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A Review on Reconfigurable Fourier and Fermat Transforms for Software Radios

Miss. Pandit M.D[*1], Prof. Godbole B.B[2], Miss. Nikam R.H[3]
[*1,2,3] Electronics Engineering Department, KBPCEP, Satara, Shivaji University ,Kolhapur, India
madhuripandit7@gmail.com

Abstract

Reconfiguration is an essential part of Software Radio (SR) technology. The systems are designed for change in operating mode with the aim to carry out several types of computations. In this SR context, the Fast Fourier Transform (FFT) operator is defined as a common operator for many classical telecommunications operations. It reviews a new architecture for this operator that makes it a device intended to perform two different transforms. The first one is the Fast Fourier Transform (FFT) used for the classical operations in the complex field. The second one is the Fermat Number Transform (FNT) used for the finite operations in the Galois Field (GF). This operator can be reconfigured to switch from an operator dedicated to compute the FFT in the complex field to an operator which computes the FNT in the Galois Field.

Keywords: Software Radio, Reconfigurability , FFT, FNT and Galois Field.

Introduction

Software Radio (SR)[1] basically refers to an ensemble of techniques which permits the reconfiguration of a communication system without the need to change any hardware system element. This reconfiguration implies the optimization of the hardware-software resources in the terminal architecture design. So as to help this optimization, a new area of research called ”parameterization” has appeared, whose goal is to identify common resources, i.e Common Operator (CO) or Common Function (CF) between all the standards involved in the reconfiguration and in the standards themselves[2]. The CO approach is presented in [3] and constitutes in which the parameterization is defined. This paper gives the FFT as a common operator and shows how it can make a basic function in many classical telecommunications operations, turning the algorithms into the frequency domain. The remainder of this paper is organized as follows. Section II addresses which FFT is used for FPGA implementation. Section III contains paramerization technique for multi standard systems that represents to exploit a parameterization approach proposed is called the common operator technique that can be considered to build a generic terminal capable of supporting a large range of communication standards. The main principle of the common operator technique was to identify common elements based on smaller structures that could be heavily reused across functions. This technique aims at designing as scalable transceiver based on medium granularity operators, larger than basic logic cells and smaller than Velcro Method or common function. Section IV gives Common Operator for Software Radio system and reconfigurable butterfly. For the transform length equal to Ft, where Ft is the Fermat number, this Number Theoretic Transform (NTT) is called the Fermat Number Transform (FNT) which presents some advantages. It is quite obvious, that FNT is suitable for VLSI implementations. The structure of the FNT is identical to that of the DFT for power of two lengths. Then the same algorithms can be used for the classical radix-2 FFT[4] and the radix-2 FNT. The only one difference is the substitution of the complex multiplication in the Fourier transform by a modulo Ft real multiplication in the case of the FNT. The following gives the definitions of FFT and FNT [3].Section V evaluates complexity. Section VI gives applications of Transform over GF (Ft) for coding. Section VII explains the conclusion.

FFT and its Performance on FPGA

The hardware description and modelling of Digital Signal Processing (DSP) algorithms and applications for implementing on Field Programmable Gate Array (FPGA) chips are challenging issues [5]. FFT algorithms including Cooley-Tukey,Radix-2 and Rader[6] methods are modelled by Verilog hardware description language and their performance are compared in terms of chip area utilization and maximum frequency operation. The results of synthesizing FFT algorithms demonstrate that the Radix-2 FFT method uses the least number of Slices and the Cooley-Tukey and Rader approaches use the most number of Slices. Furthermore, for all methods, the utilized FPGA chip area increases by increasing the number of FFT point. The Radix-2FFT method is the fastest method for calculating FFT [7] as

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compare to Cooley-Tukey FFT method and Rader FFT method. Fig.1 shows comparing FFT methods for slice utilisation and Fig.2 shows comparing FFT methods for flip-flops.

