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Ternary Digital System: A Latent Talent than the Binary Digital System

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Abstract: *Today's digital system is completely depends on binary logic. Binary logic technology has come across the dramatic changes and advances. But, the real world is not only binary. It is more intuitive to reason about a system, especially at higher levels of abstractions, in terms of variables with symbolic values. In many practical engineering situations, a device can be not only in "off" or "on" state, but also in "idle" state. Due to this fact, ternary logic is implementing in digital systems. Ternary logic has several important merits over binary. Its advantages have been confirmed in the application like memories, communications and digital signal processing etc. It was found that ternary computer is very favourable for seizing of application simplicity of programming in codes, other than permitted to design a few interpreters. This comparative study will be useful for all students, researchers and knowledge seekers to avoid the deficiency in computing. This paper will also stimulate the reader's interest to the ternary logic than the binary logic.*
Keywords: *binary Logic, ternary Logic, ternary computer*

I. Introduction

Theoretical research in number theory has a long tradition. Since many centuries, the main goal of these investigations is a better understanding of the abstract theory. Numbers are basic not only for mathematics, but more generally for all sciences; a deeper knowledge of their properties is fundamental for further progress. Remarkable achievements have been obtained, especially recently, as many conjectures have been settled. Yet, a number of old questions still remain open. Among the unexpected features of recent developments in technology are the connections between classical arithmetic on one hand and new methods for reaching a better security of data transmission on the other.

With the invention of computers, binary machines became successful because of its exclusive simple features of binary logic and data storage. Thus looking at sizeable advantages of binary machines scientists found easy to work on them rather than developing machines based on other bases which led to disinterest of researchers on the strange number systems.

But, due to the increasing complexity like speed, avoiding sign problem, zero redundancy etc. of binary number system in computing, strange number system is widely used. There are lots of system architectures which are developed by ternary number system to overcome the deficiency of traditional number system. There are many advantages of such number systems and circuits comparing with the binary ones. The main advantages of ternary number systems and circuits are: greater speed of arithmetic operations realization, greater density of memorized information, better usage of transmission paths, decreased interconnections complexity and interconnections area, decreased pin number of integrated circuits and printed boards, possibilities for easier testing [1].

It is not difficult to prove that the ternary number is more compact than the binary system. Assume, for example, that we are given 30 cardboards on which we can write decimal, binary or ternary digits. Using the decimal system we can only represent numbers with up to 3 decimal places (since we need ten cardboards, numbered 0 to 9 for each decimal position). Using the binary system, we could write numbers with up to 15 bits. And with the ternary system we could represent numbers with up to ten ternary digits. In the decimal case we can represent the numbers from 0 to 999, i.e. 1000 numbers. In the binary case we can represent 215 numbers, i.e. 32768 numbers. In the ternary case we can represent 310 numbers that is 59049 numbers. The ternary system is therefore almost twice as comprehensive as the binary system using the same number of cardboards or "states" and almost 60 times better as the decimal system!

Although many researchers and knowledge seekers know only the binary number system and are very comfortable with performing operations using this system, but it is important for them to understand that binary number system is not the only system. By studying other number systems, researchers will gain a better understanding of how ternary number systems work in general. In this paper, we elaborated detail concepts of ternary number system, their uses, needs and number representation. Their awareness and detailed explanation will be useful to all researchers for understanding various digital aspects. The basic aim of this study is to stimulate the reader's interest to the ternary logic from the binary logic.

II. Ternary Number System

The number system with base three is known as the ternary number system. Only three symbols are used to represent numbers in this system and these are 0, 1 and 2. It is also a positional number system that each bit position corresponds to a power of 3. Moreover, it has two parts, the integral part or integers and the fractional part or fractions, set apart by radix point. For example $(1202.021)_3$

In ternary number system the leftmost bit is known as most significant bit (MSB) and the right most bit is known as least significant bit (LSB). The following expression shows the position and the powers of the base 3:

$$\ldots\ldots 3^3 3^2 3^1 3^0 . 3^{-1} 3^{-2} 3^{-3} \ldots\ldots$$

As for rational numbers, ternary number system offers a convenient way to represent one-third but a major drawback is that it does not offer a finite representation for the most basic fraction one-half (and thus, neither for one-quarter, one-sixth, one-eighth, one-tenth etc.) because 2 is not a prime factor of the base [2].

A. Balanced Ternary Number System

Balanced ternary is a non-standard positional numeral system useful for comparison logic. It is a ternary system but unlike the standard (unbalanced) ternary system it uses the digits -1, 0, and 1 instead of the digits 0, 1, and 2. This combination is especially valuable for ordinal relationships between two values where the three possible relationships are less-than, equals, and greater-than. Balanced ternary can represent all integers without resorting to a separate minus sign. The most significant ternary digit (trit) of any positive balanced ternary number is positive (+) and the most significant trit of any negative number is negative (-).

