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SPINTRONIC DEVICE BASED POWER EFFICIENT VLSI CHIP DESIGN FOR UNIVERSAL CODE CONVERTER

Ankush Ghosh, J Gope, T Datta, Biplab Roy[1] and *Subir Kumar Sarkar
Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata-700032
[1]Institute of Technology and Marine Engineering, West Bengal, India

ABSTRACT

The main objective, however, till date remains device miniaturization to reduce unit cost per function, to improve device speed, to reduce power consumption and to improve performance. A major creative challenge which the circuit and system VLSI designers facing today is to design new generation products which can consume minimum power. Spintronic devices have the ability to provide digital system with very less power consumption. In today's digital world, the general decimal numbers have almost their significance and the binary digits '0' and '1' reign supreme. Indeed, use of digital systems has given today's gadgets signal processing capabilities, robustness and sophistication that were unheard of when analog systems were in vogue. In the present work, a code converter is designed by employing spintronic devices where low power consumption, high operating speed and high component integration density are financially indispensable. The system is designed for four bits. The different codes that are considered in this circuit are binary, BCD, Gray and excess-3. This conversion system can be extended for any number of bits by cascading technique.

Keywords: Spintronics; single spin logic; miniaturization; code converter. PACS: 75.10Jm, 75.10Pq, 75.10Hk, 75.25.+z, 85.75.-d

INTRODUCTION

In the recent years, the great advances made in the micro-electronics have been underpinned by rapid developments in the fabrication technology which has opened the new horizon in electronics (Kim *et al.*, 1999; Mazumder *et al.*, 2000). The minimal feature size in mass production VLSI has successfully overcome the earlier expected limit of 1μm and will probably cross 0.1μm mark in not very distant future (Korotkov, 1997; Asahi *et al.*, 1995; Sahu *et al.*, 2004). Due to the technological limitations, the critical scaling limits may be imposed by physical laws, application limits and the manufacturing limitations (Ning, 2000). A major creative challenge facing today circuit and system VLSI designers is to design new generation products which consume minimum power. In fact, power considerations have been the ultimate design criteria in special portable applications such as wristwatches, mobile cell and pacemakers for a long time. The objective in such devices was minimum power for maximum battery life time. Before we proceed further a few words about spintronics will not be out of place. The Science and Technology of manipulating the spin degree of freedom of a single charge carrier to encode, process and deliver information is called "Spintronics" (Datta and Das, 1990; Awschalom *et al.*, 2002; Bandyopadhyay *et al.*, 2005). This field is basically the outgrowth of the older and more established work on the principle of magneto-resistive effect for sensing and storing information (Bandyopadhyay and Cahay, 2005; Freitas *et al.*, 2000; Prinz, 1998). The development of programmable spintronic logic devices on magnetic tunnel junction elements (Freitas *et al*., 2000), read heads for sensing massively dense magnetic storage media, non volatile magnetic random access memory (Wang *et al*., 2005), linear applications such as rotational speed control systems (Freitas *et al*., 1999), perimeter defence systems positioning control devices in robotics and related systems (such as automobile systems) (Ku *et al*., 2000), and magnetometers and high current monitoring devices for power systems (Pelegri *et al*., 2003) etc are the major early flips in the spintronics. There are several books and review articles on spintronics thereby highlighting the advances of spin based devices (Ohno *et al*., 2002; Sarkar *et al*., 2005).

Measuring single electron spin in a solid is a fundamental problem in condensed matter physics. Recently, it has assumed additional practical importance in view of many spintronic proposals of scalable solid state quantum computers. In all of these proposals, it will be necessary to measure a single electron spin for reading out the results of exempted quantum algorithms. Spintronic devices may be better performance than their traditional electronics counterparts if special properties of "SPIN" are incorporated in the design. In spin devices if one spin polarization represents a logic bit '1' and the anti-parallel spin polarization a logic bit '0', then one can switch a logic device by merely flipping spin without requiring physical movement of charges (Ziese *et al*., 2001). Hence it is possible to save a lot of energy as they are truly low power devices. The proposed logic gates can thus reduce

*Corresponding author email: sksarkar@etce.jdvu.ac.in

power dissipation by several orders of magnitude and also it will be the progenitor of today's spin based logic gates (Sarkar *et al*., 2005).

