conclusions

In this paper we have showed FFT based technique to detect the digital signal in a very fast & précised way. Since the CM & CA is reduced to very large extent the speed of processing is very high upto 372 times faster in case of 2048 point resolution method . Since the spectrum update is done by using modified Period gram Algorithm, we can measure &

analyze spectral peaks, PSD, harmonic Distortion, Inter modulation distortion, channel capacity and channel bandwidth etc efficiently & fastly. Several Simulink models has been developed in our research work to detect various digital modulated mobile signals with reliable & effective manner. All these spectral measurement has been conducted for various ranges of SNR with filter & without filter for a white Gaussian noise channel at both transmitter & receiver. This has been compared and analyzed with existing techniques. The results clearly proved that FFT based spectrum technique gives better solutions. This efficient & fat method helps to solve the scarcity of spectrum faced in today's communication world. It is concluded that the proposed measurement technique is the necessary requirement for the proper utilization of spectrum. Such area requires more attention now a day's .It can be further extended towards the enhancement of spectrum measurement using 3 D approach specially to get better detection at very low SNR region which reduces the processing delay and computational complexities further.

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Author Profile

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