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VHDL Modeling of Noisy and MIMO Fading Channels for FPGA Based Wireless Communication System Designs

[I]Gunturi Durga Bhavani, [II]S.Ravi, [II]Gudipalli Kalyan

Abstract

A typical communication system designed with software defined radio techniques consists of an antenna, RF units, mixer, analog to digital converter and digital circuits for remaining processing. As most of the crucial part is carried out in digital and it can be reconfigurable the software defined radio based design is highly preferred today. However when we want to simulate the digital modules of the transmitter and receiver modules, we also need the modules related to channel. It is very useful for studying the performance of whole communication system, if these modules are synthesizable on hardware.

In this paper we are aiming to model the channels with their noise and fading characteristics using VHDL. Mainly the noises and fading effects observed in wireless and mobile communication band will be simulated. The Rayleigh fading model will be given more importance as it is mainly encountered in mobile communication. The issues related to multi input multi output (MIMO) systems will be considered for modeling.

Initially GNU-OCTAVE (MATLAB scripting) will be used for simulation of such noise models. In the second stage the parameterized VHDL codes will be developed for such models. FPGA synthesis will be carried out for all these blocks for analyzing the maximum frequency of operation on a selected target FPGA.

Keywords

Fading, VHDL, Rayleigh, MIMO, GNU-OCTAVE.

I. Introduction

The wireless system has developed a base for giving numerous administrations to the users it is important to understand the channel and model it. The configuration, generation and arrangement of such innovative system have high cost along these lines producers search for different options to stay away from high costs. One of these options is reproducing an effective wireless system. The benefit of reproduction is that permits low cost testing of designs.

As on today not many efforts has gone on modeling the noise and fading of channel aiming for FPGA prototyping. Verification of wireless system configuration requires a suitable noise model which is implementable in hardware equipment. We are giving versatile models which are suitable for wide class of system parameters (power, bandwidth etc). This will have the capacity to add to a model driven for the models utilized by different users.

II. Fading And Fading Channel Model

A. Fading

The term fading means fast fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short time. This may be severe to the point that large scale radio propagation loss effects may be ignored.

The difference between noise and fading is that, noise is an unwanted signal which interferes with input signal. Where as Fading is the delay produced and Doppler Effect added with input signal at Receiver. Fundamentally there are two types of fading in wireless communication.

Large Scale Fading: Due to path loss of signal as a function of separation and shadowing by extensive objects, for example, buildings and hills. This happens as the versatile travels through a distance of the order of the cell size, and is normally frequency dependant.

Small scale fading: Due to the constructive and destructive forces interference of the various signal paths between the transmitter and receiver. This happens at the special scale size of the order of carrier wavelength, and its frequency dependent.

B. Fading channel model

The wireless environment is highly unstable and fading is due to multipath propagation. Multipath propagation [1] leads to rapid fluctuations of the phase and amplitude of the signal. The presence of reflectors in the environment surrounding a transmitter and receiver make numerous paths that a transmitted signal can cross. Subsequently, the receiver sees the superposition of various copies of the transmitted signal, each crossing an alternate path. Every signal copy will encounter differences in attenuation, delay and phase shift while traveling from the source to the destination.

This can result in either constructive or destructive interference, amplifying or attenuating the signal power at the receiver. Fading may be large scale fading or small scale fading. Based on multipath time delay spread small scale fading is classified as flat fading and frequency selective fading. If bandwidth of the signal is smaller than bandwidth of the channel and delay spread is smaller than relative symbol period then flat fading occurs whereas if bandwidth of the signal is greater than bandwidth of the channel and delay spread is greater than relative symbol period then frequency selective fading occurs. Based on doppler spread small scale fading may be fast fading or slow fading. Slow fading occurs when the coherence time of the channel is larger relative to the delay constraint of the channel. The amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building comes in the main signal path between the transmitter and the receiver. Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. The amplitude and phase change imposed by the channel varies considerably over the period of use. In a fast-fading channel, the transmitter may take advantage of the variations in the channel conditions using time diversity to help increase robustness of the communication.

