Low Power High Speed Arithmetic Circuits

Kiran Kumar V G, C Shantharama Rai

Abstract: In the Design of arithmetic circuits reducing area, high speed and power are the major areas in VLSI system design. In this paper parallel prefix adders like Kogge-stone adder, Brent-Kung adder, Ladner-Fischer adder is designed. Radix-4 Booth multiplier is designed by using Kogge-Stone adder. 16 bit Vedic multiplier is done by using Urdhwa Triyambhaka sutra. 8bit Vedic division is implemented by using Crumbs method so as to reduce the area, LUT tables and increase the speed as well as to reduce the Power dissipation. The design is synthesized using Xilinx ISE 14.1 design suite.

I. INTRODUCTION

Arithmetic circuits uncover abundant applications in processing architectures. As the complication of DSP architectures is relatively higher, low power design techniques are now very promising. In the era of Internet of Things, Artificial Intelligence and Machine learning, there has been a tremendous research in the area of resource constrained devices, hence the tremendous growth research in low power VLSI system design arises from two main facts, one, as the operating frequency and processing capacity of the chip increases hence the currents to be delivered and heat dissipated increases thus proper cooling techniques has to be provided. Secondly the battery life of such resource constrained devices can be increased resulting in extended operating time. Pervasive work is performed on low-power multipliers at physical, circuit and logical levels, resulting in the design of several parallel multipliers with different area, power and speed constraints.

In this paper, the basic arithmetic operations in like addition, subtraction, multiplication and division are implemented. In the digital system design the most commonly performed arithmetic operation is addition, in this paper three different adders have been implemented. Adder is a digital circuit which performs addition of two n-bit elements and generates (n+1) bits as a sum and carry. An adder can be converted into subtractor. For subtraction, two elements are considered from which one element is unsigned and another is signed number. A signed number is then converted into unsigned number using two’s complement criteria. Both the unsigned and the result of two’s complement are added and results are obtained as difference and borrow.

This paper also deals with multiplication; the two numbers are multiplied using the Vedic technique. The term ‘veda’ denotes storehouse of knowledge. In Vedic multiplier there are 16 sutras but the best among all is Urdhwa Tiryakbyham. In today’s world, multipliers play an important role in many high-performance systems such as, Digital Signal Processors, Microprocessors, ALU etc. The performance of a system is generally examined by the multiplier's performance, as the multiplier is generally the slowest element in the system and usually consumes more space and power and long latency. Therefore, low-power with high speed multiplier design has been an important part in low-power VLSI system design. The divider circuit deals with the design of signed division which divides a number by another number with the signed bit and output are obtained as quotient and remainder.

II. LITREATURE REVIEW

A. Review Stage

In paper [1], the comparisons between several kinds of adder are made. The design of various adders such as Ripple carry adder Carry look ahead adder, Carry save adder, Carry select adder, Carry skip adder, Carry increment adder, and Carry bypass adder are discussed. On the basis of their performance parameter each of these adders are compared such as area, power and delay. In [2] the 4-bit, 8bit, 16bit and 32bit Brent Kung Adders have been implemented and simulated using CMOS logic- 45nm Technology. The results have been compared with Ripple Carry adder and Carry Look-ahead adders, a comparative study was conducted. Booth multiplier was implemented by using similar type of adders like CSA Ripple carry adder and so on. Booth multiplier was implemented by using CSA. In CSA area, delay was increased so Kogge-stone is used by which Modified Booth multiplier can be implemented which is explained in the paper [3]. In paper [4], two techniques based upon Vedic maths to improve processor speed have been implemented. There are at total 16 sutras in Vedic mathematics from which two are for multiplication application. The two methods discussed here in the paper are firstly Urdhva Tiryakbyham technique or sutra is similar to array multiplication. The gate delay, number of bit and area is increased slowly when comparison is made with other multipliers. And so the second and the advanced technique called NIKHILAM sutra is discussed. Faster mental calculation could be achieved from these sutras. This paper compares the two techniques and finds that NIKHILAM is the best.

Revised Manuscript Received on July 04, 2019.

Kiran Kumar V G, Department of Electronics and Communication Engineering, A.J Institute of Engineering and Technology, Kottara, Mangalore, Karnataka India.