Digital systems have become synonymous with the bits (binary digits) '0' and '1'. Indeed all the processing in digital systems incorporates devices working in either of the two stable states i.e. they are bistable. One state is said to correspond to the bit '1' and the other to the bit '0'. This type of operation where only two states are considered has given the digital systems their robustness (Malvino and Leach, 2001; Kohavi, 2001). The stringent circuit parameters to be used in analog systems can be relaxed as we don't have to worry about signal *accuracy* anymore. Also the two state working has given digital systems excellent noise immunity. Although the binary number system has many practical advantages and is widely used in digital computers and systems, in many cases it is convenient to work with the decimal number system, especially where the communication between man and machine is extensive, since most numerical data generated by man are in terms of decimal numbers. To simplify the communication between man and machine, a number of codes have been devised so that the decimal digits are represented by sequence of binary digits. Also merely representing the decimal numbers in binary form may not adequately serve the purpose at hand at all times. So other codes to represent decimal numbers had been derived viz. Gray, excess-3, BCD, etc. The need arises because each of these codes has some unique properties which can be exploited so as to make digital circuits more versatile, efficient, reliable and cheap depending on the job they are required to carry out (Mano, 2004; Sinha and Sinha, 2003). Also a digital system may use one type of code for one purpose and a different code for another. Hence it is very important that there should be code converters within the system so as to make use of the different coding techniques when the need arises.

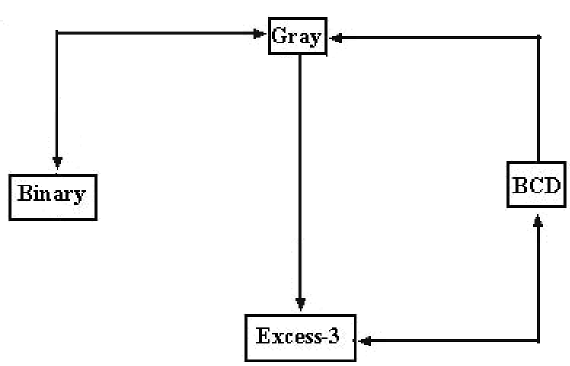

Fig. 1. Block diagram of code converter.

Basic diagram of code conversion is depicted in figure 1. Any type among Binary, Gray, BCD and Excess-3 can be input and their respective output codes can be extracted from the other terminals. From Binary to Gray convention 1 cycle is required. Similarly, Gray to BCD requires 2 cycles, BCD to Binary 1 cycle Gray to Exess-3 3 cycles and Excess-3 to Binary 2 cycles. Combining this we get the desired code conversion circuit (Fig. 1).

This work considers some of the popular code converters used in digital systems designed with the help of spintronic circuits so that not only do they become fast, they become compact and doesn't show the usual pitfalls when such systems are designed with conventional electronic circuits. In view of the above we propose here several code converters employing spintronic-based circuits.

DESIGN AND IMPLEMENTATION

Gray to Excess-3 Converter

The Excess-3 is an important 4-bit code sometimes used to represent BCD numbers. The BCD numbers are the simplest in representing decimal numbers as each decimal digit is simply replaced by its binary equivalent. The Excess-3 code is used to modify a BCD still further where a binary "011" is added with each digit representation. The Gray code, a non-weighted code has important application where there is a need to use a code where all successive codewords differ in only one digit. This code has its distinct advantage because in this system between consecutive numbers require only one bit switching there by making power efficient so far dynamic power consumption is concerned. These are needed in many practical applications, e.g. analog-to-digital converters, K map presentation etc. The required conversion expressions are:

$$A_x = B_g(\overline{C}_g + D_g) \quad (1)$$

$$B_x = C_g\overline{D}_g + \overline{B}_g D_g \quad (2)$$

$$C_x = \overline{D}_g \quad (3)$$

$$D_x = A_g\overline{D}_g + B_g(C_g\overline{D}_g + \overline{A}_g\overline{C}_g D_g) + \overline{B}_g(C_g \oplus D_g) \quad (4)$$