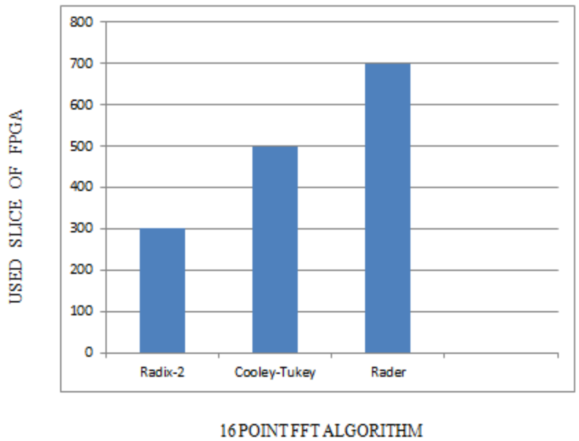

Fig.1: Comparing FFT methods for slice utilisation

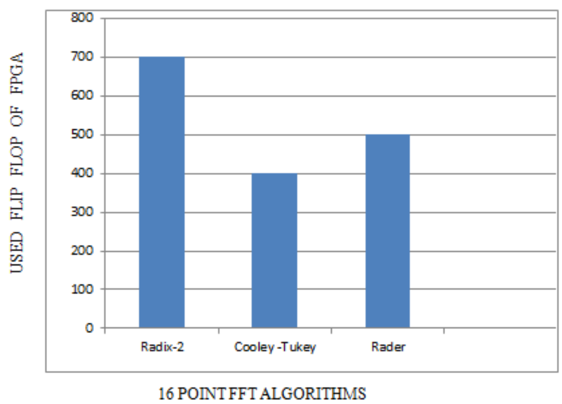

Fig.2: Comparing FFT methods for Flip-flop utilisation

Parametrization Techniques

The conventional approach to implement a multi-standard radio device is to instantiate multiple transceiver chains each dedicated to an individual mode or standard (Fig.3).With this approach most of the hardware needs to be redesigned whenever an additional standard is to be considered. This conventional approach called "Velcro" does not exploit any common aspects between the different

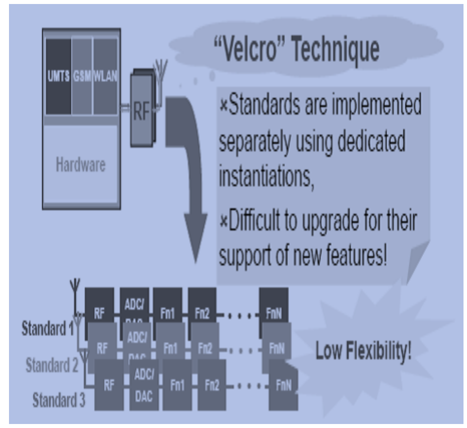

Fig.3: Velcro Technique [8]

standards.[8]. In order to capitalize on the commonalities among the various signal processing operations for different standards, it needs to identify firstly these commonalities and secondly find the optimal way to implement a generic hardware with reconfigurable modules. This idea led to the definition of the Common Function approach (CF) which consists in function sharing between different standards. For each standard all the components dedicated to the same “Functionality” were merged into the same common function. The Common part includes the components required by at least two functions (ore function modes) and each dedicated part is related to the standard specific components of each individual function. The resource sharing brought by the CF approach allows the non-duplication of redundant components and a possible complexity reduction.

Nevertheless all the above mentioned common structures of CF approach have a main drawback: these structures are directly related to a predefined set of standards. Consequently, if the receiver architecture has to be upgraded, the CF should be re-defined and re-designed to be able to meet the requirements of all standards. This has given birth to another approach that will give the possibility to build an open structure. By open structure, it mean a structure whose functionality can be used independently of the processing context or of the communication mode. This new approach called CO approach .The Common Operator (CO) [9] approach follows the principles that of Common Function and consists in identifying lower granularity common elements based on structural aspects. The intrinsic design of the CO is performed independently of standards. Thus, a CO is defined to perform signal processing operations regardless of the function executed. This approach aims at designing a scalable transceiver based on medium granularity operators, larger than basic logic cells and smaller than functions. In contrast with the CF, a CO is

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not specific to a single function set; it permits a more flexible design and scalable to a wide range of standards.

Common Operator for Software Radio System and Reconfigurable Butterfly

A. FFT over complex field

Fourier transform theory over complex field as well as finite field. In the complex field (**C**), the Discrete Fourier Transform of $f_n = (f_0, f_1, \ldots, f_{N-1})$, a vector of real or complex numbers, is a vector $F = (F_0, F_1, \ldots, F_{N-1})$, given by[8][10],

$$F_k = \sum_{n=0}^{N-1} f_n W_N^{kn} \qquad k = 0,1,\ldots\ldots,N-1$$

Where, $W_N = \exp(-2j\pi/N)$ and $j = -1$. W_N^{kn} is referred as the twiddle factor. The Fourier kernel $\exp(-2j\pi/N)$ is an N^{th} root of unity in the field **C**. In the finite field GF(q), an element α of order N is an N^{th} root of unity. Fig.4 shows 16 point radix -2over complex field.

