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# FPGA Implementation of Low Power FIR Filter using Modified Booth Algorithm

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***Abstract*— In the implementation of many digital signal processing, image processing and multimedia algorithms multipliers and adders are widely used. In this paper we can see overview of fir filter by using modified booth multiplier. The speed of the booth multiplier is increased by reducing the delay. This paper presents radix2 and radix4 modified booth multipliers along with sixteen bit full adder which is used to implement FIR filter. So by analyzing the working of booth multiplier helps to frame a better system with less power consumption and lesser area. The code is written in VHDL and the tool used is Xilinx ISE9.1i. Fir filter is implemented on Spartan-3 FPGA with the device package XC3S400.**
***Keywords*— Radix2 multiplier,Radix4 multiplier,speed ,power consumption ,Booth algorithm***

## I. INTRODUCTION

The FIR filter takes in input samples, processes them, and outputs the samples. A large percentage of filters implemented in the digital domain are Finite Impulse Response (FIR) filters. A filter is a sequence h(n) that operates on an input sequence x(n) to generate output sequence y(n). Since FIR filter has no feedback in its structure, it is always a stable filter and consumes less power. Multipliers are the key components in implementing FIR Filter. The early computer systems had what are known as multiply and Accumulate units to perform multiplication between two binary unsigned numbers. The multiply and Accumulate unit was the simplest implementation of a multiplier [1]. The very advanced efficient multiplier used in order to implement low power FIR filter is modified booth multiplier. This multiplier uses two methods that is radix2 and radix4. Radix4 method is referred as modified booth multiplier. FIR filters is simple to design. They are guaranteed to be bounded input-bounded output (BIBO) stable. It can be guaranteed to have linear phase. This is a desirable property for many applications such as music and video processing.FIR filters also have a low sensitivity to filter coefficient quantization errors. This is an important property to have when implementing a filter on a DSP processor or on an integrated circuit.

## II. MULTIPLICATION ALGORITHM

The multiplication algorithm for an N bit multiplicand by N bit multiplier is shown below:

Y= Yn-1 Yn-2 .....Y2 Y1 Y0 Multiplicand
X= Xn-1 Xn-2 ..... X2 X1 X0 Multiplier

Multiplication Algorithm in steps

1) If the LSB of Multiplier is '1', then add the multiplicand into an accumulator.
2) Shift the multiplier one bit to the right and multiplicand one bit to the left.
3) Stop when all bits of the multiplier are zero.

From above it is clear that the multiplication has been changed to addition of numbers. If the Partial Products are added serially then a serial adder is used with least hardware. It ispossible to add all the partial products with one combinational circuit using a parallel multiplier. The multiplier used in order to boost up the speed is Booth multiplier. The tool used to simulate and synthesis is Xilinx ISE9.1i using ISE Simulator.

## III.BOOTH ALGORITHM

Benefit of this algorithm is that it deals with positive and negative numbers in same way [2]. To know booth algorithm we need to know the concept of 2's complement.2's complement represents the number in negative form

### *A. Conditions for general 2's complement*

1) Any number starting with zero is positive number in 2's complement.
2) Any number starting with one is negative number in 2's complement.

Examples: +5 = 0101(it is positive)



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-5= 101 (it is negative)
+13 = 01101
-9= 01001(+9) =10111

If the number is negative, write the positive form of that number and then take the 2's complement. In Booth algorithm number is represented in 2's complement always**.**

*B. Radix 2 method*

This method tells that it always takes 2 bits as shown in Table I.

TABLE I.

| $y_i$ | $y_{i-1}$ | Partial product |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | -1 |
| 1 | 1 | 0 |

Radix 2 algorithm as follows:

1.If multiplier is Zero write all 0's and extend the sign bit till 2n positions.

