

## Design and Analysis of Low Power and Area Efficient Multiplier

M.Jayaprakash<sup>1</sup>, M.Peer Mohamed<sup>2</sup>, Dr.A.Shanmugam<sup>3</sup>

**Abstract**— A multiplier is one of the key hardware blocks in most digital and high performance systems such as FIR filters, digital signal processors and microprocessors etc [1]. The area and speed of the multiplier is an important issue, increment in speed results in large area consumption and vice versa. Performance of a system depends to a great extent on the performance of multiplier thus multipliers should be fast and consume less area and hardware. This idea forced us to study and review about the Booth's Algorithm, modified Booth's algorithm and its radix-4 forms.

**Keywords**— Booth multiplier, digital signal processing (DSP), FIR filters.

### I. INTRODUCTION

As the scale of integration keeps growing, more and more sophisticated signal processing systems are being implemented on a VLSI chip. These signal processing applications not only demand great computation capacity but also consume considerable amount of energy. While performance and Area remain to be the two major design tolls, power consumption has become a critical concern in today's VLSI system design[2]. The need for low-power VLSI system arises from two main forces. First, with the steady growth of operating frequency and processing capacity per chip, large currents have to be delivered and the heat due to large power consumption must be removed by proper cooling techniques. Second, battery life in portable electronic devices is limited. Low power design directly leads to prolonged operation time in these portable devices. Multiplication is a fundamental operation in most signal processing algorithms. Multipliers have large area, long latency and consume considerable power. Therefore low-power multiplier design has been an important part in low- power VLSI system design. There has been extensive work on low-power multipliers at technology,

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physical, circuit and logic levels. A system's performance is generally determined by the performance of the multiplier because the multiplier is generally the slowest element in the system[3]. Furthermore, it is generally the most area consuming. Hence, optimizing the speed and area of the multiplier is a major design issue. However, area and speed are usually conflicting constraints so that improving speed results mostly in larger areas. As a result, a whole spectrum of multipliers with different area- speed constraints has been designed with fully parallel.

In chapter II, the different types of adders are discussed since adder forms the basic building block of the multiplier. In chapter III, different multipliers are compared. The analysis of adders and multipliers is done in chapter IV.

### II. THE ADDERS

The adder topology used in this work are ripple carry adder, carry look ahead adder and carry select adder.

#### A. Ripple Carry Adder (RCA)

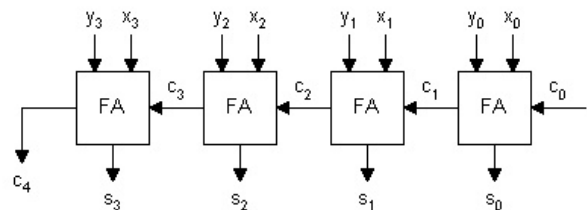


Fig.1. 4-bit Ripple Carry Adder

The ripple carry adder is constructed by cascading full adders (FA) blocks in series. One full adder is responsible for the addition of two binary digits at any stage of the ripple carry. The carryout of one stage is fed directly to the carry-in of the next stage. Even though this is a simple adder and can be used to add unrestricted bit length numbers, it is however not very efficient when large bit numbers are used. One of the most serious drawbacks of this adder is that the delay increases linearly with the bit length[4]. The worst-case delay of the RCA is when a carry signal transition ripples through all stages of adder chain from the least significant bit to the most significant bit, which is approximated by

$$t = (n-1)t_c + t_s$$

where  $t_c$  = delay through the carry stage of a full adder

$t_s$  = delay to compute the sum of the last stage.

Delay from Carry-in to Carry-out is more important than from A to carry-out or carry-in to SUM, because the carry-propagation chain will determine the latency of the whole circuit for a Ripple-Carry adder. Considering the above worst-case signal propagation path we can thus write the following equation.

For a k-bit RCA worst case path delay is

$$TRCA-k \text{ bit} = TFA(x_0, y_0 c_0) + (k-2) * TFA(Cin Ci) + TFA(Cin Sk-1)$$

**B. Carry Select Adders (CSLA)**

In Carry select adder scheme, blocks of bits are added in two ways: one assuming a carry-in of 0 and the other with a carry-in of 1. This results in two pre computed sum and carry-out signal pairs ( $s_{0i-1:k}$ ,  $c_{0i}$ ;  $s_{1i-1:k}$ ,  $c_{1i}$ ), later as the block's true carry-in ( $ck$ ) becomes known, the correct signal pairs are selected. Generally multiplexers are used to propagate carries.

