

# VLSI Implementation of Nakagami Variate Generator

Santhosh Kumar

Department of Electronics and Communication Engineering,  
University College of Engineering Kakinada, JNTUK, Kakinada

[sanjntu@yahoo.co.in](mailto:sanjntu@yahoo.co.in)

**Abstract**— The major Objective of simulating the radio propagation channels is to substantiate the design and performance of wireless communication systems. In the early stage of analysis and performance of wireless transceiver design fading channel simulators plays a vital role. The software simulators are painless to design, where as various hardware simulators have been proved that they offer distinct speed over software based simulators. Rayleigh and Rician fading channels have been achieved by now using field programmable gate arrays, hardware-based simulators of Nakagami fading channels have perceived distant less attention. Hence this paper considers the implementation of Nakagami fading simulator on single field programmable gate array.

**Keywords**— Field Programmable gate arrays, fading channels, channel simulators, Rayleigh fading, Rician fading, Nakagami fading, software simulation, Hardware Simulation

## INTRODUCTION

Wireless communication systems is used to operate over radio channels for a different types of environmental and different states of weather, it is difficult to the prototype designing of a modern wireless communication system. Good voice quality and fault less and eminent -rate data transmission are the basic prerequisites of good wireless communications system. In order to meet all these system specifications, it must be able to yield better results in divergent environments where the radio propagation characteristics vary considerably. In order to check the system performance we go for analysis simulation, prototyping and testing. But the testing process a wireless communication system is a laborious process.

Simulation is a strikingly powerful tool widely adopted in virtually all fields of science to help develop a better understanding of some phenomenon under investigation. In engineering, it is used, for instance, to successfully test equipment, Algorithms, and techniques, and, to some extent and whenever applicable, to avoid or minimize time-consuming, costly, and inexhaustible field trials. Wireless communications are no exception and in this challenging, lively, and unkind area, with systems becoming increasingly more complex, both industry and academy engage themselves in developing simulators. Simulators for wireless communications almost certainly include a block for the fading channel. The fading channel can be described by a number of models, and among those available, the general models, namely the Gaussian, Rayleigh, Rician and Nakagami distributions have been applied to model and simulate a variety of different [1]. Henceforth we go for channel simulation. Simulation plays a prominent role in wireless communication systems design and substantiation, in order to evaluate the prior verification and depiction of wireless transceiver designs fading channel simulators are used [2]. The advent of simulation is that it gives less expensive testing of designs. As the software Simulation of fading channels is simple to evolve the hardware-based simulators have been. Exhibited distinct orders of magnitude of speed-up over software-based fading channel simulators. The Speed is an especially important Factor at the time of simulating different fading scenarios which were supported by recent Wireless standards Compared to a software compilation, hardware compilation process is less stretchable, since each change of the system requires the synthesis of the design from a Register Transfer Level (RTL) model and the place route operations on the FPGA [2]. But, once this is done, the simulation can run at a very high speed and precise BER evaluation can be obtained. The testing, verification and evaluation of wireless systems is an important but challenging endeavour. Such long-running simulations are an ideal target for FPGA. But the Hardware channel simulators are desirable to test baseband processing units for performance analysis, and also for system design and verification [1]

## IMPORTANCE OF NAKAGAMI FADING

The wireless environment is highly unstable and fading is due to multipath propagation. Multipath propagation leads to rapid fluctuations of the phase and amplitude of the signal. The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver [3]. Fading (small-scale signal power fluctuations) is a fundamental characteristic of wireless channels. Due to the existence of a great variety of fading environments, several statistical distributions have been

proposed for channel modelling of fading envelopes under short-term, long-term, and mixed fading conditions. Short-term fading models include the well-known Rayleigh, Rice, Hoyt, and Nakagami [3] Among of these distributions exists that well describe the statistics of the mobile radio signal the Nakagami- distribution has been given a special attention for its ease of manipulation and wide range of applicability. More importantly, the Nakagami- distribution has been found to be a very good fitting for the mobile radio channel [7]