These expressions ((1) through (4)) are derived following conventional combinational digital circuit design technique. The spintronic based circuit for the converter is shown in Fig. 3. Here 1101 is given as the input giving A_g=1, B_g=1, C_g=0, D_g=1. Considering the expression for B_x, we find that C_g yields '0' and Dg yields '1' giving B_x as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 3. The logic value of the other expression evaluates out to correct values giving the output as 1100 which can be verified from the spin diagram vide figure 3.

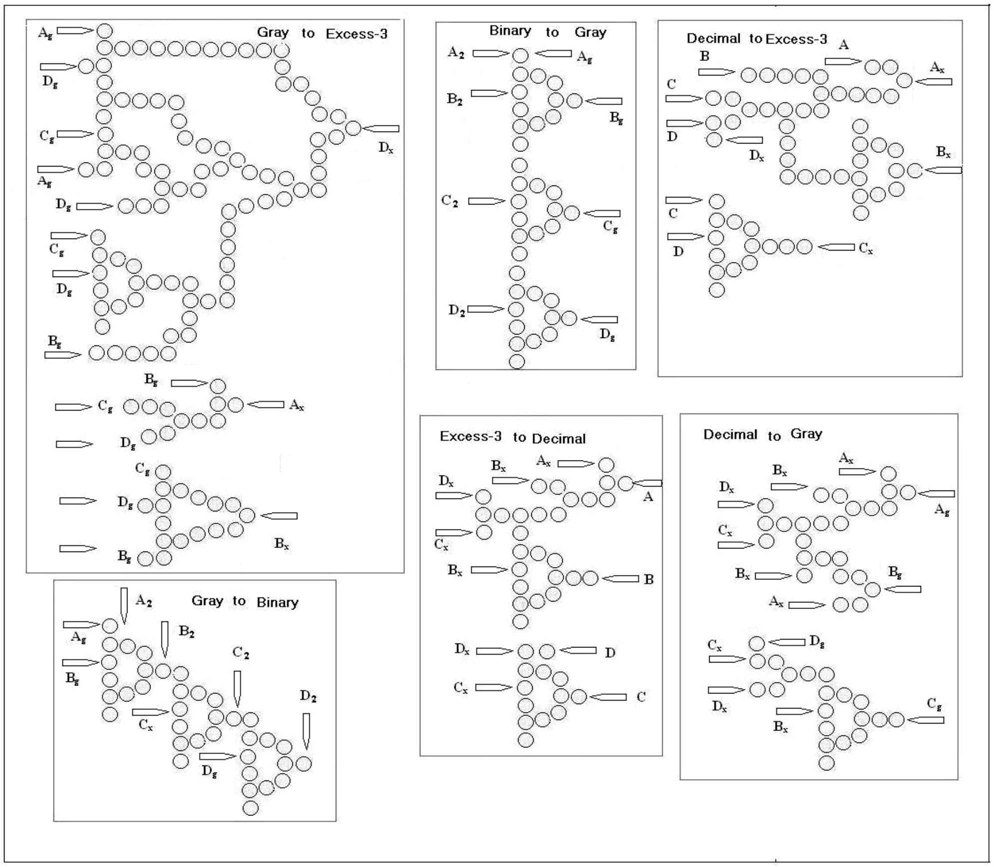

Fig. 2. Single spin logic realization of code converter.