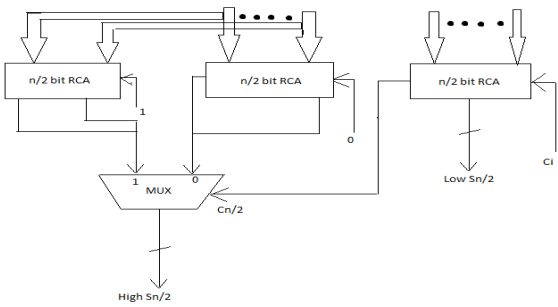


Fig.2. Carry Select Adder

We always go for Carry Select Adder while working with smaller no of bits. The propagation path delay is given by

$$s_{i-1:k} = c_k s_{0i-1:k} + c_k s_{1i-1:k} \quad c_i = c_k c_{0i} + c_k c_{1i}$$

**C. Carry look ahead Adder**

In ripple carry adders, the carry propagation time is the major speed limiting factor[13]. Accordingly, reducing the carry propagation delay of adders is of great importance. Different logic design approaches have been employed to overcome the carry propagation problem. Carry look-ahead adder is designed to overcome the latency introduced by the rippling effect of the carry bits. The propagation delay occurred in the parallel adders can be eliminated by carry look ahead adder. This adder is based on the principle of looking at the lower order bits of the augends and addend if a higher order carry is generated. This adder reduces the carry delay by reducing the number of gates through which a carry signal must propagate. Carry look ahead depends on two things: Calculating for each digit position, whether that position is

going to propagate a carry if one comes in from the right and combining these calculated values to be able to deduce quickly whether, for each group of digits, that group is going to propagate a carry that comes in from the right. The net effect is that the carries start by propagating slowly through each 4-bit group, just as in a ripple-carry system, but then moves 4 times faster, leaping from one look ahead carry unit to the next. Finally, within each group that receives a carry, the carry propagates slowly within the digits in that group.

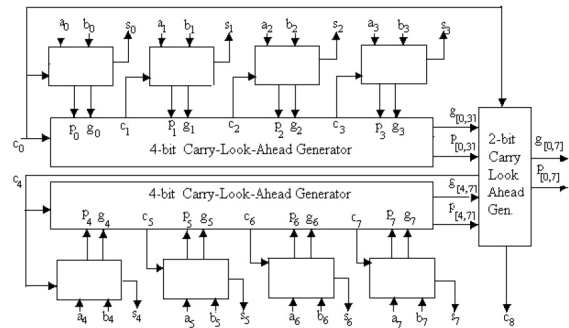


Fig.3. 8-bit Carry Look ahead Adder

This adder consists of three stages: a propagate block/generate block, a sum generator and carry generator[6]. The generate block can be realized using the expression

$$G_i = A_i B_i \text{ for } i=0, 1, 2, 3$$

Similarly the propagate block can be realized using the expression

$$P_i = A_i \oplus B_i \text{ for } i=0, 1, 2, 3$$

The carry output of the (i-1) th stage is obtained from

$$C_i(cout) = G_i + P_i C_{i+1} \text{ for } i=0, 1, 2, 3$$

The sum output can be obtained using

$$S_i = A_i \oplus B_i C_{i+1} \text{ for } i=0, 1, 2, 3$$

An 8 bit look ahead adder using two four bit look ahead block is shown in Figure 3 the COUT of the 4-bit CLA is given as the CIN for the second 4-bit CLA.

III. THE MULTIPLIERS

A. The Wallace Tree Multiplier

The Wallace tree multiplier is considerably faster than a simple array multiplier because its height is logarithmic in word size, not linear. However, in addition to the large number of adders required, the Wallace tree's wiring is much less regular and more complicated. As a result, Wallace trees are often avoided by designers, while design complexity is a concern to them. Wallace tree styles use a log-depth tree network for reduction. Faster, but irregular, they trade ease of layout for speed. Wallace tree styles are generally avoided for

low power applications, since excess of wiring is likely to consume extra power[4][5]. While subsequently faster than Carry-save structure for large bit multipliers, the Wallace tree multiplier has the disadvantage of being very irregular, which complicates the task of coming with an efficient layout. The Wallace tree multiplier is a high speed multiplier. The summing of the partial product bits in parallel using a tree of carry-save adders became generally known as the “Wallace Tree”.