C. Multipath fading channel

Fading channel models are used to demonstrate the effects of electromagnetic transmission of data over the air in cellular systems and shows communication. Fading channel [2] models are additionally utilized as a part of submerged acoustic communications to demonstrate the distortion caused by the water.

Multipath Fading Effects:

1. Fast changes in signal quality over a small distance or time interval.
2. Random frequency modulation because of changing Doppler shifts on different multipath signals.
3. Time scattering or echoes occurred by multipath propagation delays.

III. Rayleigh and Rician Fading

A. Rayleigh fading

Rayleigh fading is occurred by multipath reception. The portable receiving wire gets a large number, say N, reflected and scattered waves. As a result of wave cancellation effects, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna. Although fading is a random procedure, deep fades tend to happen at every half a wavelength of motion.

B. Rician fading

The model behind Rician fading is like that for Rayleigh fading, with the exception of that in Rician fading is the presence of strong dominant component. This dominant component can for example be the line-of-sight wave. Refined Rician models also consider that the dominant wave can be a phasor whole of two or more dominant signals, e.g. the line-of-sight, in addition to a ground reflection. This mixed signal is then considered as a deterministic procedure and that the dominant wave can also be subject to shadow attenuation. This is a popular assumption in the modeling of satellite channels.

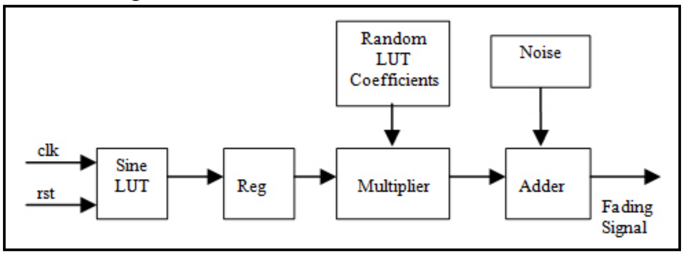

Fig.1 : Block diagram of fading model

A Sine wave is generated using a random Look Up Table which is having 64 address locations and 32 bit width. The samples are first fed to registers and then the buffered data is given to multiplier. The other input of multiplier is fed with the coefficients which are generated from random LUT coefficient block.

Sine wave samples are multiplied with the fading coefficients and are given to adder block which is immediate next to multiplier. Finally, adder output is a signal affected by fading and noise.

IV. Modeling of Channels

A. Model of ideal channel

Here a fixed antenna radiating into free space, in the far field the electric field and magnetic field at any given location are perpendicular to each other and to the direction of propagating from the antenna. In response to the transmitted sinusoid $\cos 2\pi ft$ we can express the electric far field at the time t as

$$E(f, t,(r, \theta, \psi)) = \frac{\alpha(\theta, \psi, f) \cos 2\pi f(t-r/c)}{r} \qquad (1)$$

Here (r, θ ,ψ) represents the point u in space at which the electric field is being measured , where r is the distance from transmitting antenna to u and where the (θ ,ψ) represents the vertical and horizontal angles from the transmitting antenna to u respectively. The constant c is the speed of light and α (θ, ψ, f) represents the radiation pattern of the sending antenna at a frequency f in the direction of (θ, ψ) it also contains a scaling factor to account for antenna losses. The phase of the field varies with fr/c, corresponding to the delay caused by the radiation traveling at a speed of light. As the distance r increases the electric field decreases by 1/ r. and thus the power per square meter in free space reduces by $1/r^2$. The total power radiated through the sphere remains constant, but the surface area increases by r^2 .Then the power per unit area must decrease as $1/r^2$ .Suppose there is fixed receiving antenna at a location u=(r, θ ,ψ)

The received waveform (in absence of noise) in response to the above transmitted sinusoid will be

$$E(f, t, u) = \frac{\alpha(\theta, \psi, f) \cos 2\pi f(t-r/c)}{r} \qquad (2)$$

Where the product of the antenna patterns of is receive and transmit antennas in the given direction. Placing a receive antenna there changes the electric fielding the vicinity of u.