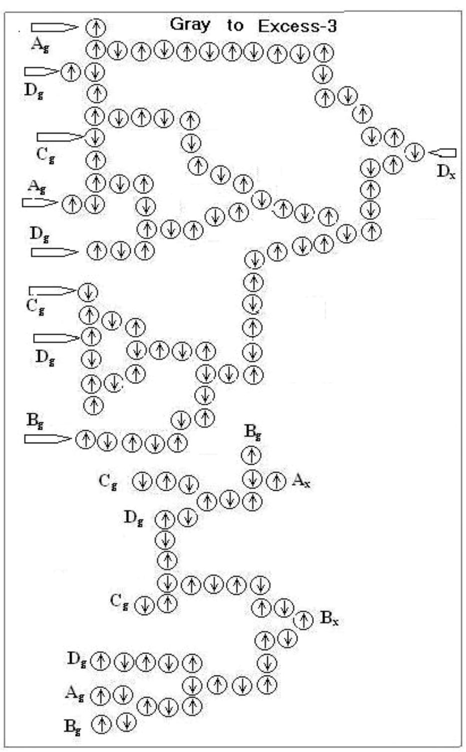

Fig. 3. Spin orientation of Gray to Eexcess-3 Converter.

Gray to Binary Converter

Digital systems process information mostly in binary form (machine language). However owing to the Gray code having many excellent properties (easier representation for sequential decimal numbers, reflective property, etc.) for storage purposes it provides an excellent option (Freitas *et al*., 1999; Ku *et al.*, 2000). So this type of converter finds extensive usage in conversion from stored data to processed information. The required conversion expressions are:

$$A_2 = A_g \quad (5)$$

$$B_2 = A_g \oplus B_g \quad (6)$$

$$C_2 = A_g \oplus B_g \oplus C_g \quad (7)$$

$$D_2 = A_g \oplus B_g \oplus C_g \oplus D_g \quad (8)$$

These expressions are also derived in the similar way as expressions (1) through (4) are derived. The spin based logic circuit for the converter is depicted in Fig. 4. Here 1011 is given as the input giving A_g=1, B_g=0, C_g=1 D_g=1. Considering the expression for C_2, we find that A_g yields '1' B_g yields '0' and C_g yields '0' giving C_2 as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 4. The logic value of the other expression evaluates out to correct values giving the output as 1101, which can be verified from the spin diagram, vide figure 4.

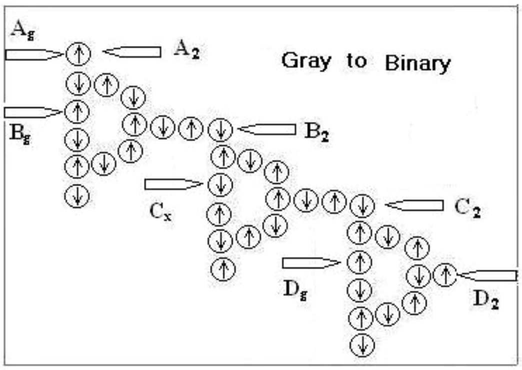

Fig. 4. Spin orientation of Gray to Binary Converter.

Binary to Gray Converter

This type of converters find extensive use at the inputs to digital systems as it is not convenient to directly express a decimal number into its Gray form. In fact no rules are there for such a conversion. So the decimal numbers are expressed in their binary form and then converted to their Gray equivalent. The fact that Gray code is a reflected code makes the conversion still easier and faster. The required conversion expressions are:

$$A_g = A_2 \tag{9}$$

$$B_g = A_2 \oplus B_2 \tag{10}$$

$$C_g = B_2 \oplus C_2 \tag{11}$$

$$D_g = C_2 \oplus D_2 \tag{12}$$

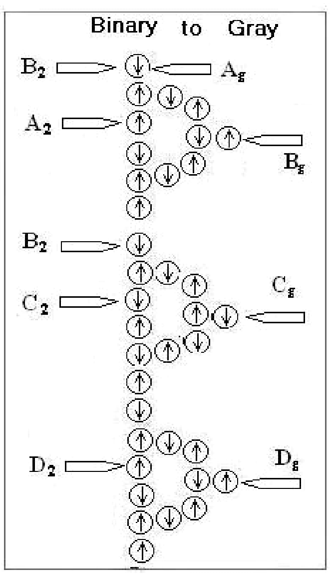

Fig. 5. Spin orientation of Binary to Gray Converter.