Three step processes are used to multiply two numbers.

1. Formation of bit products.
2. Reduction of the bit product matrix into a two row matrix by means of a carry save adder.
3. Summation of remaining two rows using a faster Carry Look Ahead Adder (CLA).

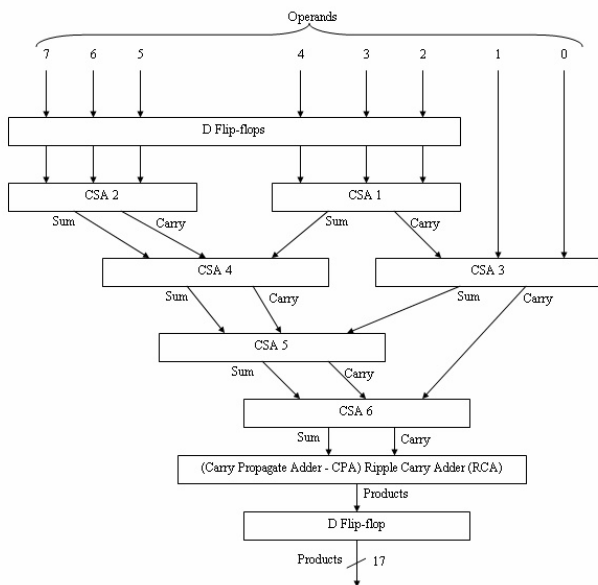


Fig.4. Wallace Tree Multiplier

In order to design an n-bit Wallace tree Multiplier (Generic: =N) an algorithm was derived from the flow diagram developed. The flow diagram shows the intermediate state reductions of the multipliers are being done by Carry save adders and half adders while the final step additions being done by a Carry Look Ahead Adder. After generating the flow diagram for 8-bit × 8-bit we generalized the algorithm for n-bit and hence we designed a Generic Wallace Tree.

**B. The Booth's Multiplier**

Though Wallace Tree multipliers were faster than the traditional Carry Save Method, it also was very irregular and hence was complicated while drawing the Layouts. Slowly when multiplier bits gets beyond 32-bits large numbers of logic gates are required and hence also more interconnecting

wires which makes chip design large and slows down operating speed Booth multiplier can be used in different modes such as radix-2, radix-4, radix-8 etc. But we decided to use Radix-4 Booth's Algorithm because of number of Partial products is reduced to n/2.

**Booth Multiplication Algorithm**

One of the solutions realizing high speed multipliers is to enhance parallelism which helps in decreasing the number of subsequent calculation stages. The Original version of Booth's multiplier (Radix – 2) had two drawbacks.

1. The number of add / subtract operations became variable and hence became inconvenient while designing Parallel multipliers.
2. The Algorithm becomes inefficient when there are isolated 1s .

These problems are overcome by using Radix 4 Booth's Algorithm which can scan strings of three bits with the algorithm given below. The design of Booth's multiplier in this project consists of four Modified Booth Encoded (MBE), four sign extension corrector, four partial product generators (comprises of 5:1 multiplexer) and finally a Wallace Tree Adder. This Booth multiplier technique is to increase speed by reducing the number of partial products by half. Since an 8-bit booth multiplier is used, so there are only four partial products that need to be added instead of eight partial products generated using conventional multiplier. The architecture design for the modified Booths Algorithm is shown in figure 5.

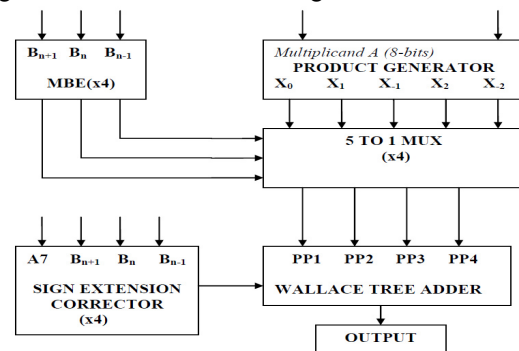


Fig.5. Modified Booth Multiplier Architecture

**Modified Booth Encoder**

Modified Booth encoding is most often used to avoid variable size partial product arrays. Before designing a MBE, the multiplier has to be converted into a Radix-4 number by dividing them into three digits respectively as shown in Booth Encoder Table 1. Prior to convert the multiplier, a zero is appended into the Least Significant Bit (LSB) of the multiplier. The figure 5 shows that the multiplier has been divided into four partitions and hence that mean four partial

products will be generated using booth multiplier approach instead of eight partial products being generated using conventional multiplier.