Shantharama Rai C, Principal, AJ Institute of Engineering, Kottara, Mangalore, India.
Here for the processor speed to be increased, this paper discusses techniques for modification of architecture of vedic multiplier. In paper [5] Parvartya yojayet algorithm is been implemented. High performance divider could be developed from this divider algorithm. To the Vedic divider and the conventional divider, static timing analysis is done here.

III. PROPOSED LOW POWER HIGH SPEED ARITHMETIC CIRCUITS

A. Parallel Adders

Parallel adder [6] is very important in the leading technology for the implementation of the VLSI chips. In parallel structure calculation is computed synchronously in parallel way. It is one among the fastest and wider adder. It is mainly focused on better improvement of delay enhancement of the adder. Parallel adder is classified into three phases:

- Pre-computing phase
- Prefix phase
- Final processing phase

The description of parallel adder is given in figure 1.

![Figure 1: Parallel Adder](image1)

In Pre-computing phase propagate and generate signal is generated

\[ Pi = Ai \oplus Bi \]

In Prefix phase generate or propagate bit is generated.

- Black bit generates ordered bit and grey cell generates left bit.
- Black cell: \[ Gi = Gi \oplus (Pi \text{ and } Gj) \]
- Grey Cell: \[ Gij = Gi \oplus (Pi \text{ and } Gj) \]
- In final stage sum and carryout is obtained

\[ Ci = Gi \]

\[ Si = Pi \oplus Ci \]

B. Brent-Kung Adder/Subtractor.

The Brent–Kung adder is a parallel prefix adder (PPA) form of carry look-ahead adder (CLA). Compared to the Kogge stone adder (KSA), it introduces higher regularity in the adder structure and has less wiring congestion resulting in better performance and less chip area to implement stone adder (KSA). It’s better than ripple carry adder as well.

The Ripple-carry adders were the starting multi-bit adders that were set up in the early days and got their name from the ripple effect that the carry made while propagating from right to left. The time taken for addition was directly proportional to the length of the added bit. This is opposite in Brent–Kung adders where the carry is calculated in parallel and thus reducing the addition time drastically. Furthermore, to suit low power VLSI design Brent Kung Adders and other Parallel adders are designed to reduce chip area, power consumption and increase speed. Brent-Kung adder has increased performance due to the nature of tree structure of propagating carry which also leads to low power consumption as carry bit has to travel through fewer stages and hence there is minimum switching of transistor. The Brent-Kung adder computes the prefixes for 2-bit groups and using these prefixes 4-bit groups are computed, which in turn the prefixes for 8-bit groups are calculated and so on. The carry out of each stage is calculated using these prefixes. These carries with group propagate of next stage will be added to compute the sum bit of that stage.

![Figure 2: Prefix Adder](image2)

Figure 2 shows the carry generation and carry propagation in parallel prefix adder

\[ gi = ai + bi \]

\[ pi = ai \oplus bi \]

The carry and sum in terms of pi and gi is expressed as

\[ ci = pi \oplus gi \cdot ci-1 \]

\[ si = pi \oplus ci-1 \]

C. Kogge Stone adder

KSA is one type of carry tree adder which is similar to the CLAA. It is one of the fastest adder because it has less logic depth. It is widely used in design of VLSI chips. Kogge stone adder is the best adder because of its structural layout. It has efficient logic depth when compared to other structures of adder. It is one of the widely used adders because of its efficient performance in industry. It depends on generate and propagate signal.
Hence the performance of the adder depends on logic depth and delay. Various components are used in this adder such as black cell, grey cell, generate and propagate block, buffer. Black cell is used for computing propagate and generate signal. Grey cell is used for computing generate signal. Buffer is used for loading the effect. Delay is obtained by \( \log_2 N \) where \( N \) is derived as input. Area is obtained by \( (n \log_2 n - n + 1) \) where \( n \) is the input. Kogge Stone adder has 34 black cell and 15 grey cell. The 16-bit KSA block diagram of is shown in figure 3.

