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# Computation ofExtendedSuzuki MobileFadingChannel (TypeII) Parameters

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***Abstract:*** *Multipath fading occurs in any environment where there is multipath propagation and there is some movement of elements within the radio communications system. This may include the radio transmitter or receiver position, or in the elements that give rise to the reflections. The multipath fading can often be relatively deep, i.e. the signals fade completely away, whereas at other times the fading may not cause the signal to fall below a useable strength. In this paper we discuss a model for extended Suzuki process (type II) and an appropriate deterministic model, and we present and analyze simulation results based on these proposed models.*
***IndexTerms:*** *Fading channels, mobile radiochannels, wireless communications,extendedSuzukiprocesses.*

## I. Introduction

Multipath fading may cause distortion to the radio signal. As the various paths that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at the receiver over a spread of times. This can cause problems with phase distortion and inter-symbol interference when data transmissions are made. In any terrestrial radio communications system, the signal will reach the receiver not only via the direct path, but also as a result of reflections from objects such as buildings, hills, ground, water, etc. that are adjacent to the main path. Besides the multipath propagation, also the Doppler Effect has a negative influence on the transmission characteristics of the mobile radio channel. Due to the movement of the mobile unit, the Doppler Effect causes a frequency shift of each of the partial waves. Hence, the spectrum of the transmitted signal undergoes a frequency expansion during transmission. This effect is called frequency dispersion. Suzuki processes can be considered to be models for the random fluctuations of the received signal in flat-fading land mobile radio systems. Therefore, modified and extended Suzuki processes with cross-correlation and dependence between the normal processes have been introduced [1],[2],[3]. The Extended Suzuki process of Type II is one of the Channel model processes to be applied to flat-fading (that is frequency- nonselective fading) channels. This process results from the product of the extended Rice process ξ(t) and a lognormal process λ(t) i.e.,

$$\eta(t) = \xi(t).\lambda(t) \tag{1}$$

Thelong-term fadingsignalisheremodeled bylognormal process$\lambda(t)$takingtheslowtimevariationoftheaveragelocal receivedpowerintoaccount,whereastheextendedRiceprocess $\xi(t)$modelstheshort-termfadingofthereceivedsignal. The extendedSuzukiprocess$\eta(t)$issuitableasastochasticmodel for a large class of satellite and land mobile radio channels in environments, where a direct line-of sight connection between the transmitter and the receiver cannot be ignored. The probability density function $p_\eta(t)$of the extended Suzuki process *η(t)* can be calculated by means of the relation [2]

$$p_\eta(z) = \int_{-\infty}^{\infty} \frac{1}{|y|} p_{\xi\lambda}\left(\frac{z}{y}, y\right) dy \tag{2}$$

where$p_{\xi\lambda}\left(\frac{z}{y}, y\right)$ is the joint probability density function of the processes $\xi(t)$ and $\lambda(t)$ at the same time instant $t$. Assuming that these two processes are independent, we can find the following integral equation for the probability density function of the extended Suzuki processes of type II

$$p_\eta(z) = \frac{1}{2\pi\psi_0|\sin\theta_0|}\int_0^\infty \frac{e^{-\frac{[\ln\left(\frac{z}{y}\right)-m_3]^2}{2\sigma_3^2}}}{\sqrt{2\pi}\sigma_3(z/y)} . e^{-\frac{y^2+\rho^2}{2\psi_0 \sin^2\theta_0}} . \int_{-\pi}^{\pi} e^{\frac{y\rho\cos(\theta-\theta_\rho)}{\psi_0 \sin^2\theta_0}} . e^{\frac{\cos(\theta_0)}{\psi_0 \sin^2\theta_0}[y^2 \sin 2\theta + \rho^2 \sin 2\theta_\rho - 2y\rho \sin(\theta-\theta_\rho)]} d\theta dy \tag{3}$$

where $z \geq 0$, and $\psi_0$ is the average power of the two real-valued Gaussian random processes determining the extended Rice process $\xi(t)$, while $\theta_0$ is the phase difference between these two processes. The parameters $\rho$ and $\theta_\rho$ represent the amplitude and phase of the line of sight component m(t), while $\sigma_3$ and $m_3$ are the statistical parameters of the long term fading as will be discussed in section III [2],[7].