$$Z_n = -2 * B_{n+1} + B_n + B_{n-1}$$

Let's take an example of converting an 8-bit number into a Radix-4 number. Let the number be  $-46 = 11011100$ . Now we have to append a '0' to the LSB. Hence the new number becomes a 9-digit number, that is  $110111000$ . This is now further encoded into Radix-4 numbers according to the following given table. Starting from right we have  $0 * \text{Multiplicand}$ ,  $-1 * \text{Multiplicand}$ ,  $2 * \text{Multiplicand}$ ,  $-1 * \text{Multiplicand}$ .

$B_{n+1}$	$B_n$	$B_{n-1}$	$Z_n$	Partial Product	1M	2M	3M
0	0	0	0	0	1	1	0
0	0	1	1	$1 * \text{Multiplicand}$	0	1	0
0	1	0	1	$1 * \text{Multiplicand}$	0	1	0
0	1	1	2	$2 * \text{Multiplicand}$	1	0	0
1	0	0	-2	$-2 * \text{Multiplicand}$	1	0	1
1	0	1	-1	$-1 * \text{Multiplicand}$	0	1	1
1	1	0	-1	$-1 * \text{Multiplicand}$	0	1	1
1	1	1	0	0	1	1	0

Table 1. Modified Booth Encoder's table

Table 1 shows  $B_{n+1}$ ,  $B_n$  and  $B_{n-1}$  which are three bits wide binary numbers of the multiplier  $B_{in}$  which  $B_{n+1}$  is the most significant bit (MSB) and  $B_{n-1}$  is the least significant bit (LSB).  $Z_n$  is representing the Radix-4 number of the 3-bit binary multiplier number. For example, if the 3-bit multiplier value is "111", so it means that multiplicand A will be 0. And it's the same for others either to multiply the multiplicand by -1, -2 and so on depending on 3 digit number. And thing to note is generated numbers are all of 9-bit. From the table 4.1, the M, 2M and 3M are the elect control signals for the partial product generator[7][8]. It will determine whether the multiplicand is multiplied by 0, -1, 2 or -2. M and 2M are designed as an active low circuit which means if let's say the multiplicand should be multiplied by 1 then the M select signal will be set to low "0" whereas If the multiplicand should be multiplied by 2 then the 2M select signal will be set to low "0". The 3M is representing the sign bit control signal and its active high circuit which means if the multiplicand should be multiplied by -1 or -2, then the sign, 3M will be set to high "1"[16].

#### IV. ANALYSIS OF ADDERS AND MULTIPLIERS

##### A. Analysis of Adders

We compared 3- different adders Ripple Carry Adders, Carry Select Adders and the Carry Look Ahead Adders. The basic purpose of our experiment was to know the time and power trade-offs between different adders which will give us a clear picture of which adder suits best in which type of

situation during design process. Hence below we present both the theoretical and practical comparisons of all the three adders which were taken into consideration.

Adder Name	Delay for n-bit	Area for n-bit	Area Delay Product
Ripple Carry Adder (RCA)	$2n$	$7n$	$14n^2$
Carry Select Adder (CSLA)	$2.8(n)^{1/2}$	$14n$	$39.6(n)^{3/2}$
Carry Look ahead Adder (CLA)	$4\log_2 n$	$4n$	$16n\log_2 n$

Table 2. Theoretical Area Delay product

Adder Name	Delay for 8-bit
Ripple Carry Adder (RCA)	20.2 ns
Carry Select Adder (CSLA)	12.4 ns
Carry Look ahead Adder (CLA)	13.4 ns

Table 3. Simulated Adders Delay

As can be seen above we have stated the theoretical comparison of area required and both the theoretical and simulated value of time required. The values stated above are the values for 8-bit adders. So analyzing the above facts we reached at the following conclusions about different adders and intelligent use of them in different circumstances according to the space time trade-off. The results can be summarized as follows.

1. Regarding the circuit area complexity in the adder architectures, the ripple-carry adder (RCA) in the first class is the most efficient one, but the carry select adder (CSLA) in the fourth class with highest complexity is the least efficient one.