2. If multiplier is one write the multiplicand as it is and extend the sign bit till 2n positions.

3. If multiplier has -1, take the 2's complement of multiplicand and extend the sign bit till 2n positions.

*C. Radix 4 method*

This method tells that it always takes 3 bits as shown in Table II. The problem with radix 2 method is that it is not suitable for synchronous designs[3]. Hence we go for grouping 3 bits and It is referred as Modified Booth Algorithm. In Radix 4 method multiplier bits are grouped together and for each group of three bits partial product is generated. The overlapping is necessary so as to know what was happened in the last block as the MSB of the block act as sign bit.

TABLE II

| Multiplier bits | | | Operation On Multiplicand |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | +1 |
| 0 | 1 | 0 | +1 |
| 0 | 1 | 1 | +2 |
| 1 | 0 | 0 | -2 |
| 1 | 0 | 1 | -1 |
| 1 | 1 | 0 | -1 |
| 1 | 1 | 1 | 0 |

*D. Adders*

In order to implement FIR Filter sixteen bit full adder is used. A full adder is a logical circuit that performs an addition operation on three binary digits. The full adder produces a sum and carries value, which are both binary digits. It can be combined with other full adders or work on its own.



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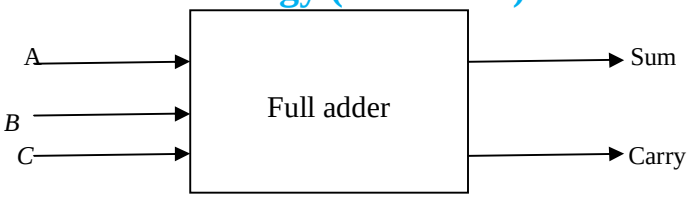


Fig1.Block diagram of Full Adder

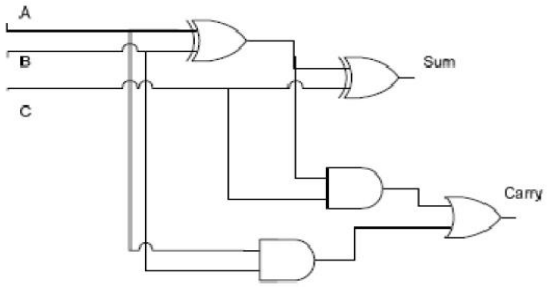


Fig 1. Gate level representation of a FULL ADDER.

Sum=A XOR B XOR C
Carry=(A OR B) AND (B OR C) AND (C OR A)

*D. Finite Impulse Response (FIR) Filter*

FIR filters have impulse responses of finite lengths. In FIR filters the present output depends only on the past and present values of the input sequence but not on the previous output sequences. Thus they are non recursive hence they are inherently stable.FIR filters possess linear phase response [4]. Hence they are very much applicable for the applications requiring linear phase response.

The difference equation of an FIR filter is represented as

$$y(n)= x(n) * h(n)$$

x(n) is the input sample and h(n) is the filter co-efficient. The output of FIR filter is the convolution of x(n) and h(n). FIR filters possess linear phase response. Hence they are very much applicable for the applications requiring linear phase response [5] .