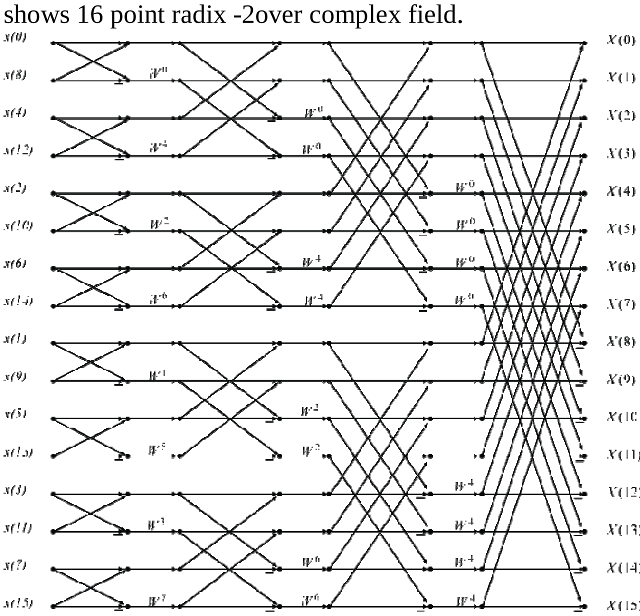

Fig.4: 16 point Radix -2 Decimation in Time over complex field

B. FFT over finite field

With the Fourier Transform, the concept of coding theory can be described in a setting that is much closer to the methods of signal processing. In complex field, the Fourier kernel exp(-2jπ/N) is an N^{th} root of unity in the field of complex numbers. In the finite field $GF(q)$ an element α of order N is an N^{th} root of unity. Drawing on the analogy between exp(-2jπ/N) and α, Fourier transform over finite field can be defined as follows let $f = (f_0, f_1, \ldots, f_{N-1})$ be a vector over $GF(q)$, and let α be an element of $GF(q)$ of order N. The Fourier transform of vector f is the vector $F = (F_0, F_1, \ldots, F_{N-1})$ whose components are given by[3][8],

$$F_j = \sum_{n=0}^{N-1} f_i \alpha^{ij} \qquad j = 0, \ldots.\mathrm{N}-1.$$

Vector f is related to its spectrum F by,

$$f_j = \frac{1}{N}\sum_{n=0}^{N-1} F_j \alpha^{ij} \qquad i = 0, \ldots.\mathrm{N}-1.$$

It is natural to call the discrete index i time taking values on the time axis 0, 1, ...,N-1, and to call f the time-domain function' or the 'signal'. Fourier transform in Galois field closely mimics the Fourier transform in the complex field with one important difference: in the complex field an element W of order N (e.g. exp (-2jπ/N)), exists for every value of N but in $GF(q)$, such an element W exists only if N divides q-1. Moreover, if for some values of m, N divides q^{m-1} then there will be a Fourier transform of length N in the extension field $GF(q^m)$.Fig.5 represent 16 point Radix -2 decimation in time domain over GF(F_n)

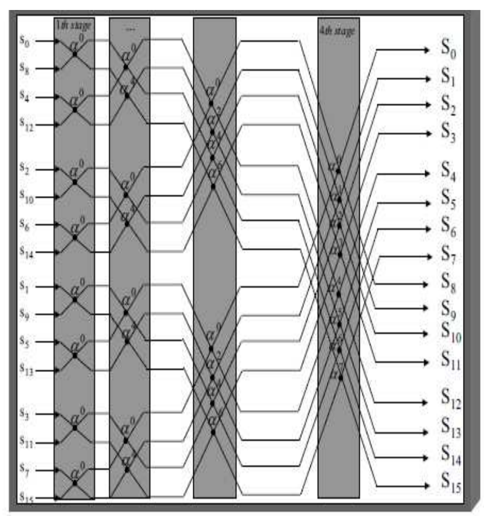

Fig.5: 16 point Radix -2 decimation in time domain over GF(F_n)

C. Reconfigurable butterfly

Hardware realization of the common operator can be now presented to perform with the same architecture Fourier transforms over $GF(F_t)$ and over complex field**.** The classical complex FFT architecture is re-design in way to enable to perform the FNT. A radix-2 FFT implementation is considered because it has advantages in terms of regularity of hardware, ease of

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computation and number of processing elements. Obviously, for a given transform length N power of 2 (or power of 4), the algorithm chosen to be applied to perform FFT should be valid to perform the FNT. Indeed, since the symmetry and periodicity properties $\alpha^{K+N}=\alpha^{K}$ and $\alpha^{K+N/2}=-\alpha^{k}$ are verified, every radix-2 algorithm applied to FFT can be applied to the FNT. The heart of this algorithm known as the "butterfly" is redesigned. Here re-designing means taking into account the reconfiguration of the operators constituting the butterfly as well as the connection between those operators. The switching from FFT mode to FNT mode should be accompanied by the replacement of the twiddle factor W by the primitive element α of the given Galois field [11].