The spintronic based circuit for the converter is shown in figure 5. Here 1011 is given as the input giving A_2=1, B_2=0, C_2=1, D_2=1. Considering the expression for B_g, we find that A_2 yields '1' and B_2 yields '0' giving B_g as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 5. The logic value of the other expression evaluates out to correct values giving the output as 1101 which can be verified from the spin diagram vide figure 5.

Excess-3 to Decimal Converter

Since the Excess-3 code is basically the BCD code itself with minor modifications, a converter for the conversion is shown here. Using this converter we can directly get the required decimal number back without going through the Excess-3 – BCD – Decimal path. The required expressions are:

$$A = A_x(B_x + C_xD_x) \tag{13}$$

$$B = \overline{B_x} \oplus (B_x + C_xD_x) \tag{14}$$

$$C = C_x \oplus D_x \tag{15}$$

$$D = \overline{D_x} \tag{16}$$

Figure 6 depicted the spin based circuit for the converter. Here 1100 is given as the input giving A_x=1, B_x=1, C_x=0, D_x=0. Considering the expression for C, we find that C_x yields '0' and D_g yields '0' giving C as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 6. The logic value of the other expression evaluates out to correct values giving the output as 1001 which can be verified from the spin diagram vide Fig. 6.

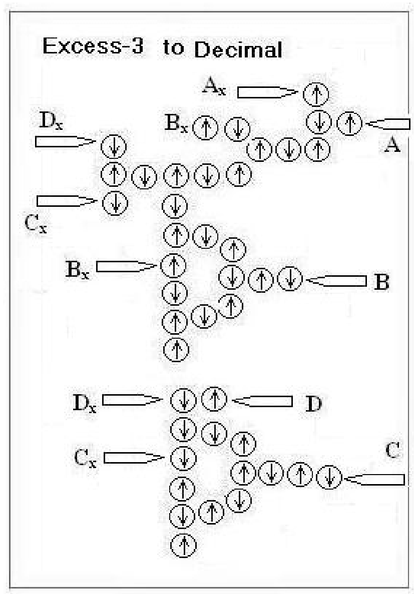

Fig. 6. Spin orientation of Excess-3 to Decimal Converter.

Decimal to Excess-3 Converter

This converter finds extensive usage where it is necessary to use decimal numbers but coded in binary form. Also this type of representation of decimal numbers is very simple and can be done quite fast, a requirement for today's systems. The required expressions are:

$$A_x = A + B(C + D) \quad (17)$$
$$B_x = B \oplus (C + D) \quad (18)$$
$$C_x = C \overline{\oplus} D \quad (19)$$
$$D_x = \overline{D} \quad (20)$$

The logic expression for the converter is verified in Fig. 7. Here 1101 is given as the input giving A=1, B=1, C=0, D=1. Considering the expression for B_x, we find that C yields '0' and D yields '0' giving B_x as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 7. The logic value of the other expression evaluates out to correct values giving the output as 1001 which can be verified from the spin diagram vide figure 7.