D. Ladner Fischer adder

LFA is one more type of carry tree adder. Ladner Fischer adder minimum delay and has maximum fan-out similar to BKA. To generate carry signal \( 0(\log n) \) time is required. It is also one among the fastest adder. The performance of this adder depends on minimum delay and high fan-out. Ladner Fischer adder has large area when compared to Brent Kung adder. The 16-bit LFA block diagram of is shown in figure 4.

E. Vedic Multiplier

Among those 16 Sutra one of the sutra which is used for perform Vedic Multiplication operation \([7]-[10] \) is Urdhwa Tiryakbhyam. Urdhwa Tiryakbhyam means column and cross way. The main advantage of this multiplier is all the operation is done simultaneously and also to minimize the delay. It is used in many areas like medical, X-ray field, video compression, and also in fields of electronics. Figure 5 shows how multiplication is done. This method can also be extended for any no. of digit. The multiplier with urdhwa tiryakbhyam technique has added advantage that is, the gate delay and area increases very slowly compared to other conventional multipliers as the number of bits increases. The figure 5 shows the flow of 4-bit numbers get multiplied using urdhva tiryakbhyam technique.

F. Urdhwa triyambaka multiplier

The 2×2 method is done by 2 bit number \( A=A_1A_0, B=B_1B_0 \). The design is done by AND gate and half adder. The structure of is similar to Array multiplier. The structure of 2×2 Vedic Multiplier is shown in figure 6.

G. 4×4 Urdhwa triyambaka multiplier

4×4 multiplier consist of 4 bit number \( A=a_3a_2a_1a_0, B=b_3b_2b_1b_0 \). 4×4 Method designed by 4 2×2 Vedic multiplier and 3adders are used. 2×2 multiplier is done using 2 half adder and 4 gates. By using 4 bit input 8 bit product is obtained. The structure of 8×8 urdhwa triyambaka method is given in Figure 7.
H. Analysis of division method

In this sutra first only compliment of the divisor is taken leaving the MSB bit. The number of which the compliment is taken is multiplied with the sum of each number of the dividend and is carried out by addition in order to obtain the quotient and remainder. Consider an example where dividend is 13650 and divisor is 123. So using this methodology iteration is reduced to 8. Figure 8 shows an example for division of two numbers.

![Diagram of Vedic division of two numbers]

Table 1: Analysis of Crumb Encoding

| Dividend | Sign bit | Value bit | Crumb Representation |
|----------|----------|-----------|----------------------|
| 0        | 0        | 0         | 00                   |
| 1        | 0        | 1         | 01                   |
| 1        | 1        | 1         | 11                   |

The modified algorithm of Vedic division is elaborated into three stages:

- In order to perform partial multiplication, the crumb encoded digit of divisor is complemented.
- The algorithm which is used for division is designed using addition and multiplication.
- At the end quotient is decoded into bits.

Depending on these stages in the 1st step: bitwise xor method is done for crumb encoded digit of divisor except the MSC (most significant crumb). Using XOR logic 01 will be same and MSC bit will remain the same it is not complemented. In second stage 2x2 partial multiplier and 2 bit adder is used.
### Table 2: Simulation results for Arithmetic circuits

|                      | Name                        | Logic Signals | IOs | Area (nW) | Total Power (nW) | Delay nS |
|----------------------|-----------------------------|---------------|-----|-----------|------------------|----------|
| Spartan 6            | Kogge Stone Adder (16bit)   | 69            | 90  | 49        | 394              | 9.566    |
|                      | Used                        | 1920          | 66  |           | 16786.314        |          |
|                      | Total Available             | 1920          |     |           | 16786.314        |          |
|                      | Utilization %               | 3.6           | 0   | 75.8      |                  |          |
|                      | Brent Kung Adder (16bit)    | 40            | 63  | 50        | 360              | 16.440   |
|                      | Used                        | 1920          | 66  |           | 16116.889        |          |
|                      | Total Available             | 1920          |     |           | 16116.889        |          |
|                      | Utilization %               | 2.1           | 75.8|           |                  |          |
|                      | Brent Kung Subtractor (16bit)| Used | 49  | 63        | 547              | 18.253   |
|                      | Total Available             | 1920          |     |           | 21147.336        |          |
|                      | Utilization %               | 2.1           | 75.8|           |                  |          |
|                      | Ladner Fischer adder (16bit)| Used | 38  | 61        | 370              | 16.447   |
|                      | Total Available             | 1920          |     |           | 16655.233        |          |
|                      | Utilization %               | 2.0           | 75.8|           |                  |          |
|                      | 16 bit Vedic Multiplier     | Used | 7168 | 141      | 7762             | 29.0094  |
|                      | Total Available             | 1920          |     |           | 377496.974       |          |
|                      | Utilization %               | 3.8           | 41.1|           |                  |          |
|                      | Modified booth multiplier (16bit)| Used | 43  | 68        | 7168             | 31.115   |
|                      | Total Available             | 1920          |     |           | 344456.567       |          |
|                      | Utilization %               | 2.2           | 53.0|           |                  |          |
|                      | 16 bit Vedic Division (crumb encoding) | Used | 270 | 7168 | 21568 | 1092888.474 | 348.397 |
|                      | Total Available             | 514           |     |           |                  |          |
|                      | Utilization %               | 58            | 41.1|           |                  |          |