## II. Modeling And Analysis Of The Short-Term Fading

Thestochastic reference modelforextendedSuzukiprocessesofTypeIIisshown inFig. 1,wheretheshort-term fadingismodeledbytheprocess

$$\xi(t) = |\mu_\rho(t)| = |m(t) + \mu(t)| \quad (4)$$

where,

$$\mu(t) = \mu_1(t) + j\mu_2(t) \quad (5)$$

represents the sum of all scattered non-line-of-sight components of the received un-modulated carrier signal over the mobile fading channel, and

$$m(t) = m_1(t) + jm_2(t) = \rho e^{j(2\pi f_\rho t + \theta_\rho)} \quad (6)$$

is the line-of-sight signal component, where $\rho$, $f_\rho$, and $\theta_\rho$ denote the amplitude, the Doppler frequency, and the phase oftheline-of-sight component,respectively.

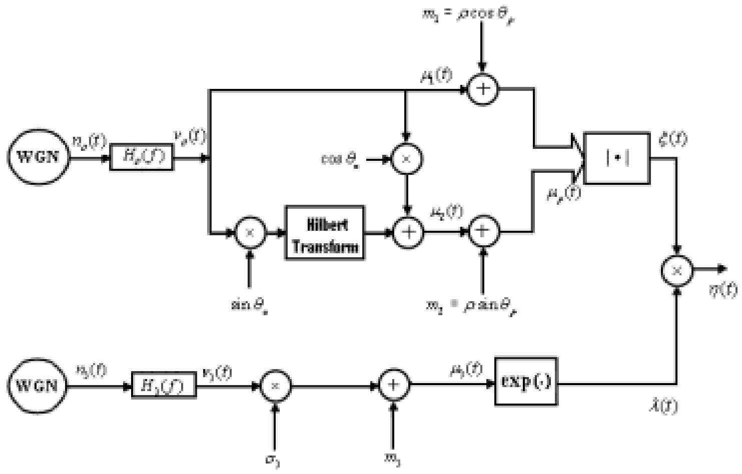

**Fig.1.**Stochasticreferencemodelfor extendedSuzukiprocessesofTypeII

Inordertosimplify themodel,wewillassumethattheDopplerfrequency ofthe line-of-sightcomponentisequaltozero,hencetheline-of-sight componentcanbeexpressedas

$$m = m_1 + jm_2 = \rho e^{\theta_\rho} \quad (7)$$

Asa result,thestochasticprocess$\xi(t)$which will be called theextended Rice process, can be given as

$$\xi(t) = |\mu_\rho| = \sqrt{(\mu_1(t) + m_1)^2 + (\mu_2(t) + m_2)^2} \quad (8)$$

The Doppler power spectral density $S_{v_o v_o}(f)$ of the process $v_o(t)$ is described by

$$S_{v_o v_o}(f) = \begin{cases} \frac{\sigma_0^2}{\pi f_{max}\sqrt{1-(f/f_{max})^2}}, & |f| \le \kappa_0 . f_{max} \\ 0 & , \quad |f| > \kappa_0 . f_{max} \end{cases} \quad (9)$$

where$f_{max}$ denotesthemaximumDopplerfrequency,andthe variable$0 < \kappa_0 \le 1$ givesasimpleandeffectivemethodto reduce theDopplerspread of$S_{v_o v_o}(f)$,tomakeitmorecloser toreality. FromFig.1,thefollowingrelationsholdforthe underlyingprocesses:

$$\mu_1(t) = v_0(t) \quad (10)$$

$$\mu_2(t) = cos\theta_0 . v_0(t) + sin\theta_0 . \check{v}_0(t) \quad (11)$$

where$-\pi \le \theta_0 < \pi$,and$\check{v}_0(t)$istheHilberttransformof$v_i(t)$for($i$=1,2).

Herethespectralshapingof$v_0(t)$isbasedon filteringofwhite Gaussiannoise byusing anideal filter whose transfer function is given by $H_o(f) = \sqrt{S_{v_o v_o}(f)}$. The autocorrelation functions $R_{\mu_1\mu_1}(\tau)$ and $R_{\mu_2\mu_2}(\tau)$ as well as the cross-correlation functions $R_{\mu_1\mu_2}(\tau)$ and $R_{\mu_2\mu_1}(\tau)$ can be expressed in terms of the autocorrelation function $R_{v_o v_o}(\tau)$ of the processes $\check{v}_0(t)$ and $v_0(t)$ as follows[2]:-

$$R_{\mu_1\mu_1}(\tau) = R_{\mu_2\mu_1}(\tau) = R_{v_o v_o}(\tau) \quad (12)$$

$$R_{\mu_1\mu_1}(\tau) = cos\theta_0 . R_{\nu_o\nu_o}(\tau) - sin\theta_0 . R_{\nu_o\nu_o}(\tau) \quad (13)$$

$$R_{\mu_2\mu_1}(\tau) = cos\theta_0 . R_{\nu_o\nu_o}(\tau) + sin\theta_0 . R_{\breve{\nu}_o\nu_o}(\tau) \quad (14)$$