2. Considering the circuit delay time, carry select adder (CSLA) is the fastest one for every n-bit length, so has the shortest delay. Otherwise, ripple carry adder (RCA) is the slowest one, due to the long carry propagation.

We defined a term area-delay product which gave us the clear picture of the space-time tradeoff. It is worthy to note that while we consider all the adders discussed above ripple carry adders and carry select adders are the two sides of the spectrum. Because, while ripple carry adders have a smaller area and lesser speed, in contrast to which carry select adders have high speed (nearly twice the speed of ripple carry adders) and occupy a larger area. But carry look ahead adder (CLA) has a proper balance between both the area occupied and time required. Hence among the three, carry look ahead adder has the least area delay product. Hence we should use carry look ahead adders when it comes to optimization with both area and time. For an instance, the last stage of the wallace tree adder in booth multiplier is a carry look ahead adder.

*B. Analysis of Multipliers*

The different multipliers are compared on the basis of their speed and power parameters. We used Xilinx ISE version 10.2 for our simulation of different multipliers and knowing their delays. We analyzed Array Multipliers, Wallace Tree Multipliers and Booth Multiplier (Radix-2 and Radix-4) and analyzed their speed and power consumption using the above.

Parameters	Values
Number of Slices	96
Number of 4-input LUTs	178
Number of Bonded Input	32
Number of Bonded Output	32
Power	124mW

Table 4. Array Multiplier

Parameters	Values
Number of Slices	72
Number of 4-input LUTs	130
Number of Bonded Input	32
Number of Bonded Output	32
Power	114mW

Table 5. Booth Multiplier (Radix-2)

Parameters	Values
Number of Slices	69
Number of 4-input LUTs	125
Number of Bonded Input	32
Number of Bonded Output	32
Power	81mW

Table 6. Wallace Tree Multiplier

Parameters	Values
Number of Slices	96
Number of 4-input LUTs	178
Number of Bonded Input	32
Number of Bonded Output	32
Power	76mW

Table 7. Booth Multiplier (Radix-4)

consuming highest amount of power. Then comes the Radix – 2 booth multiplier which consumes lesser power than array multiplier. The Wallace Tree multiplier and Booth Multiplier Radix-4 have nearly same amount of delay while Radix-4 Booth consuming lesser power than the other. Hence we reach to a conclusion that Booth Radix-4 Multiplier is best for situations requiring Low power Applications.

**Booth Multiplier Output**

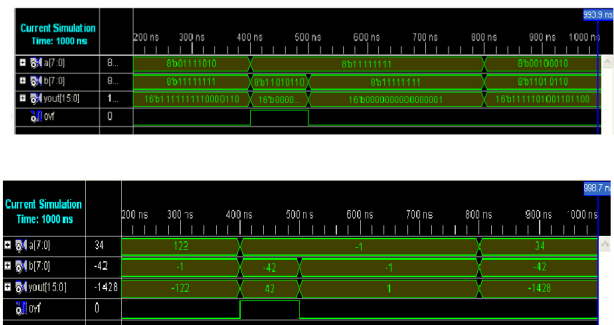


Fig.6. Output of Booth Multiplier (Radix-8)

**V. CONCLUSION AND FUTURE WORK**

We studied about different adders among compared them by different criteria like Area, Time and then Area-Delay Product etc. so that we can judge to know which adder was best suited for situation. After comparing all we came to a conclusion that Carry Select Adders are best suited for situations where Speed is the only criteria. Similarly Ripple Carry Adders are best suited for Low Power Applications. But Among all the Carry Look Ahead Adder had the least Area-Delay product that tells us that, it is suitable for situations where both low power and fastness are criteria such that we need a proper balance between both. Coming to Multipliers we studied different Multipliers starting from Array Multiplier to Wallace Tree, Booth Multipliers. We found that parallel multipliers are much better than the serial multipliers due to less area consumption and hence the less power consumption. Comparing Radix-2 and Radix-4 booth multipliers we found that radix-4 consumes less power than radix-2, because radix-4 uses almost half number of iterations than radix-2. We saw Wallace tree having nearly same delay as of radix-4 multipliers where as consuming a little more power than the former. The Power efficiency of the circuits can be increased by proper recording schemes.



If we compare the above values among each other we can observe that the Array Multiplier is the worst case multiplier



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