### IV. SIMULATION AND RESULTS

The module design and description of the arithmetic circuits is implemented in using Verilog HDL. Each of the arithmetic operations listed above have been individually simulated using Xilinx ISE (Integrated Software Environment) 14.1 and CADENCE 45 nm Technology simulations are performed in Xilinx 14.1 and synthesized using Xilinx Plan Ahead Virtex6 and also power Area and Delay report are obtained in Cadence 45nm Technology.

**A. Simulation Results**

The proposed arithmetic circuits are implemented. Various performance measurements for the proposed multiplier and the existing multiplier are parametrically obtained and listed in Table 2 Figure 11 shows Power comparison Figure 10 shows Delay comparison and Figure 10 shows Area Comparison.

### Table 2: Modified Division using Crumb

| Divisor | Dividend | Q | R |
|---------|----------|---|---|
| 01 00 01 01 | 01 00 00 01 00 00 01 01 | 01 11 11 | 00 00 00 |
|         | 00 01 01 | 00 00 00 | 00 11 11 |
|         | 01 00 11 00 01 | 01 00 00 | Q= 10001-00100 |
|         | Q= 01101  | R=100 |
V. CONCLUSION
Depending on LUT Ladner Fischer has less area, and Ladner Fischer has less No of Slices, when comparing the delay Kogge Stone has less delay. In Vedic division when compared to the previous paper it has less delay compared to other normal division method. Since Kogge Stone adder is used in Modified Booth multiplier, it has a less delay in radix-4 when compared to radix-8. Vedic Multiplier has less area and delay when other multiplier is used.

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AUTHORS PROFILE

Kiran Kumar V G is an Assistant Professor of Electronics and Communication Engineering at AJ Institute of Engineering and Management Kottara Mangalore. He has 18 years of teaching experience. He has served at Sahyadri College of Engineering and Management, Canara Engineering College and PA College of Engineering. He is currently pursuing his Ph.D. degree in Cryptography and VLSI at Canara Engineering College recognized by VTU Belagavi, and has completed M.Tech. degree in Microelectronics and Control Systems securing III Rank from the VTU Belagavi in 2005. He has done his BE in Electrical and Electronics Engineering from NMAMIT Nitte. His research interests include Cryptography, Digital VLSI design and Analog Design.

Dr. Shantharama Rai C has completed his Engineering (B.E) from Mangalore University, M.Tech from N.I.T.K. surathkal and PhD from V.T.U Belagavi with specialization of power electronics and control system. He also member of Indian society for technical education New Delhi and Indian society for lighting engineers New Delhi. He has served in different institutions/organizations like K.V.G. College of Engineering, Sullia, N.M.A.M. Institute of Technology, Nitte, St. Joseph Engineering College Vamanjoor and Canara Engineering college Mangalore in various capacities for more than 18 years. He has published/presented more than 40 papers in international/national journals/conferences in the field of engineering. He was the Coordinator for the Mangalore region to assess the Quality Of Electrical Distribution Governance and Performance in Karnataka (MESCOM Region) appointed by K.S.C.S.T Bangalore for the year 2007-2008.