Frequency-hopping Signals Analysis Based on FPGA

Dong Pei ,Zhongxing Tao ,Huixin Pei ,Lijun Chen ,Yan Gao

College of physics and Electronic Engineering,

Northwest Normal University

Lanzhou, 730070, Gansu, China

e-mail: Peidong@nwnu.edu.cn

Abstract-**A method which bases on FPGA to realize the frequency-hopping (FH) signal analysis system is proposed. It designs a Radix-4 DIT FFT processing unit circuit firstly, then makes a Short-Time Fourier Transform(STFT) to FH signal and gets spectrum amplitude values. According to the features of the spectrum amplitude structure, we can obtain a non-linear mapping method which makes spectrum amplitude display more accurate, make a non-linear mapping transform of spectrum amplitude values, and get signal spectrum diagram of pseudo color index results.At last output the signal spectrum diagram of pseudo color displayed on VGA. Analysis FH signals and compare with Matlab simulation results, we can see that this design method is correct.**

Keywords-FPGA; Frequency-Hopping(FH); STFT; nonlinear transform; pseudo-color

I. INTRODUCTION

The basic idea of the time-frequency analysis method is to construct a joint function of time and frequency, it is used to describe the energy density or intensity of signal at different times and different frequencies, and to estimate the characteristic parameters of the signal [1]. Time-frequency analysis method can be divided into linear and nonlinear, typical linear time-frequency presentations are Short Time Fourier Transform (STFT), Gabor expansion and wavelet transform [2], while typical non-linear presentations are Wigner Ville Distribution(WVD) and Cohen Class, it is a kind of quadratic time-frequency representation.

FH signal is a typical signal of the non-stationary signal and changes over time. Mere time domain or frequency domain analysis method is difficult in its accurate analysis, while time-frequency analysis method which can describe the joint time-frequency characteristics of the signal [1] is a more effective way. Using smooth pseudo WVD time-frequency analysis, the parameters of FH signal i.e. hop cycle, hop timing and hopping frequencies [3] can be estimated without knowing any priori knowledge. Using atomic decompositions the parameters of FH signal can also be estimated [4]. The Fast Hartley Transform(FHT) can be used by the relationship between Hartley transform and Fourier transform, then do Short Time Fourier analysis of frequency hopping signal [5]. In recent years, for the time-frequency signal analysis method of VLSI structure is also versatile [6].

This paper designs the Radix-4 DIT 1024-point FFT unit firstly, then according to the characteristics of amplitude spectrum structure, the non-linear mapping method which can display the details of amplitude spectrum is founded, i.e. to obtain the value of the signal amplitude spectrum by nonlinear mapping transformation, then the palette index value, finally the signal spectrum will be achieved by pseudo-color VGA display.

II. TIME-FREQUENCY ANALYSIS BASED ON STFT

Short Time Fourier analysis is a simple method to analyze the non-stationary signal and it is one of the common time-frequency analysis methods. It also has the advantages of easier hardware implementation and shorter processing time.

Supposing $x(m)$ is a long sampling signal sequence, and it is time-varying, $w(n-m)$ is a window sliding along the time axis, its width is limited. Therefore, STFT can be defined as:

$$X(n,k) = \sum_{m=0}^{N-1} x_n(m) e^{-j\frac{2\pi km}{N}} \qquad (1)$$

Where: $x_n(m) = x(m)w(n-m)$, $0 \le k \le N-1$, $|X(n,k)|$ is the short-time amplitude spectrum, thus obtains the power spectrum function:

$$P(n,k) = |X(n,k)|^2 = X(n,k)X^*(n,k) \qquad (2)$$

The amplitude spectrum is calculated by the following formula:

$$|X(n,k)| = \sqrt{[\text{Re}(X(n,k))]^2 + [\text{Im}(X(n,k))]^2} \quad (3)$$

$P(n,k)$ is a two-dimensional non-negative real valued function, uses time as the abscissa and frequency as the vertical axis, reflects the signal power density spectrum, it has similar graph with magnitude, but the sizes are different, the power spectrum is not contain phase information.

III. TIME-FREQUENCY ANALYSIS OF THE FPGA REALIZATION

Use of three-port RAM within the FPGA store the signal through the ADC firstly, and then STFT, i.e the sub-frame windowed signal processing, and Fast Fourier Transform for windowed signal. According to the output of the real and imaginary part obtains the amplitude spectrum, after nonlinear mapping, changes the amplitude spectrum into a gray value, and displays the final resulting image in VGA mode. Figure 1 shows time-frequency analysis system

block diagram;

A. STFT Architecture

The STFT often uses FFT algorithm to calculate. With the rapid development of FPGA technology, FFT algorithm implementation using FPGA become a hot research [7][8][9][10]. After researching the law of data address and twiddle factor address in detail, then this paper designs the Radix-4 DIT 1024-point FFT processing unit, which is characterized by 1024 points, 16-bit word length, fixed-point complex FFT processor.