The Nakagami-m distribution has founded many applications in technical sciences. It has been shown by extensive empirical measurement that this distribution is an appropriate model for radio links this kind of distribution has been used in many engineering applications statistical distribution which can accurately model a variety of fading environments. It has greater flexibility in matching some empirical data than the Rayleigh, Lognormal or Rice distributions owing to its characterization of the received signal. The Nakagami fading is known to be a special case of Rayleigh fading and it possesses good auto correlation properties. This is used to study the moderate to severe fading channels using distinct values of parameter m. the Nakagami fading is similar to Rayleigh fading when the value of  $m=1$ . The augmentation of numerous Rayleigh-fading signals which were independent and identically distributed (i.i.d.) yields a signal with Nakagami distributed amplitude [3]. The Nakagami distribution matches some empirical data better than other distributions. In order to analyze the stats and ability of fading channel environment in complicate media like urban environment, we go for the Nakagami distribution [7].

### DESIGN APPROACH OF NAKAGAMI FADING CHANNEL SIMULATOR

In order to generate Nakagami variates first we generates a correlated Rayleigh variates, and. The hardware model first generates correlated Rayleigh fading variates and then a sequence of logarithmic and linear domain. [1] Segmentations along with piece-wise linear approximations is used to precisely implement the nonlinear numerical functions used to transform the correlated Rayleigh fading process into Nakagami- variates [1]. In order to generate the Rayleigh Variates from Rayleigh variate generator. In distinct types of variate generators can be yielded from the uniform random number generators. To hatch the random numbers we use LFSR (Linear feedback shift register). Here LFSR is used as a Random number generator.

### GENERATION OF RANDOM NUMBERS USING LFSR

Random numbers are generated by various methods. The two types of generators used for random number generation are pseudo random number generator (PRNG) and True random number generator (TRNG). The numbers generated are random because no polynomial – time algorithm can describe the relation amongst the different numbers of the sequence. Numbers generated by true random number generator (TRNG) or cryptographically secure pseudo random number generator (CSPRNG). The sources of randomness in TRNG are physical phenomena like lightning, radioactive decay, thermal noise etc. The source of randomness in CSPRNG is the algorithm on which it is based.

A linear feedback shift register (LFSR) is a shift register whose input bit is a linear function of its previous state. The only linear function of single bits is xor, thus it is a shift register whose input bit is driven by the exclusive-or (xor) of some bits of the overall shift register value [5]

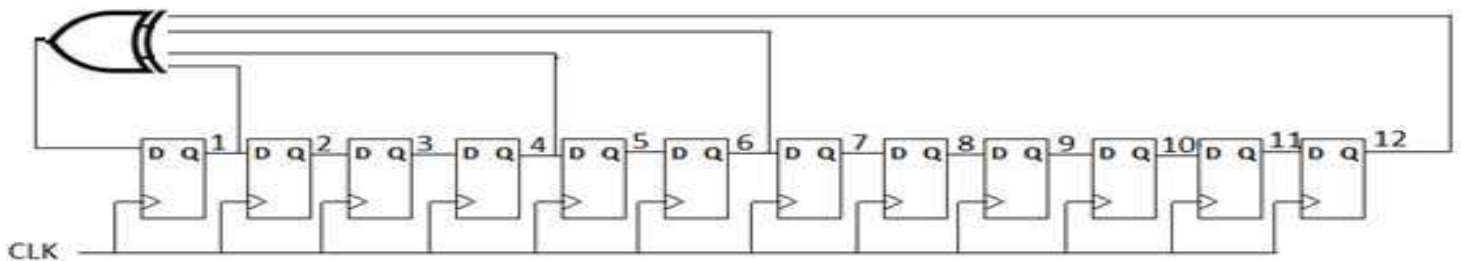


Fig.1. Schematic of 12-bit LFSR [4]

Here we are using 12-bit LFSR hence the number of random variables generated =4k (i.e.4096 numbers) In order to generate the LFSR with large sequence we have to opt appropriate feedback polynomial which was presented by Xilinx. The construction of 12-bit LFSR using simple D flip flops is as shown in Fig.1.