By using these equations as well as the relation

$$R_{\mu\mu}(\tau) = R_{\mu_1\mu_1}(\tau) + R_{\mu_2\mu_2}(\tau) + j[R_{\mu_1\mu_2}(\tau) - R_{\mu_2\mu_1}(\tau)] \quad (15)$$

we get

$$R_{\mu\mu}(\tau) = 2R_{\nu_o\nu_o}(\tau) - j2sin\theta_0 . R_{\breve{\nu}_o\nu_o}(\tau) \quad (16)$$

After Fourier transforming $R_{\mu\mu}(\tau)$, the power spectral density can be given as

$$S_{\mu\mu}(f) = 2S_{\nu_o\nu_o}(f) - j2sin\theta_0 . S_{\breve{\nu}_o\nu_o}(f) \quad (17)$$

which can be expressed in terms of $S_{\nu_o\nu_o}(f)$ as

$$S_{\mu\mu}(f) = 2[1 + sgn(f). sin\theta_0]. S_{\nu_o\nu_o}(f) \quad (18)$$

## III. Modeling And Analysis Of The Long-Term Fading

Measurements have shown that in many wireless communication systems the statistical behavior of long-term fading is quite similar to a lognormal process [2]. With such a process, the slow fluctuation of the local mean value$\lambda(t)$ of the received signal, which is determined by shadowing effects, is given by

$$\lambda(t) = e^{\sigma_3\nu_3(t)+m_3} \quad (19)$$

where$\nu_3(t)$ is a real-valued Gaussian random process with mean of zero and variance of unit. The model parameters $m_3$ and $\sigma_3$can be used in connection with the parameters of the extended Rice process ($\sigma_0^2$ , $f_{max}$ , $\kappa_0$ , $\theta_0$ , $\rho$, $\theta_\rho$) to fit the model behaviortothestatisticsofreal-worldchannels. Weassume that the stochastic process$\nu_3(t)$ is statistically independent of the process $\nu_0(t)$.$S_{\nu_3\nu_3}(f)$is assumed to have the form of the Gaussian power spectraldensity[2],[4]:

$$S_{\nu_3\nu_3}(f) = \frac{1}{\sqrt{2\pi\sigma_c}} . e^{-\frac{t^2}{2\sigma_c^2}} \quad (20)$$

the 3-dB-cut-off frequency $f_c = \sigma_c\sqrt{2ln2}$is in general much smaller than the maximum Doppler frequency $f_{max}$ . The autocorrelation function of the process $\nu_3(t)$ can be expressed as

$$R_{\nu_3\nu_3}(\tau) = e^{-2(\pi\sigma_c\tau)^2} \quad (21)$$

which corresponds to the inverse Fourier transform of $S_{\nu_3\nu_3}(f)$. The autocorrelation function $R_{\lambda\lambda}(\tau)$ of the lognormal process can be expressed in terms of $R_{\nu_3\nu_3}(\tau)$ as

$$R_{\lambda\lambda}(\tau) = e^{2m_3+\sigma_3^2[1+R_{\nu_3\nu_3}(\tau)]} \quad (22)$$

The power spectral density $S_{\lambda\lambda}(f)$ can now be expressed in terms of the power spectral density $S_{\nu_3\nu_3}(f)$as follows

$$S_{\lambda\lambda}(f) = e^{2m_3+\sigma_3^2} . [\delta(f) + \sum_{n=1}^{\infty} \frac{\sigma_3^{2n}}{n!} . \frac{S_{\nu_3\nu_3}\left(\frac{f}{\sqrt{n}}\right)}{\sqrt{n}}] \quad (23)$$

where$\delta(f)$is the Dirac-Delta function.

