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IFAC-PapersOnLine 49-25 (2016) 378–383

Asynchronous Linear Combinational Circuits as a Base for Programmable Logic Device. Binary and Ternary Cases

Rustam Kh. Latypov * **Evgeni L. Stolov** **

* *Kazan Federal University, Kazan, 420008 Russia (e-mail: Roustam.Latypov@kpfu.ru).*
** *Kazan Federal University, Kazan, 420008 Russia (e-mail: ystolov@kpfu.ru)*

Abstract: Programmable logic devices on base of asynchronous combinational circuits with feedback are considered. The main aim of the research is to obtain a method for designing a circuit with a set of prescribed stable states or a circuit without stable states — a generator of true random numbers. Both the cases of binary and ternary logics are studied.

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Keywords: programmable logic device, asynchronous linear circuit, feedback,ternary logic,binary logic

1. INTRODUCTION

A programmable devices containing identical units are widely used in many industries because of their functional versatility and use of a range of different devices Kilts (2007); Czerwinski and Kania (2013). Linear combinational gates based design has not entered the mainstream design technology due to the lack of interest to acyclic linear circuits since its outputs are linear combinations of input signals.This paper is a step toward addressing this gap. We present the array architecture in which the basic cells are linear combinational gates with feedback over GF(2) or GF(3). If the circuit has feedbacks then its behavior becomes more complex. Such a circuit might exhibit sequential behavior, or it may be unstable, or it can be combinational. Although introducing in of the feedback loops might lead to either an undesirable or ill-defined behavior, it is well known that, in some cases, it might produce well-behaved combinational circuits consisting of fewer components than equivalent acyclic circuits. In Kautz (1970) W.Kautz demonstrated that any minimal combinational circuit which realizes a specific three-input three-output Boolean function using only NOR gates must contain feedback. In Huffman (1971) D.Huffman proved that any function can be realized with just one inverter, plus AND and OR gates if feedback is used. In Rivest (1977) R.Rivest presented an example explaining that the feedback path in combinational circuits allows them to become smaller in size. Cyclic combinational circuits require less logic gates than an equivalent acyclic circuit. In Malik (1994) S.Malik presented a formal analysis of cyclic combinational circuits. In his paper he explained the techniques for the logical and timing analyses of such circuits. T.Shiple, G.Berry, and Touati in Shiple et al. (1996) proposed a constructive analysis of a cyclic circuit. It was shown that the class of circuits that Malik's procedure decides to be combinational consists of precisely those that well-behave electrically, according to the up-bounded inertial delay model. In Riedel and Bruck (2003) the authors described a general methodology for the synthesis of multilevel combinational circuits with cyclic topology. In Neiroukh et al. (2006) O.Neiroukh, S.Edward, and X.Song proposed an algorithm to characterize exactly all combinational behaviors of a cyclic circuit. Recently, one can observe considerable interest in such circuits; the main results can be found in J.H.Chen et al. (2015); Gange et al. (2014). In first of the papers the authors proposed a formal algorithm using logic implication to identify cyclifiable structure candidates directly, or to create them aggressively in circuits. Another paper presents arguments for use of four truth values in tests for good behavior of cyclic circuits. Nevertheless, one of the fundamental problems in the theory of combinational circuits with feedback, i.e., a description of all stable states, was not solved yet in general case. Suppose we have a combinational circuit with feedback; in this case, a phenomenon (known as 'jittering') arises (see Golic (2006)). Under some assumptions with respect to that process, one can develop a theory of jittering and create a circuit, which will work as a generator of random values. Many authors used that idea in binary case. In that case all possible stable states must be excluded. Some references to the original papers can be found in Sunar et al. (2007); Golic (2006); Kuznetsov et al. (2008). Our paper deals with combinational circuits that contain feedback loops and work as an asynchronous automaton (AA). We solve the problem of stable states of a circuit consisting of linear gates (i.e. gates implementing linear functions) with feedback. We suggest a technique which provides a method for detecting all stable states of circuit depending on control input signals. It is shown that such an AA can be used as a 'soft transformer': it converts the input signal into one of the stable states with prescribed properties. The application of such a circuit as a generator of true random values is given.

The paper has the following structure. In Section II we introduce a connection matrix as an object, completely

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10.1016/j.ifacol.2016.12.074