**GENERATION OF RAYLEIGH VARIABLES**

The generation of different types of random number by using LFSR's is shown in Fig.2 In order to generate different random variables from uniform random number generator Box Muller algorithm and Inverse transformation method plays a vital role. The conclusion of Box Muller algorithm is as follows [6].If U1 and U2 are two random variables of interval(0,1) then consult the two random variables X1,X2 such that [6]

$$X1 = \sqrt{-2 \ln U1} \cos 2\pi U2 \tag{1}$$

$$X2 = \sqrt{-2 \ln U1} \sin 2\pi U2 \tag{2}$$

Then (X1, X2) were the duo of random variables which follows Normal distribution with zero mean and unit variance. Coming to the architectural design uniform random numbers were generated by 12-bit LFSR's then look up table (LUT) is used to calculate and store the values of X1 and X2. As the LFSR yielded 4096 random numbers [4]

The LUT uses 4 RAM's such that each RAM can accommodate 1024 states (i.e. 1K X 16-bit) for each expression [4]. The value of sigma is the variance ( $\sigma^2$ ) of the Rayleigh distribution. The non restoring divider is used to divide the Value of X2 with the value of lambda ( $\lambda$ ) to yield the exponential distribution. The Rayleigh distributed output is having only magnitude(r) and it is converted into a complex number ( $c_i + jc_q$ ) with two variates  $c_i$  and  $c_q$  having zero mean and Equal variance. Such that the value of  $r_R^2$  is modulus of the complex number [2]