The system uses of FPGA in parallel structure of the 1024 Radix-4 FFT algorithm design, requires a total of five stages, each stage deals with 1024 data, and requires 256 butterfly to complete. Each stage is equipped with a dual-port RAM, an address generating unit, a twiddle factor generator unit and a Radix-4 butterfly unit. The collected data is stored in three-port RAM within the FPGA, three-port RAM has a write address lines and a input data port, two read address lines and two output data ports, ideal for the occasion that one way data written at the same time while needs two output data ports. When collection and storage unit storing enough data, then start the first stage arithmetic unit, read data from the three-port RAM, while obtain needed twiddle factor from the twiddle factor generator unit, after the butterfly operation, then store into the dual-port RAM with the origin site, at this point the second stage and the back-end stages are in the waiting and stopped states. When the third stage starts to calculate, the fourth and fifth stages are not to calculate, the first stage starts operating again and the second stage keeps in waiting and stopped states. So, calculation of the first frame data is completed, follow-up data are putted into the pipeline processing. When the first, third, and fifth stages is calculating, the second and fourth stages keep in a waiting state, and vice versa. After the fifth stage calculated, data stored in dual-port RAM of the fifth stage need to output in the inversion sequence, and output data is divided into real and imaginary part .

As for the twiddle factor generator unit design, the general method uses software tools to calculate the twiddle factor, and then makes a twiddle factor lookup table to be applied, the method is simple, and easy to implement. In addition, you can use Cordic algorithm [7], real-time calculate the value of the sine and cosine, then get the required twiddle factor. With better generality, but will bring calculation errors, and difficult to control time delay. In this paper, use of look-up table method, save up twiddle factor calculated by MATLAB in advance.

B. Nonlinear mapping of amplitude spectrum

After STFT signal processing, get the signal amplitude spectrum, the data width are 16 bits, then store the results of successive multi-frame transformation, and generate 65536 of grayscale gray images, line said the time, and column said the frequency, that is the spectrum of time-frequency analysis. This spectrum usually uses 256 grayscale images to show changed information of the spectrum, and also to facilitate the follow-up processing, needs to compress

high-resolution grayscale image into low-resolution grayscale images, one of the advantages doing so is that we can save memory resources. However, the grayscale image compression can reduce the gray scale resolution, and also change the original intensity distribution of image, to make the transformed image hided, or weaken the interested part, so it would require grayscale image enhancement. Magnitude spectrum showed in this paper, compresses the high-resolution image into low gray low-resolution image firstly, and then converts grayscale images to pseudo-color images to display.

Figure 3 shows a common spectrum amplitude structure, if use linear mapping, it is showed as a straight line in figure, and cannot reflect the meticulous part of the spectrum structure, but if use non-linear mapping method it is showed as a curve, it better reflects the meticulous part of the spectrum structure. In the paper, the amplitude spectrum is 16-bit unsigned integer, so the maximum value is 65535, to map it to a number between 0 and 255.

Non-linear mapping method concrete realization formula is:

$$y = \frac{65535}{256 - x} - 255, \quad 0 \le x \le 255 \quad (4)$$

So:

$$x = 256 - \frac{65535}{y + 255} \quad (5)$$

Observe equation (4), if you want to achieve and design in the FPGA, there are two ways to select: First, according to the formula (5) directly, it can be achieved by calling the internal divider of FPGA. Another method is look-up table.

C. Pseudo-color

Each pixel of pseudo-color images is actually an index value or an address, according to this value the R, G, B color value can be detected. Usually for different applications, if we select appropriate color palette the spectrum can be achieved exactly, but for some specific applications that require custom color palette, it mainly designs a palette board encoding to fit the specific needs [12][13]. Methods used in this article is different from literature [12] and [13], the encoding of palette is not changed non-linear directly, but non-linear map the color index of palette first, that is, do transform of grayscale compression, then find the value of RGB color components in the palette.