## IV. RESULTS

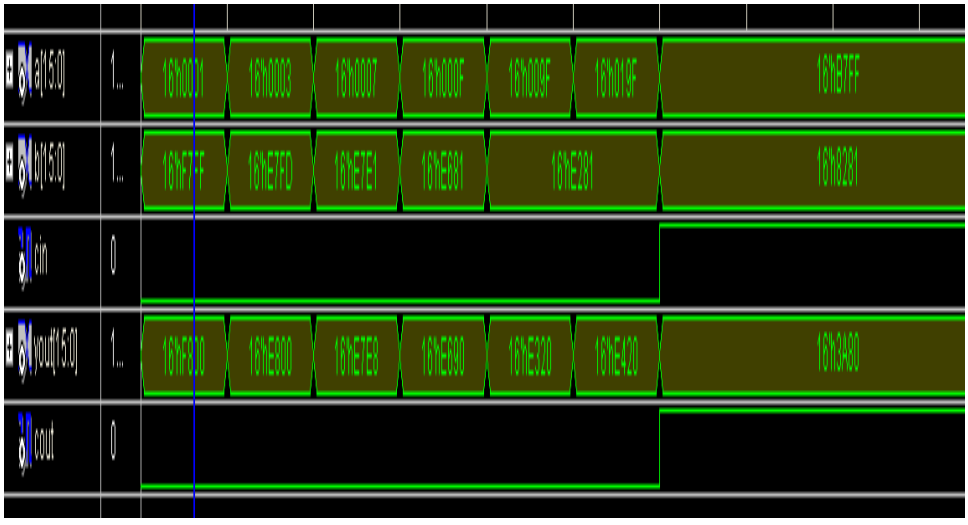


Fig 2: Simulation of 16-bit carry adder



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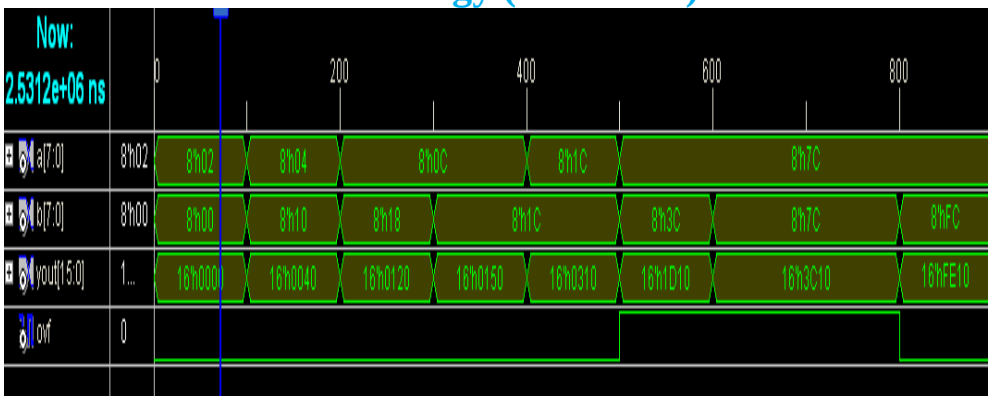


Fig 3: Simulation of Radix-4 Multiplier

| Max Delay | Netname |
|---|---|
| 4.020 | b_3_IBUF |
| 3.257 | b_4_IBUF |
| 3.078 | b_0_IBUF |
| 2.827 | b_2_IBUF |
| 2.820 | a_4_IBUF |
| 2.771 | b_1_IBUF |
| 2.762 | b_5_IBUF |
| 2.714 | a_6_IBUF |
| 2.651 | a_2_IBUF |
| 2.550 | a_1_IBUF |
| 2.531 | b_6_IBUF |
| 2.476 | a_3_IBUF |
| 2.445 | a_5_IBUF |
| 2.443 | yout_14_OBUF |
| 2.426 | a_0_IBUF |
| 2.414 | a_7_IBUF |
| 2.401 | yout_10_OBUF |
| 2.207 | yout_12_OBUF |
| 2.120 | b_7_IBUF |
| 2.073 | u3/N11 |