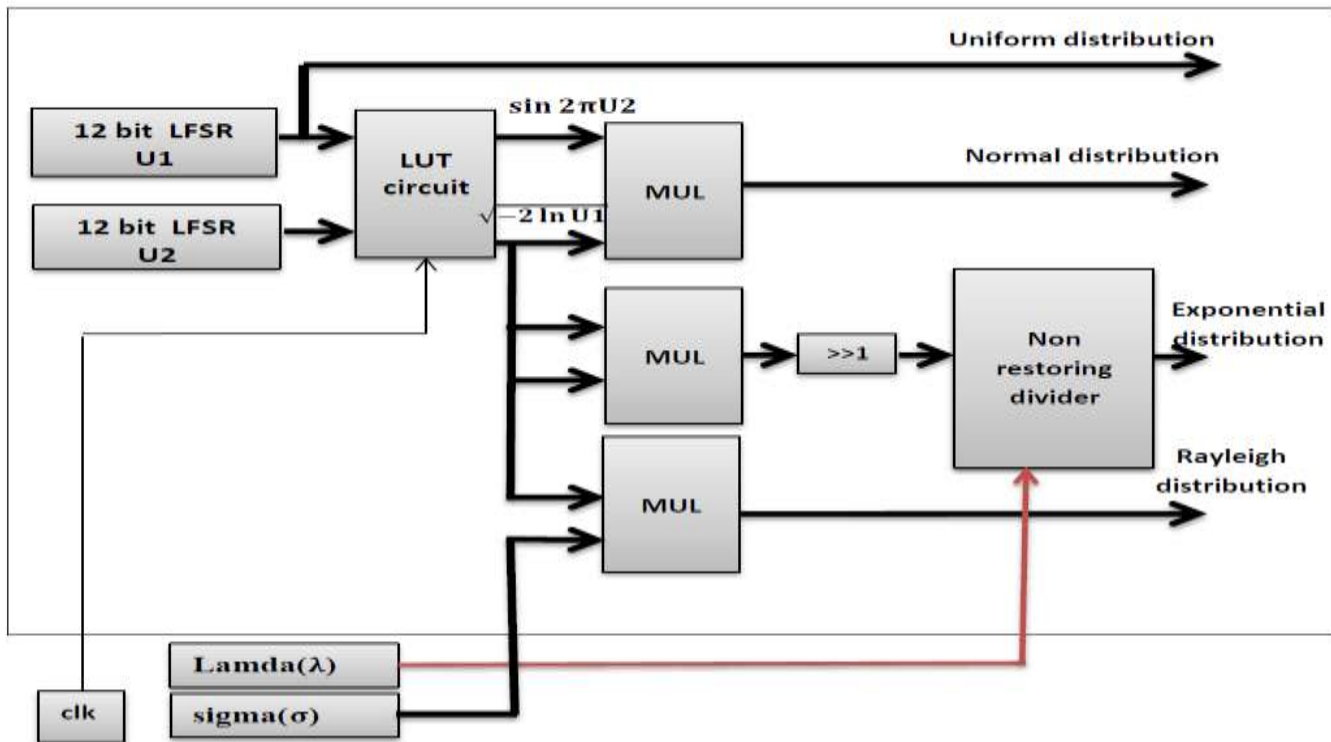


Fig2. Architecture of distinct random number generators [4]

DESIGN OF NAKAGAMI FADING CHANNEL SIMULATOR

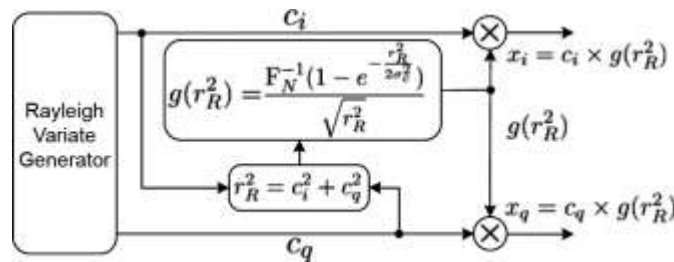


Fig.3. Nakagami variate Generator [1]

A high-level block diagram of Nakagami variate generator is shown in above figure. First the Rayleigh Variate Generator block generates a sequence of zero-mean unit-variance Complex Gaussian random variates  $c=c_i + jc_q$  and the Squared envelope  $r_R^2$  from the corresponding Rayleigh process is calculated as  $r_R^2 = c_i^2 + c_q^2$ . Then the transfer function  $g(r_R^2)$  is approximated in [1] and the in-phase and quadrature components are found by multiplying the Transfer function by  $c_i$  and  $c_j$  respectively.

GENERATION OF NAKAGAMI VARIATES

A uniform random variable  $U$  can be transformed into a Nakagami- random variable  $n_N$  using the nonlinear transformation of its ICDF as in below equation [1].

$$n_N = F_N^{-1}(U) \tag{3}$$

$F_N^{-1}$  is the inverse Nakagami-cdf in this process first Rayleigh RVs with the desired ACF are generated. A sequence of Rayleigh random variates  $r_R$  can be transformed into samples with a uniform distribution and the same ACF between samples using the inverse CDF transformation [1].

$$U = F_R(r_R) = 1 - e^{-\frac{r_R^2}{2\sigma^2}} \tag{4}$$

Then the uniform random variates transform into Nakagami variates using Eq.3. A useful rational proportional approximation for  $F_N^{-1}(U)$  is proposed as follows [1]

$$F_N^{-1}(U) \approx \eta(U) + \frac{a_1\eta(U) + a_2\eta(U)^2 + a_3\eta(U)^3}{1 + b_1\eta(U) + b_2\eta(U)^2} \tag{5}$$

$$\text{where } \eta(U) = \sqrt[m]{\ln \frac{1}{1-u}} \tag{6}$$

For a given value of  $m$ , the five coefficients  $a_1, a_2, a_3, b_1$  and  $b_2$  are calculated to minimize the approximation error. Suitable coefficient values for different values of  $m$  [7]. Now the generated Nakagami variates are

$$\dot{N} = g(r_R^2) * (c_i + jc_q) \tag{7}$$

$$\text{Where the transfer function } g(r_R^2) = \frac{F_N^{-1}(1 - e^{-\frac{r_R^2}{2\sigma^2}})}{\sqrt{r_R^2}} \tag{8}$$

RESULTS AND SIMULATIONS

This architecture of random number generator was implemented and Nakagami variate generators are practically in Xilinx ISE. The following shows the practical results of various random number generators, LFSR and Nakagami Variate Generator. The complete architecture design was implemented on Xilinx. The results of simulation for the values of sigma=2 are observed in Fig.4 and Fig.5 It is clear from the simulation results that all the numbers for all distributions are generated in every clock cycle.