IV.   SIMULATION ANALYSIS AND RESULTS

FH signal is a typical non-stationary signal and has the transient nature, traditional Fourier Transform cannot be analyzed accurately, so it needs to adopt time-frequency analysis method which associates the signal time-frequency with characteristics of the frequency. For FH signal, the general form can be expressed as:

$$S(n) = m(t)\cos(2\pi f_j t + \theta_j) \quad (6)$$

$m(t)$ is a data signal and $\cos(2\pi f_j t + \theta_j)$ is carrier

in formula, f_j and θ_j is frequency and phase of the time interval $jT \leq t \leq (j+1)T$, T is frequency hopping interval. In the simulation, we make $\theta_j = 0$, sampling frequency is taken to 10MHz, carrier frequency is hopped from 0MHz to 5MHz. There are 8 hopping frequency points in total: $f_1 = 1.5MHz$, $f_2 = 2.8MHz$, $f_3 = 1.0MHz$, $f_4 = 3.7MHz$, $f_5 = 0.5MHz$, $f_6 = 2.3MHz$, $f_7 = 0.4MHz$, $f_8 = 2.0MHz$; Set one carrier signal in each frequency hopping interval. The specific form of signals is:

$$S(n) = \begin{cases} \sin(2\pi f_1 nT_s) & 0 \leq n \leq 4095 \\ \sin(2\pi f_2 nT_s) & 4096 \leq n \leq 8191 \\ \sin(2\pi f_3 nT_s) & 8192 \leq n \leq 12287 \\ \sin(2\pi f_4 nT_s) & 12288 \leq n \leq 16383 \\ \sin(2\pi f_5 nT_s) & 16384 \leq n \leq 20479 \\ \sin(2\pi f_6 nT_s) & 20480 \leq n \leq 24575 \\ \sin(2\pi f_7 nT_s) & 24576 \leq n \leq 28671 \\ \sin(2\pi f_8 nT_s) & 28672 \leq n \leq 32768 \end{cases} \quad (7)$$

The hamming window is selected, the width is 256 points and 512 points, the FPGA simulation results shown in Figure 4, from the figure we can see the spectrum characteristics of FH signal in the time-frequency domain.

The background of time-frequency spectrum using FPGA simulation is different from Matlab simulation, the main reason is that the design mainly uses a nonlinear mapped amplitude spectrum number between 0 and 255, and then uses this number to find the pseudo-color color-coded table directly, but not to normalize the spectrum values, so the overall result is dark in color. In the time-frequency analysis, good or bad distinguish in signal processing, largely depends on the choice of window function. From the figure we can see the effect of window function on the spectrum: long window allows STFT a better frequency resolution and the details of the frequency domain, short window can reserve the transient characteristics of the signal and describe the fine structure of the signal in time domain.

V. CONCLUSION

In the paper, according to the characteristics of FPGA, a method which bases on FPGA to realize the frequency-hopping (FH) signal analysis system is proposed.
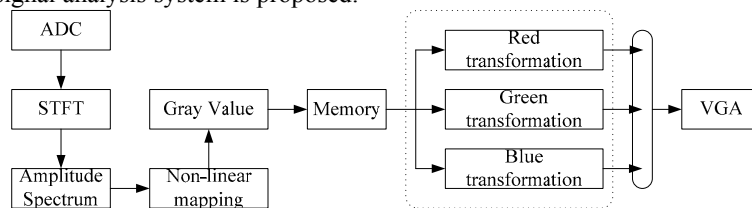
The method does short-time fourier transform of the signal firstly, then according to the structure features of the amplitude spectrum, find a better non-linear mapping method to display the amplitude spectrum, non-linear mapping the calculated 16-bit signal amplitude spectrum, transform it into 8-bit pseudo-color image pixel gray value, by this value the three-component RGB can be found through the lookup table to display, and pseudo-color display of signal spectrum be achieved through the VGA finally. Analysis FH signals and compare with Matlab simulation results, we can see that this design method is correct.

REFERENCES

[1] L.Cohen, Time-Frequency Analysis. Prentice Hall, Englewood Cliffs, New Jersey, 1995.

[2] C.S.Burrus, R.A.Gopinath, and H.Guo, Introduction to Wavelets and Wavelet Transforms, A Primer.Prentice,1998.

[3] Zhao Jun, Zhang Zhao-yang, Lai Li-feng, Cao Qian-qian. Blind Parameter Estimation of Frequency-Hopping Signals Based on Time-Frequency Analysis[J]. Journal of circuits and systems.2003,8(3):46-50.

[4] FAN Hai-ning, Guo Ying. Novel Blind Parameter Estimation Algorithm Of Frequency-Hopping Signals [J].Signal processing, 2009,25(11):1754-1758.

[5] Zhang Xi, Du Xingmin. Time-Frequency Analysis Of Frequency-Hopping Signals Based On Short-Time Hartley Transform[J]. Signal processing, 2009, 25(11):1754-1758.

[6] M.G.Amin, K.D.Feng, Short time Fourier transform using cascade filter structures[J]. IEEE Trans. on Circuits and Systems-II,1995,42(10):631-641.

[7] Wan Hong-xing, Chen He, Han Qiu-yue. A VLSI Architecture Design of High Speed Parallel FFT Processor[J]. Application of Electronic Technique, 2005, 31 (5):45-48.

[8] Wang Chao, HAN Yun Peng. Twin Butterfly High Throughput Parallel Architecture FFT Algorithm[J]. 2008 International Symposium on Information Science and Engieering, 2008:637-640.