Fig4: Delay report of Radix-4 Multiplier

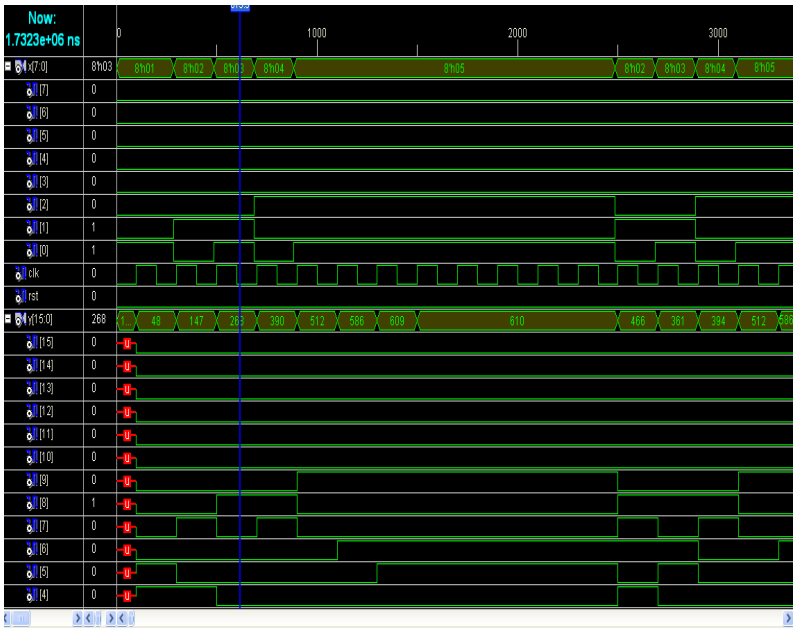


Fig5: Simulation of FIR Filter


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| | |
|---|---|
| Ambient Temperature (°C) | 25 |
| Junction Temperature (°C) | 26.85 |
| Case Temperature (°C) | 26.51 |
| Part Type | Commercial |
| Airflow (LFM) | 0 |
| Package | tq144 |
| **Total Power (mW)** | 56.01 |

Fig 6: Total estimated power of FIR Filter

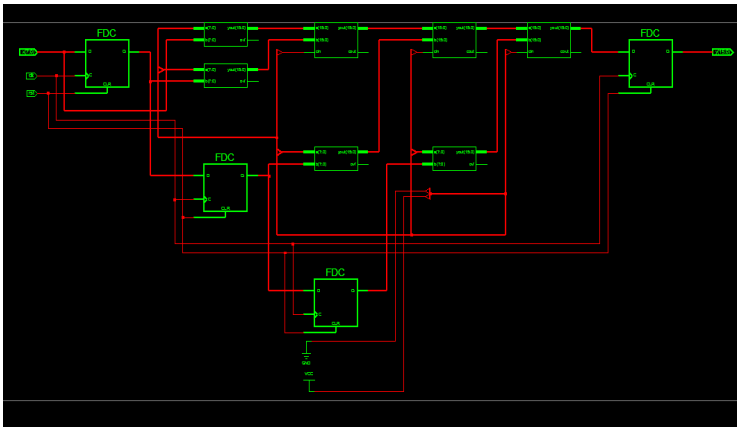


Fig 7: RTL Schematic of FIR Filter

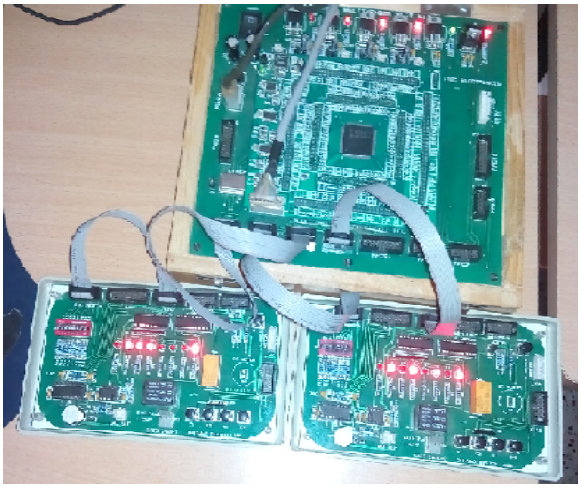

Fig.8: Fir filter Hardware implementation on Spartan-3 on FPGA

## V. CONCLUSION

The modified booth multiplier is successfully implemented in tap delay Fir Filter. The code is written in VHDL and successfully simulated and synthesized using Xilinx ISE9.1 using Spartan-3 FPGA. It is shown that modified booth multiplier is fast in computation as a result speed increases. Hence when computations steps reduce FIR filter consumes less area and power. Hardware implementation of FIR Filter is done on Spartan-3 FPGA and the device used is XC3S400 with package TQ144. Hence we can conclude that radix 4 modified booth algorithm works the best.



