Wireless Channel Modeling Simulation and Hardware Implementation

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Abstract. Channel simulator is an important part of the accurate evaluation of the fading characteristics of wireless channel. Efficient design and implementation of wireless channel simulator is very important for the design and verification of wireless systems. The greatest impact on the wireless communication system is a small-scale fading variation. According to the transmission characteristics, this paper analyzed the small scale fading model, the mathematical modeling simulation and hardware implementation. The measured results show that the statistical characteristics of hardware simulators output decline signal in conformity with the theoretical value, can simulate the attenuation, decline of wireless communication system, and doppler frequency shift and other transmission characteristics.

Introduction

Mobile communications is one kind of radio communication in a special environment, Wireless channel is an integral part of the mobile communication system[1]. Wireless signal in transmission process show that the variable characteristics, influencing factors including the signal frequency, bandwidth, transceiver speed, sending and receiving antenna type, height and Angle, the spread of the actual geographical environment and terrain, and climate conditions, etc. In order to accelerate the development of wireless communication devices, shorten the development cycle, Wireless channel simulator is widely used to test communication systems.

According to the channel parameter generation, wireless channel simulator can be divided into two categories. The channel parameters calculated in advance by the software, and repeated calls are made in the simulation. Its benefits include reduced hardware resource requirements, simplifying the multi-channel simulation design of the structure, increasing the number of channels and the number of simulation paths. But the original design of this kind of channel simulator is to carry out static simulation. The other is to generate the channel parameters in real time through the FPGA chip. The channel simulator is used to generate the channel parameters in real time, and the repetition period of the channel parameters is very long, which can meet the requirement of dynamic simulation. Flat fading channel model is presented in this paper on the basis of modeling and simulation, and implement channel simulator based on FPGA hardware platform.

Small Scale Fading Channel Modeling and Simulation

Effect of the radio channel on the wireless communication system can be divided into three main areas, large scale fading, medium scale fading and small scale fading. Small scale fading is refers to the wireless signals in a short time or short distance when its amplitude, phase, or multipath delay rapidly changing. The short time and short distance fast changes make the influence of the large scale fading and the medium scale fading to the receiver's signal can be ignored. Small scale fading is caused by the tiny time difference of the same signal to the receiver, which means that the multipath propagation of the wireless communication signal leads to the generation of small scale fading. The channel can be modeled as a delayed tap model [4], as shown in Figure 1, \( s(t) \) and \( y(t) \) represent the equivalent baseband signal input and output.
Clarke first proposed the classic Clarke model [5], Clarke statistical model is the most commonly used for flat fading channel model of a small scale fading. Clarke statistical model is a kind of channel model based on scattering theory, and it is in line with the characteristics of the distance from the wireless communication in the city, so it is widely used. Its mathematical expression is

\[ g(t) = \sum_{n=1}^{N} C_n \cos(2\pi f_d t + \omega_n \cos \alpha_n + \varphi_n) \]  

Among them, \( C_n \) is the different electric wave amplitude, \( \varphi_n \) is random phase, \( \omega_n \) is the Doppler frequency shift of different plane waves, \( \alpha_n \) is the incident angle of different plane wave. \( N \) represents the number of scattering branch. Clarke statistical model is a mathematical model for the physical channel model, the focus is consistent with the statistical properties of the established mathematical model simulation results with the physical model. The simulation branches number of Clarke model tends to infinity, Clarke model can not be applied to mathematical simulation. To make up for the shortcomings of the Clarke model, Jakes put forward the hypothesis that the angle of arrival is symmetrical. Using Symmetry to reduce the number of sine waves greatly reduce the computational complexity [6]. The defect of Jakes model is its high order statistical characteristics and Clarke model has a great difference, it is a non generalized stationary process. The Statistical characteristics of Jakes model output signal is non-sense stationary, which is caused by the correlation between the initial phase shift [7, 8]. The mathematical expression of improved model is

\[ X_c(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \cos(\omega_{\alpha} \cdot t \cdot \cos \alpha_n + \phi_n) \]  

\[ X_s(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \cos(\omega_{\alpha} \cdot t \cdot \sin \alpha_n + \varphi_n) \]  

\[ \alpha_n = \frac{2\pi n - \pi + \theta_n}{4M} \quad n = 1, 2, \ldots, M \]  

\[ X(t) = X_c(t) + j * X_s(t) \]  

where \( \phi_n \), \( \varphi_n \), \( \theta_n \) are statistically independent and uniformly distributed on \([-\pi, \pi]\) for all \( n \).

**Hardware Implementation of Channel Simulator**

To facilitate the FPGA implementation, using the \( k \cdot dt \) instead of \( t \), continuous time expression (2), (3), (5) to be modified as

\[ X_c(k) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \cos(\omega_{\alpha} \cdot k \cdot dt \cdot \cos \alpha_n + \phi_n) \]
\[ X_s(k) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \cos(\omega_t \cdot k \cdot dt \cdot \sin \alpha_n + \varphi_n) \]  

(7)

\[ X(k) = X_s(k \cdot dt) + j \cdot X_s(k \cdot dt) \]  

(8)

where \( \phi_n, \theta_n, \phi_n \) are statistically independent and uniformly distributed on \([-\pi, \pi]\) for all \( n \), \( s \) is the reciprocal of the sampling frequency.

In order to implement on FPGA flat fading channel simulator, random number needs to be updated every once in a while. The design of sequential control is divided into two parts. The first part is a random number generation module; the second part is \( \omega_t \cdot k \cdot dt \cdot \cos \alpha_n + \varphi_n \) multiply-add module. Figure 2 shows the flowchart of the flat fading channel simulator.

![Figure 2. The flowchart of flat fading channel simulator.](image)

![Figure 3. The simulation results of fading signal.](image)

![Figure 4. The spectrum of fading signal.](image)

![Figure 5. The envelope distribution of fading signal.](image)

The statistical properties of the improved model output fading signal is consistent with Clark model when \( M \) is equal to 8, so the channel simulator used eight sine wave to generate decline factor.
Through the Modelsim software to simulate the fading module, the synthesis process will be finished by the ISE 12.1 software. The simulation results are shown in Figure 3.

The spectral analysis results of the fading signal in Figure 6 is shown in Figure 4; statistical distribution of the amplitude envelope of the histogram is shown in Figure 5.

Summary
In this letter, a proved class of sum-of-sinusoids statistical simulation models is proposed for mobile fading channels. It has been shown that the autocorrelations of the quadrature components, the cross-correlations of the quadrature components, the auto correlation of the complex envelope of the new simulators match the desired ones exactly even if the number of sinusoids used to generate the channel fading is as small as 8. A hardware implementation scheme based on the sine wave superposition method is proposed. The measured data show that the statistical distribution of the output of the hardware simulator is in agreement with the theoretical value, which can be used for the test and development of wireless communication equipment.

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References