## IV. Deterministic Simulation Model For The Extended Suzuki Process Of Type II

Stochastic multipath propagation models for indoor and out- door mobile radio channels are in general derived by employing colored Gaussian noise processes. Efficient design and realization techniques of such processes are therefore of particular importance in the area of mobile radio channel modeling [5]. Figure 2 shows the deterministic simulation model for extended Suzuki process of Type II that approximates the behavior of the stochastic reference model shown in Fig. 1. Using Eq.(10) and Eq.(11), we get

$$\tilde{\mu}_1(t) = \sum_{n=1}^{N_1} c_{1,n} cos(2\pi f_{1,n} t + \theta_{1,n}) \quad (26)$$

$$\tilde{\mu}_2(t) = \sum_{n=1}^{N_1} c_{1,n} cos(2\pi f_{1,n} t + \theta_{1,n} - \theta_0) \quad (27)$$

From these two equations, it can be noted that the Doppler phases $\theta_{2,n}$ of the second deterministic process $\tilde{\mu}_2(t)$ depend on the Doppler phases $\theta_{1,n}$of the first deterministic process$\tilde{\mu}_1(t)$, because $\theta_{2,n} = \theta_{1,n} - \theta_0$ . The complex-valued deterministic process $\tilde{\mu}(t) = \tilde{\mu}_1(t) + \tilde{\mu}_2(t)$can be expressed as

$$\tilde{\mu}(t) = \sum_{n=1}^{N_1} c_{1,n} e^{\pm j(2\pi f_{1,n} t+\theta_{1,n})} \quad (28)$$

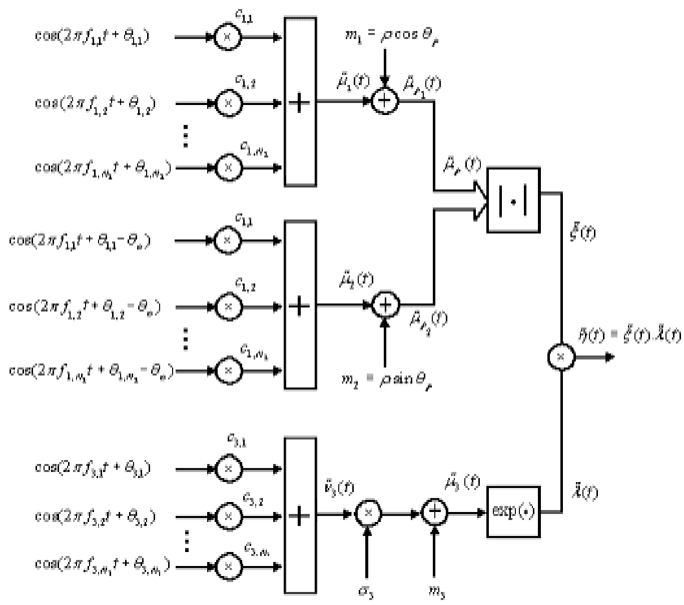

**Fig.2.**DeterministicsimulationmodelforextendedSuzukiprocessesofType II

The autocorrelation functions of the processes $\tilde{\mu}_1(t)$and $\tilde{\mu}_2(t)$can be given as:

$$R_{\nu_1\nu_1}(\tau) = R_{\nu_2\nu_2}(\tau) = \sum_{n=1}^{N_1} \frac{c^2{}_{1,n}}{2} cos(2\pi f_{1,n}\tau) \quad (29)$$

Andthecross-correlationfunctionsare:

$$R_{\nu_1\nu_2}(\tau) = R_{\nu_2\nu_1}(-\tau) = \sum_{n=1}^{N_1} \frac{c^2{}_{1,n}}{2} cos(2\pi f_{1,n}\tau - \theta_0) \quad (30)$$

Using the Method of Equal Distances [2],[5] to calculate the Doppler coefficients $c_{1,n}$ and $f_{1,n}$ , we get

$$c_{1,n} = \frac{2\sigma_0}{\sqrt{\pi}} [\arcsin\left(\frac{n}{N_1'}\right) - \arcsin\left(\frac{n-1}{N_1'}\right)]^{1/2} \quad (31)$$