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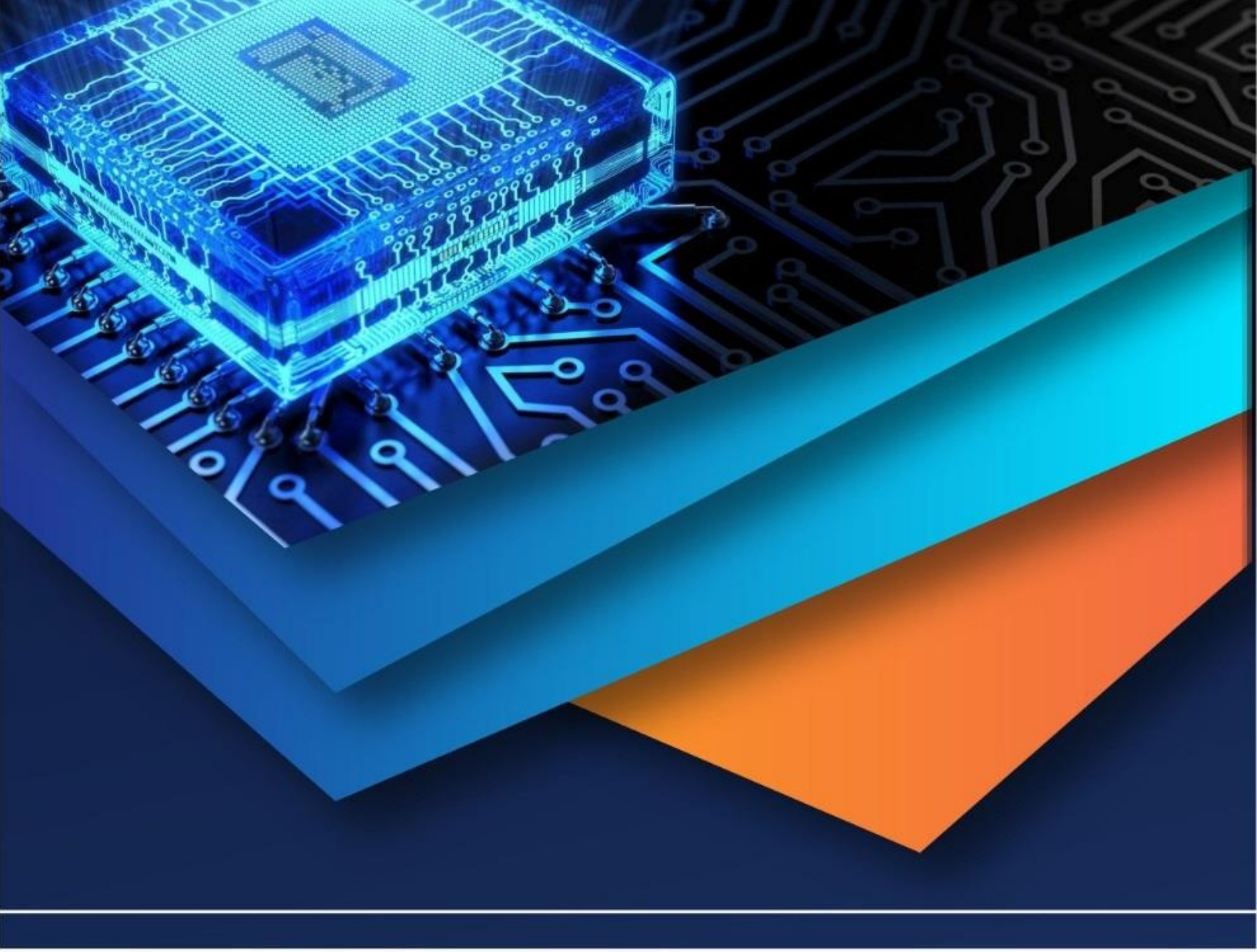

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