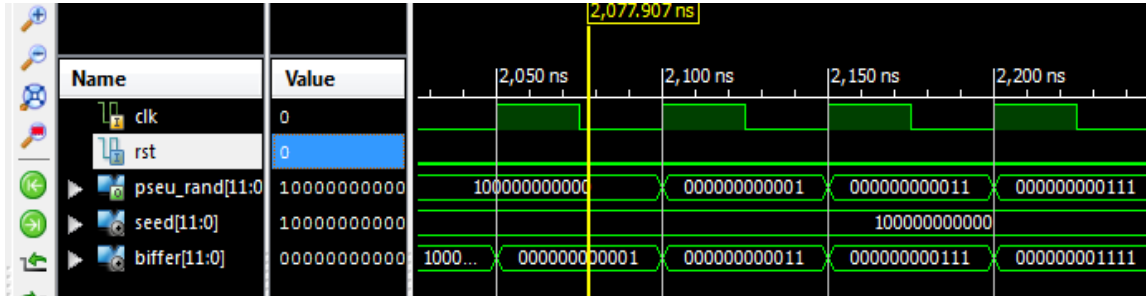


Fig.4. Simulation Results of 12-bit LFSR

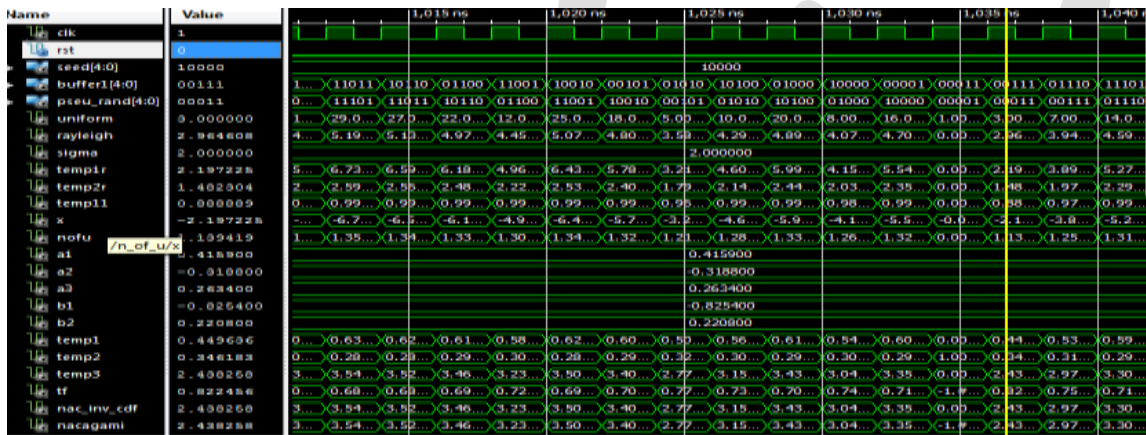


Fig5. Simulation results of Rayleigh and Nakagami random variate generators.