AndtheDopplerfrequencies

$$f_{1,n} = \frac{f_{max}}{2N_1'}(2n-1) \quad (32)$$

where

$$N_1' = \frac{N_1}{\frac{2}{\pi}\arcsin(\kappa_0)} \quad (33)$$

is an auxiliary variable that depends on the frequency ratio $\kappa_0 = f_{max}/f_{min}$ . The Doppler phases $\theta_{1,n}$ are assumed to be realizations of a random variable uniformly distributed within the interval $(0, 2\pi]$.The computation of the discrete Doppler coefficients $c_{3,n}$ of the deterministic Gaussian process $\tilde{\nu}_3(t)$, whose power spectral density is Gaussian shaped, are given by the solution to

$$c_{3,n} = \sigma_0\sqrt{2}[erf\left(\frac{n\kappa_c\sqrt{ln(2)}}{N_3}\right) - erf(\frac{(n-1)\kappa_c\sqrt{ln(2)}}{N_3})]^{1/2} \quad (34)$$

where$erf(.)$ is the error function. The Doppler frequencies $f_{3,n}$ can be computed as

$$c_{3,n} = \frac{\sqrt{2}f_{max}}{N_3}(2n-1) \quad (35)$$

## V. Simulation Results

Figure 3 shows the power spectral density (as determined by the method of equal distances) as well as the autocorrelationfunction of$\mu_i(t)$, for $i = 1,2$, where the number of harmonic functions Ni is considered as 19 (ideally ∞), and the maximum Doppler frequency $f_{max}$ is 85Hz. The difference between the autocorrelation function of the reference model and the simulation model decreases by increasing the number of harmonic functions ($N_i$). The power spectral density of $\nu_3(t)$ shown in Fig. 4, resembles the Gaussian power spectral density given by eq. 20. Here again the difference between the auto- correlation function of the reference model and the simulation model decreases by increasing the number of harmonic functions $N_3$. The cut-off frequency $f_c$ is selected in such a way that the mean power of the Gaussian power spectral density obtained makes up at least 99.99% of its total mean power. This demand is fulfilled with $f_c = \sqrt{ln2}f_{max}$ [6].

The parameters $\sigma_0$ , $f_{max}/f_c$ , $\kappa_0$ , $\theta_0$ , $\rho$, $\theta_\rho$, $\sigma_3$, $m_3$ were experimentally optimized in [2] for heavy and light shadowing, the optimized values are shown in Fig.5. Using these values of the parameters and assumed values for $N_1$ , $N_3$ , and $f_{max}$ in simulating the extended Suzuki process of type II, we get Fig. 6 for heavy shadowing regions and Fig. 7 for light shadowing regions. From these two figures, it can be seen that the average signal level for heavily shadowed line-of-sight component is smaller than that for lightly shadowed line-of-sight component. Also, the deep fades for heavy shadowing regions are much larger than that for light shadowing regions. These results are expected because as the strength of the line-of-sight component increases, it dominates the received signal, hence the effect of fading becomes less significant[6].

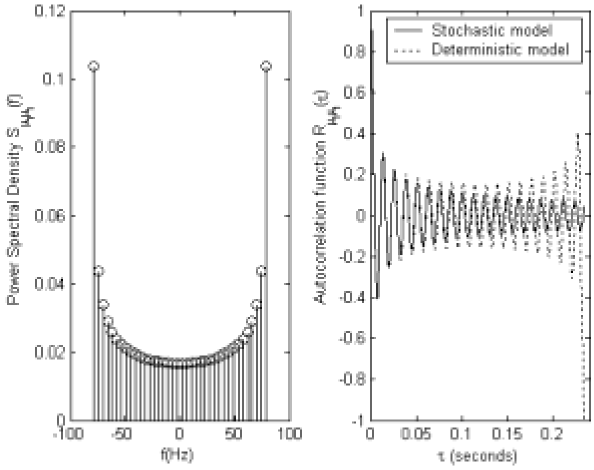


**Fig.3.**Powerspectraldensity$S_{\mu_i\mu_i}(f)$andAutocorrelationfunction $R_{\mu_i\mu_i}(\tau)$for$i$=1,2, with$N_i$=19,$f_{max}$=85$Hz$,$\sigma^2$ =1.