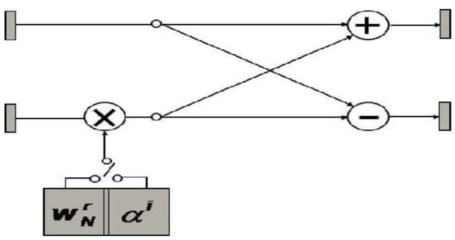

Fig.6: FFT/FNT butterfly

Fig.6 shows butterfly structure with two operating mode This architecture consist of three arithmetic operator: multiplier adder and subtractor. In the FFT mode these operators process complex data by performing complex multiplications and additions. In the FNT mode data are defined over finite field and the operations performing FNT are done modulo F_t. So, these arithmetic operators should be re-designed to be able to support complex and modular operations.

In the FFT mode these operators process complex data by performing complex multiplications and additions. In the FNT mode data are defined over finite field and the operations performing FNT are done modulo F_t. in Fig.7. One can consider two operating modes: the first one is the Fast Fourier Transform computation over complex field; then the Fourier kernel $exp(-j2\pi/N)$ is downloaded and the block "Mod F_n" is switched to an idle mode. The second one is the Fast Fourier Transform computation over $GF(F_n)$; in this operating mode, the primitive element α^n is downloaded and the block "mod F_n" is switched on to perform the division modulo F_n for the output of the "FFT" block [10].

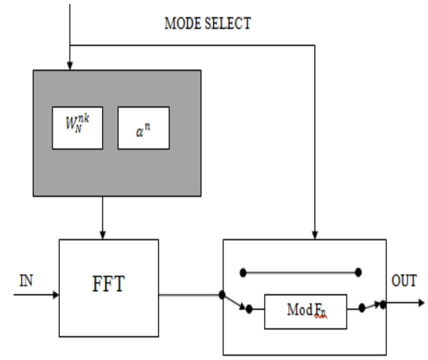

Fig.7: The reconfigurable FFT operator

Complexity Evaluation

In order to evaluate the complexity and speed performance of this operator, it is considered Dual Mode FFT (DMFFT) implementation on FPGA. Compared to a Velcro FFT/FNT operator, its exhibits larger gains in terms of memory saving. For a transform length N=64 implemented with different word lengths ($9\leq n_c \leq 16$), DMFFT operator shows a memory saving[11].

Table I shows the implementation measures given by A. Al Ghouwayel and Yves Louet , for the DMFFT-64 implemented for different word-lengths n_c. The Fourier/Fermat transforms that can be performed in this same architecture have N=64 as transform length. According to these figure it notice that depending on word length DMFFT exhibits a memory saving.

TABLE 1.Comparison between DMFFT and Velcro ON FPGA for N= 64[11]

n_c	9	10	11	12	13	16
Velcro	4205 ALUT	4768 ALUT	5156 ALUT	5831 ALUT	6064 ALUT	8143 ALUT
DMFFT	3109 ALUT	3744 ALUT	4112 ALUT	4857 ALUT	5182 ALUT	7387 ALUT
Memory saving (%)	33	31	29	27.2	25.7	21.9

Application of Transform Over GF(F_t)

The most popular class of Reed-Solomon (RS)[12] cyclic codes are defined over $GF(q=2^m)$. RS codes are considered as ones of the most powerful algebraic codes and have found many applications in telecommunications in the last years. RS codes are characterized by their powerful correction capacity of burst errors. They are used extensively for correcting both errors in many systems as space communication links, Compact- Discs (CD), audio systems, High-

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Definition (HD) TV, Digital Versatile Discs and wireless communication systems. So this reconfigurable FFT is to be applied to RS codes as well as to requiring the complex Fourier Transform.

Conclusion

In this paper using software Radio concept and it's feature reconfiguration can be achieved using the parameterization technique for Fast FFT as common operator in telecommunication system.

For this purpose Radix-2 algorithm is used because of its features .So the re-design of the FFT operator in such a way to be able to provide two functionalities: complex Fourier transform and Fermat transform. DMFFT CO constitutes a promising candidate for integrating a SR system intending to support several standards. So the design of arithmetical operator able to operate over complex field and Galois field.

In order to evaluate the complexity and speed performance , it implemented on FPGA.

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