Chapter 3
Methodology for FPGA Implementation of a Chaos-Based AWGN Generator

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ABSTRACT

Additive White Gaussian Noise (AWGN) generators are a basic tool for the test and measurement of digital systems. One drawback for hardware implementation of the classically used algorithms is that they require the hardware implementation of complex operations (such as sinusoidal and logarithmic functions). In this chapter, a method for the design and hardware implementation of an AWGN generator based on chaotic maps is described. The advantage is that deterministic chaotic systems are described by simple nonlinear equations, and therefore, they are straightforward to implement in hardware. To ensure that the generated sequence has the desired Probability Density Function (PDF), the chaotic map, which is the heart of the system, is synthesized using an approach based on the theory of positive matrices method. The hardware implementation was developed using an Altera Cyclone III FPGA with the 3C120 Development Board.
INTRODUCTION

Hardware generation of Gaussian random numbers is a key capability for simulations across a wide range of disciplines. Many engineering applications involve the usage of Gaussian-like excitations in the generation, processing, and/or transmission of signals. Also, the AWGN channel is a standard in the evaluation of communications systems, mainly because they are a good approximation of a wide range of real channels.

The reason why Gaussian curve occurs so frequently in nature may be that the sum of noise with different distributions results in Gaussian noise, as predicted by the Central Limit theorem. Roughly, this theorem states that the distribution of the sum (or average) of a large number of independent, identically distributed variables will be approximately normal, regardless of the underlying distribution. The Central Limit theorem is of fundamental importance because it means that it is possible to approximate the distribution of certain statistics, even knowing very little about the underlying sampling distribution.

Ergodic sequences generated by chaotic maps, after a transient, which depends on the mixing property of the map, converge to a single Invariant Probability Density Function (IPDF). This distribution, as well as the mixing parameter ($r_{mix}$), is reflected by the Frobenius Perron Operator (FPO) which depends on the map’s structure. In this chapter the implementation of a Random Number Generator with Gaussian distribution using a chaotic map as the heart of the system is proposed. This is achieved thanks to a technique that has the ability to synthesize chaotic maps with desired IPDF and $r_{mix}$ (Lasota & Mackey, 2008). The synthesized maps are piecewise linear maps so are ideal to be implemented in FPGA devices, principally to take advantage of their concurrent nature.

The technique is presented here, including the considerations needed to select the parameters of the method and the details of its structure, explaining the necessary steps for it to be carried out. In order to exemplify the procedure the design and a hardware implementation of a chaotic map with Gaussian approximate PDF and small mixing constant are detailed here. The same methodology can be extended to implement other generators with arbitrary PDFs, by piecewise approximation.

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