B. Model of channel with moving receiver

Consider the fixed antenna and free space model above with a receiving antenna that is moving with a velocity of v in the direction of increasing distance from transmitting antenna. That is we assume the receive antenna is at a moving location described by

$$u(t) = r((t), \theta, \psi) \text{ with } r(t)=r_0 + vt \qquad (3)$$

Thus the sinusoid at a frequency of f has been converted to a sinusoid of frequency of f (1-v/c) there has been a Doppler shift of –fv/c due to motion of observation point. Intuitively, each successive crestin the transmitted sinusoid has to travel a little further before it gets observed at the moving observation point. If the antenna is now placed at u(t) , and the change of field due to antenna presence is again represented by receive antenna pattern.

V. Simulation Results

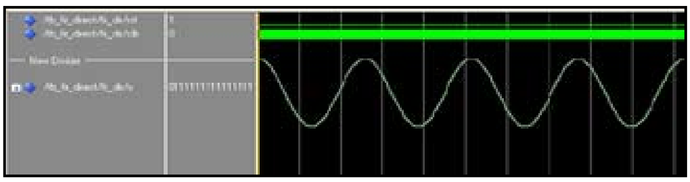

Fig.2: simulation result of input signal

The above figure shows simulation result of the inputs applied to the system. There are three inputs clock, reset and sine signal.

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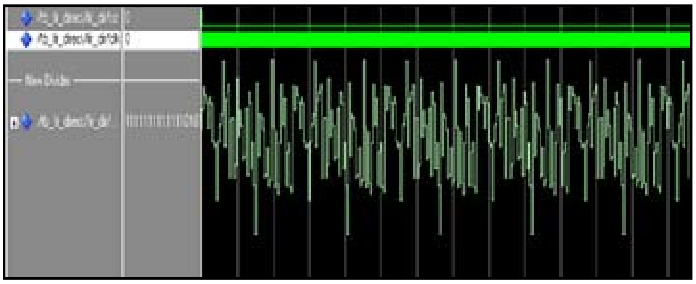

Fig.3 : Simulation result of noise signal

The above figure shows the simulation result of the noise which is generated by using random LUT.

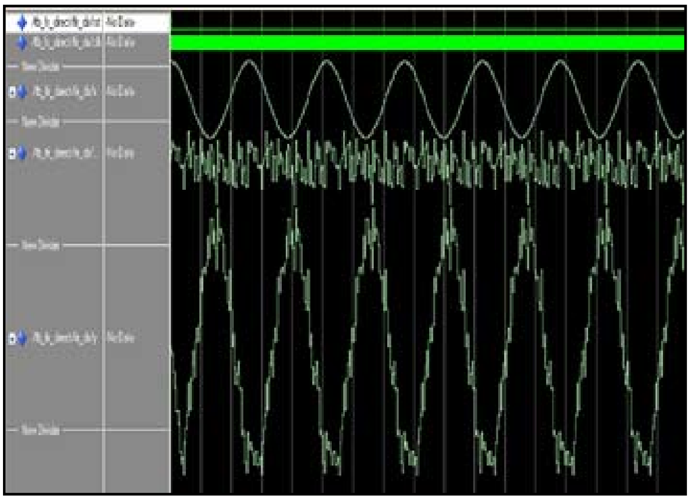

Fig. 4 : Simulation result of output signal effected by noise

The above figure shows the simulation results of final output. The noise affected signal can be seen above clearly. So, the fading and noise effect on a signal can be observed clearly.

VI. Conclusion

In this work we presented FPGA modeling of noise and fading effects of channels by MATLAB coding and VHDL coding which is capable to address MIMO system modeling issues. FPGA synthesis and analysis of usage such models for on chip communication system prototyping.

The effect of fading and noise on a signal in wireless communication system is modeled and also proved with modelsim simulation results. The same is implemented for the Spartan 3E FPGA device.

We are giving scalable models which are suitable for wide class of system parameters (power, bandwidth etc).

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Authors Profile

Ms. Gunturi Durga Bhavani pursuing M.Tech in VLSI System Design at Arjun College of technology & sciences.

Mr. S.RAVI, working as Assistant Professor at Arjun College of technology & sciences.
E-Mail: ravi4a3vits@gmail.com

Mr. G. KALYAN is presently working as Application Engineer in Unistring Tech Solutions Pvt Ltd, Hyderabad, Telangana, India.