B. Uses of Ternary Number System are as follows:

- Used in comparison logic.
- Used in ternary computers.
- Used in Islam to keep track of counting Tasbih to 99 or to 100 on a single hand for counting prayers.
- Used to denote fractional parts of an inning in baseball.
- Used to convey self-similar structures like a Sierpinski Triangle or a Cantor set conveniently.
- The "root base" for bases 9 and 27.
- Used in a few cultures.
- Multi-Valued Logic, Quantum Computing.

III. Benefits of Ternary Number System

We live in a binary world of computers, accepting the inevitability of dealing with strings of 0's and l's, simply because this is dictated by the two-valued nature of switching primitives which make up the machines. Yet there is little doubt that most of us would prefer ternary number system if they were available. Since last few decades ternary number system has been a possible alternative to binary logic. Unfortunately, the development of ternary number system was not keeping up with the speed of the binary counterparts. The potential advantages of ternary number system distinguish them from the binary number system and make them worth an extra look; some of these features include [4, 5]:

- Greater speed of arithmetic operations realization
- Greater density of memorized information
- Better usage of transmission paths
- Decreasing interconnections complexity and interconnections area
- Decreasing pin number of integrated circuits and printed boards
- Avoid sign problem and zero redundancy problem

Ternary number system offers important advantages like more information can be processed over given set of lines to reduce the burden of interconnections & there by switching. The information content per interconnection can be raised from the present binary number system to ternary number system.

Perhaps the most significant immediate benefits of ternary number system approaches lay in their potential for reduction of the wiring complexity. Integrated circuit technology has placed a premium on the cost of interconnections. Thus, the number of wires needed in a given network often determines the feasibility of its practical implementation.

IV. Study of various System Architectures using Ternary Number System

Modern computers use the binary system, i.e. all arithmetical operations are performed internally using 2 as numerical base. An alternative is ternary computers which compute using base 3. The ternary system uses ternary logic where the truth values are "true", "false" and "unknown".

C. The Ternary Calculating Machine of Thomas Fowler

The first recorded practical Ternary Machine ever built, was a mechanical model built by Thomas Fowler, in 1840 (Glusker, 2008). This machine was designed to give mechanical form to these techniques, the choice of balanced ternary allowing the mechanisms to be simple, though the values had to be converted to balanced ternary before processing and the results converted back to decimal at the end of the calculation [7].

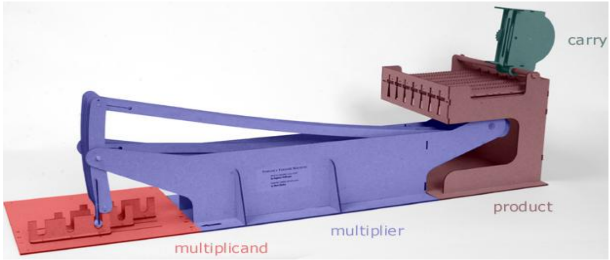

Fig.1. The Ternary Calculating Machine of Thomas Fowler

D. Setun

At the dawn of computer era, Setun was a more complicated ternary machine, built by Nikolai P. Brousentsov and his colleagues at Moscow State University in Russia in 1958. This machine is regarded as experimental, and as an educational training program for engineers. However, simplicity, economy and elegancy of computer architecture are the direct and practically very important consequence of the ternarity, more exactly signed bit representation by code with digits 0, +1, -1, decreases the amount of conditional instructions and the arithmetic operations allow free variation of the length of operands and may be executed with different lengths; the ideal rounding is achieved simply by truncation, i.e. the truncation coincides with the rounding and there is the best approximation the rounding number by rounded [3, 11].

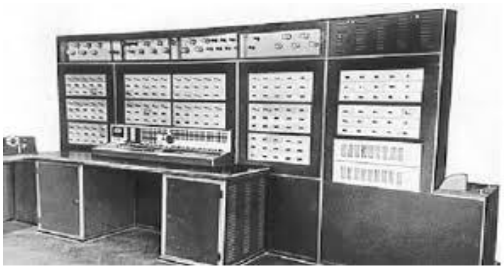

Fig.2. Experimental "Setun" Computer 1958

E. Setun 70

On the base of Setun's positive experience it was designed and exhaustively determined in Algol-like programming language the architecture of other ternary computer. This computer named Setun 70 was introduced in 1970. In Setun 70 the peculiarities of ternarity are embodied with more understanding and completeness.