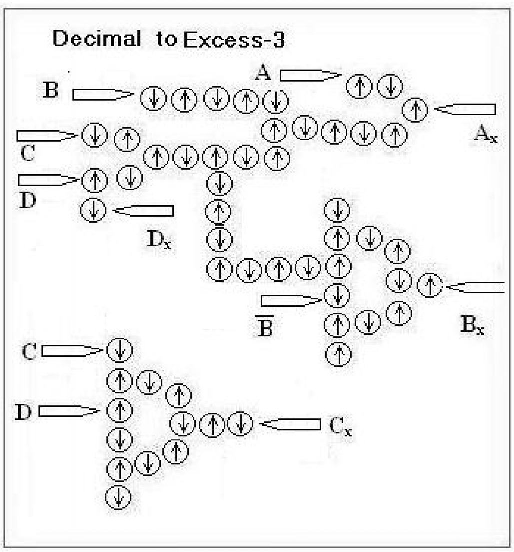

Fig. 7. Spin orientation of Decimal to Eexcess-3 Converter.

Excess-3 to Gray Converter

This converter can be used for direct conversion of outside-world data to a storage-able format. The spintronic based circuit for the converter is depicted in Fig. 8. Here 1001 is given as the input giving A_x=1, B_x=1, C_x=0, D_x=1. Considering the expression for C_g, we find that C_x yields '0' and D_x yields '0' giving B_x as '0'. The spintronic equivalent circuit also output the same as can be seen from the Fig. 8. The logic value of the other expression evaluates out to correct values giving the output as 1101 which can be verified from the spin diagram vide figure 8.

$$A_g = A_x + (B_x + C_x D_x) \quad (21)$$
$$B_g = A_x + B_x C_x D_x \quad (22)$$
$$C_g = B_x \overline{\oplus} (C_x + D_x) \quad (23)$$
$$D_g = \overline{C_x} \quad (24)$$

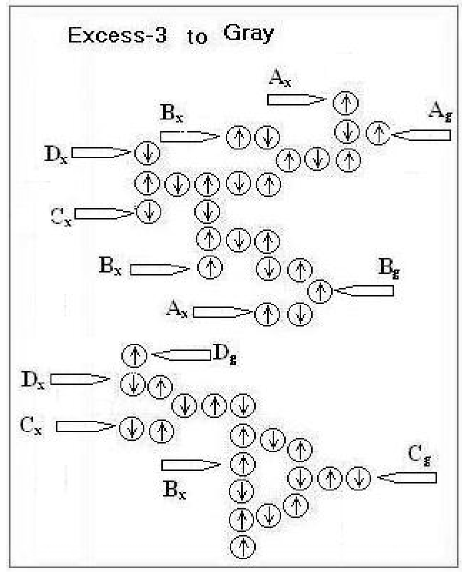

Fig. 8. Spin orientation of Eexcess-3 to Gray Converter.

RESULTS AND DISCUSSIONS

An inter code converter circuit is designed and implemented employing spintronic devices so that we can have a converter where low power consumption, high operating speed and high integration density are achieved there by making the converter compact, handy and user convenient. Binary information is encoded by spin orientation of electron dots and processed with the help of spin degree of freedom. We have utilize a linear array of cells where each cell is downward (logic '0') if its two nearest neighbors are upward oriented, otherwise the cell is upward (logic '1') oriented. The cell orientation is established by the week external dc magnetic field applied all over the chip. In the present arrangement linear array of odd number of cells are considered for wiring i.e., connecting the function with a remote one. The functionality of the cell arrangement of each type of converter is shown here [Fig. 3 through Fig. 8] by utilizing proper spin orientation of each cell for at least one input combination for each converter. Their explanation is also available in the design section of the converters. The results are found to be consistent and show the expected outputs. It is also possible to provide the converters in a single VLSI chip form.

CONCLUSION

In this paper we presented several code converter circuits using the novel spintronic approach which not only make the circuits fast but also make them more compact which ultimately will reduce the size of the digital systems which incorporates them into their design. Low power design becoming a new era in VLSI techniques, as it impacts many applications: In that sense the present work is an important fruitful step towards the realization of low power consuming system in the form of a chip. The utility of such converters will be best understood when they will appear in the market.

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