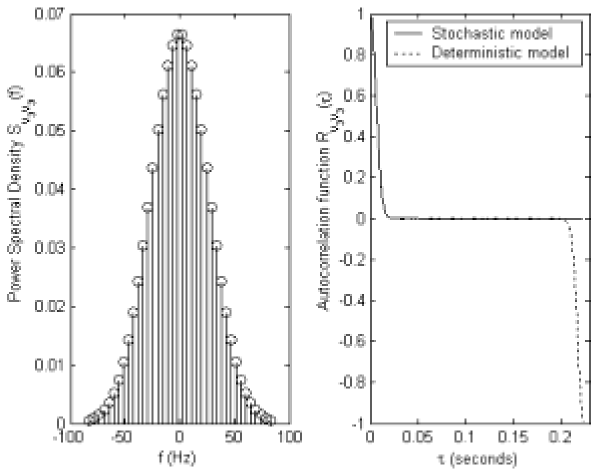


**Fig.4.**.Powerspectraldensity$S_{\nu_3\nu_3}(f)$andAutocorrelationfunction $R_{\nu_3\nu_3}(\tau)$with$N_3$=19,$\sigma^2$ =1,and$f_{max}$=85Hz.

| Shadowing | $\sigma_0$ | $\kappa_0$ | $\theta_0$ | $\rho$ | $\theta_\rho$ | $\sigma_3$ | $m_3$ | $f_{max}/f_c$ |
|---|---|---|---|---|---|---|---|---|
| heavy | 0.2774 | 0.506 | $30^0$ | 0.269 | $45^0$ | 0.0905 | 0.0439 | 119.9 |
| light | 0.7697 | 0.4045 | $164^0$ | 1.569 | $127^0$ | 0.0062 | -0.3861 | 1.735 |

**Fig.5.**Theoptimizedparameters ofthereferencechannelmodelforareas withheavyandlightshadowing.

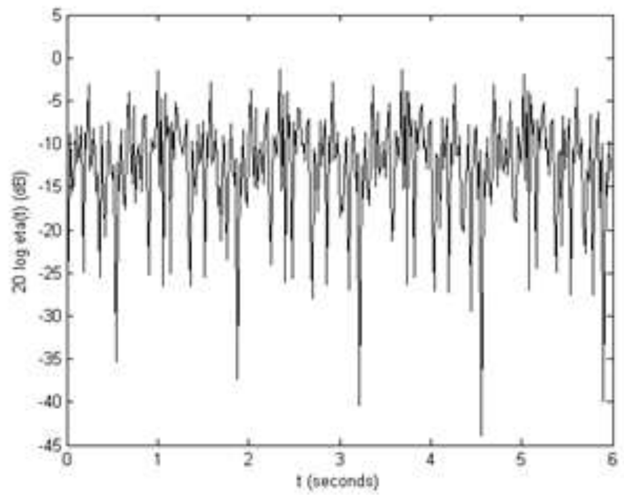


**Fig.6.**Simulation oftheextendedSuzukiprocess$\eta(t)$ofTypeIIforheavy shadowingregions,$N_1$=19,$N_3$=19,and$f_{max}$=85$Hz$.

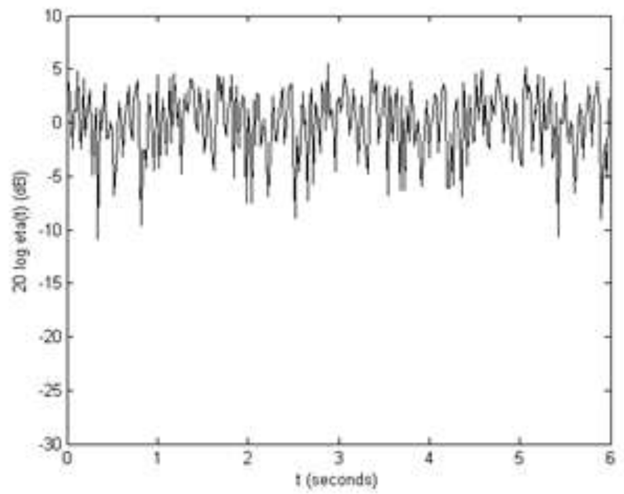


**Fig.7**.Simulation oftheextendedSuzukiprocess$\eta(t)$ofTypeIIforlight shadowingregions, $N_1$=19,$N_3$=19,and$f_{max}$=85$Hz$.

## VI. Conclusions

In this paper, we discussed stochastic and deterministic (simulation) models for the extended Suzuki process of type II. The exact Doppler spread method was used to compute the primary parameters of the simulation model (Doppler coefficients and discrete Doppler frequencies), where finite numbers of harmonics were used to simulate the short term and long term fading components of this model. As a result, it was found that the deep fades for heavy shadowing regions are much larger than that for light shadowing regions.

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