F. Ternac

In 1973 Gideon Frieder and his colleagues at the State University of New York at Buffalo designed a complete base-3 machine they called ternac, and created a software emulator of it. The TERNAC computer implementation was intended primarily to discover if the implementation of a nonbinary structure on a binary computer is feasible, and to discover the cost in memory storage and time for such an implementation. As a feasibility test, this effort was successful, and the first version of this implementation has proved that both the speed and price are on the order of the speed and price of binary computers [12].

G. Trinary

Trinary is the computer rumored to be used by the Tholians in Star Trek.

H. Dytrax 1000

Dytrax 1000is an imaginary computer in the science fiction series "The Fall of Binary Symbolism". However, the web site has disappeared off the face of the Internet and no further information can be found.

I. TRIPS Processor

COMP203 (1997 Mid-trimester Test) at Victoria University of Wellington mentions the imaginary TRIPS processor, which supports ternary arithmetic in 3's complement using 4-trit fixed-width operands.

J. Team R2D2's 64-tert SRAM

Team R2D2, composed of Daniel Chillet, Ekue Kinvi-Boh, and Olivier Sentieys described VHDL models of ternary basic logic and arithmetic cells and some arithmetic processing units (adder, multiplier, and shifter) in the project "Multiple-Valued Logic architectures and circuits". Excerpt:

A 64-tert SRAM and a 4-tert adder have been designed and fabricated at UCL (University College London). These two circuits represent the very first full-ternary circuit ever fabricated. They have been successfully tested using specifically fabricated test equipments.

K. Ternary Computing Testbed

It is a complete ternary computer capable of running a simple numerical guessing game. The transistor-level architecture design successfully simulates in the LTspice circuit simulation program and behaves as expected.

L. Whirlwind Computer

Herbert R. J. Grosch proposed a ternary architecture for the Whirlwind computer project at MIT (Massachusetts Institute of Technology). Whirlwind evolved into the control system for a military radar network, which stood vigil over North American airspace through 30 years of the Cold War. Whirlwind was also proving ground for several novel computer technologies including magnetic core memory, but ternary arithmetic was not among the innovations tested; Whirlwind and its successors were binary machines.

V. Comparative Study

The complexity of binary number system is steadily increasing in today's computing. A basic motivation of these investigations is connected with overcoming a number system of essential deficiencies of the binary number system, especially binary number system. The most well known of these are (a) the sign problem (it is impossible to represent negative numbers and perform arithmetical operations over them in direct code) that complicates arithmetical computer structures, (b) the problem of zero redundancy (all binary code combinations are permitted) and (c) limitation of speed of modern computers in performing the arithmetic operations such as addition, subtraction and multiplication suffer from carry propagation delay that does not allow the checking of informational processes in processors and computers effectively [13].

To overcome these complexities of binary number system in computing, ternary number system is widely used. The first attempt to overcome the sign problem of the binary number system was made a ternary computer, called 'Setun' by Nikolai P. Brousentsov in 1958 at Moscow University in Russia. To overcome the problem of zero redundancy, another original discovery in number-system theory, called 'Tau System' was made by the American mathematician George Bergman in 1957 and in QSD number system carry propagation chain are eliminated which reduce the computation time substantially and enhancing the speed of the machine [4, 11].

It is also known that the ternary number system arithmetic has essential advantages as compared with the binary one that is used in present-day computers. Now, when the binary computers predominate, it is hard to believe in the reality of such assumption, but if this would happen, not only the computer arithmetic but the informatics on the whole would become most simple and most perfect. Strange number system has better accordance with the Nature and human informal thinking.

Inception digital devices have been designed using binary number system till date. Researchers found that the development in binary number system is cumbersome, complex and difficult to understand. Strange number system enables more information to be packed in a single digit; hence, researchers have been working on strange number system since many years.

Logical operations can be defined that are more general than the binary logical operations. However, although the ternary system is more compact and more general logical operations are possible, the cost of ternary electronic components is much higher than the cost of binary elements. Binary computers are therefore more cost effective.

VI. Conclusion

Here we explained the concepts and applications of ternary number systems. As we have already seen that ternary number system has been already used in different cultures and in different technologies from the ancient times for genuine mathematical distinction in its favor. From the beginning of the design of computers, ternary number system was also used with binary number system. If we look back in the past, ternary number system has been used for creating some of the machines which were successful but could not become popular than the binary systems. In today's scenario, strange number system is used in various viable fields' i.e. multi-valued logic, quantum computing etc. to avoid the complexity of binary number system. The study of ternary number system is useful to the researchers of computing due to the fact that these number systems other than the binary number system offers great benefits and can be helpful in overcoming certain flaws of the present system in the computer field.

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