[9] Zhang Shi-qun, Yu Dun-shan. Design and implementation of a parallel real-time FFT processor[C]. Proceedings of Solid-State and Integrated Circuits Technology, Beijing, 2004: 1665-1668.

[10] Ray Andraka. A survey of CORDIC algorithms for FPGA based computers[C]. ACM/SIGDA Sixth International Symposium on FPGAs, Monterrey, CA, 1998: 191-200.

[11] J.A.Vite-Frias, R.de J.Romero-Troncoso, A.Ordaz-Moreno. VHDL Core for 1024-Point Radix-4 FFT Computation[C]. Proceedings of the 2005 International Conference on Reconfigurable Computing and FPGA, 2005.

[12] Zhang Jing, Yu Xiao-qing, Xu Hai-Qiong. Speech spectrogram display in pseudo-color based on non-linear transform method[J]. Journal of Computer Applications, 2010, 30(1):270-273.

[13] Cao Mao-Yong, Yu Dao-yin. Pseudo-color coding of high gray-resolution image[J]. Optical Technique,2002,28(2):115-117.
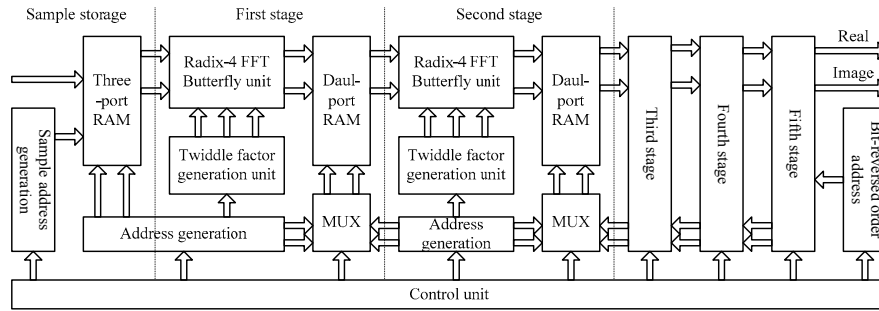
Figure 1. Diagram of Time-Frequency Analysis

Figure 2. Structure of Radix-4 DIT 1024-point FFT processor

Figure 3. Amplitude spectrum mapping method

(a) Window width is 512 points

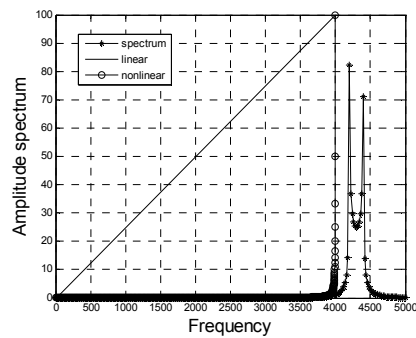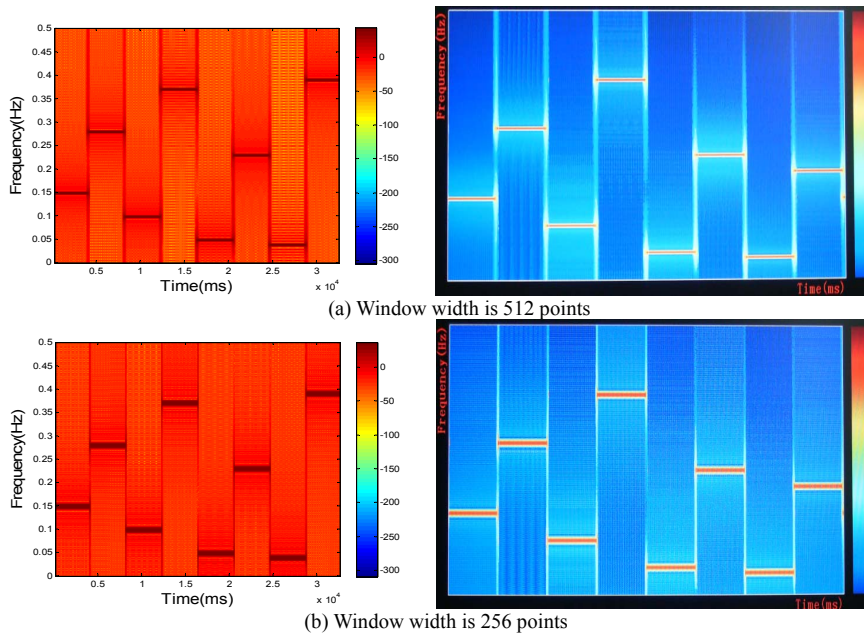(b) Window width is 256 points

Figure 4. Contrast results of STFT based on MATLAB and FPGA