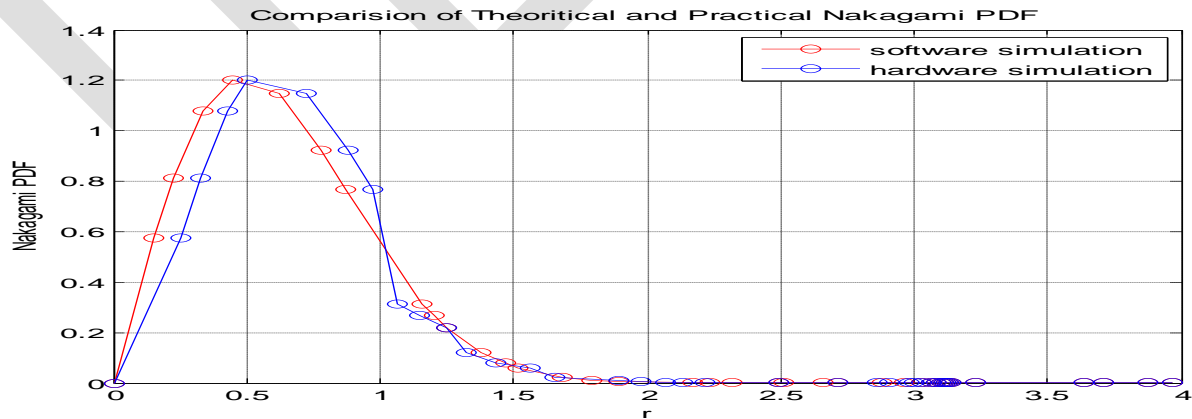


Fig.6. the contrast between standard Nakagami pdf and simulated pdf

The Fig.6 shows the similarity between the Hardware simulated Nakagami pdf and the standard Nakagami pdf

## CONCLUSION

This discussion presents the study of the design approach of sophisticated and adequate performance of random variate generators with accurate Nakagami distributions along with Nakagami fading channel simulator. In order to study and investigate the wireless communications systems thoroughly we use these both Rayleigh and Nakagami distributions. The Rayleigh variates are generated from the uniform Random number generator. Here we use LFSR's as a random number generator. And by processing the results of Box Muller algorithm to the Look up Table (LUT) circuits and using the value of sigma and Rayleigh variates are generated. The Nakagami simulator proposed here transforms the time correlated Rayleigh variates to Nakagami variates.

## REFERENCES:

- [1] A Alimohammad, M Saeed Fouladi Farad, S, and B.F. Cockburn, "Hardware Implementation of Nakagami and Weibull Variate Generators", IEEE TRANSACTIONS ON VERY LARGE SCALE INTEGRATION (VLSI) SYSTEMS, VOL. 20, NO. 7, JULY 2012
- [2] A. Alimohammad and B. F. Cockburn, "Modeling and hardware implementation of Rayleigh and Rician fading channel simulators," IEEE Trans. Veh. Technol., vol. 57, no. 4, pp. 2055–2069, Jul. 2012.
- [3] Sarmad Fakhruddin Ismael, Dr. Basil Shukr Mahmood "Architectural Design of Random Number Generators and Their Hardware Implementations", March 2014
- [4] EfficientShiftRegisters,LFSRCounters,andLongPseudoRandomSequenceGenerators,[http://www.xilinx.com/support/documentation/application\\_notes/xapp052.pdf](http://www.xilinx.com/support/documentation/application_notes/xapp052.pdf)
- [5] G. Box and M. Muller, "A Note on the Generation of Random Normal Deviates", Annals Math. Statistics, Vol. 29, 1958, pp. 610-611.
- [6] Elina Pajala, Tero Isotalo, Abdelmonaem Lakhzouri, Elena Simona Lohan, "An improved simulation model for Nakagami- $m$  fading channels for satellite positioning applications", PROCEEDINGS OF THE 3rd WORKSHOP ON POSITIONING, NAVIGATION AND COMMUNICATION (WPNC'06)81
- [7] A. Papoulis and S. U. Pillai, Probability, Random Variables and Stochastic Processes, 4th ed. New York: McGraw-Hill, 2002.
- [8] Xilinx Inc., San Jose, CA, "Xilinx UG190Virtex-5 FPGA User Guide,"2009
- [9] J. G. Proakis, Digital Communications, 4th ed. New York: McGraw- Hill, 2001.
- [10] G. L. Stüber, Principles of Mobile Communication. New York: Kluwer Academic Publishers, 2001
- [11] David Bishop, "Fixed point package user's guide", <http://www.vhdl.org/vhdl-200x/vhdl-200x-ft/packages/files.html>,2006
- [12] W. C. Jakes, *Microwave Mobile Communications*. Piscataway, NJ:Wiley-IEEE Press, 1994