Probability Density Functions of Derivatives in Two Time Instants for SSC Combiner in Rician Fading Channel

Dragana Krstić
Department of Telecommunications,
Faculty of Electronic Engineering, University of Niš
Aleksandra Medvedeva 14
Niš, Serbia
dragana.krstic@elfak.ni.ac.rs

Petar Nikolić
Tigartyres, Pirot, Serbia
nikpetar@gmail.com

Goran Stamenović
Tigar, Pirot, Serbia
goran.stamenovic@tigar.com

***Abstract*—The probability density functions (PDFs) of derivatives in two time instants for output signals from dual branch Switch and Stay Combiner (SSC) in the presence of Rician fading are determined in this paper. The second order statistics such as the average level crossing rate and the average fade duration can be calculated by using obtained closed-form expressions.**

Keywords-probability density function; Rician fading; Switch and Stay Combining; time derivative

I. INTRODUCTION

Fading is one of the most important causes of degradation signals in wireless communication systems [1]. Ricean fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution [2], [3].

Rayleigh fading is the specialized model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of Rician fading. In Rayleigh fading, the amplitude gain is characterized by a Rayleigh distribution.

In telecommunications, a diversity scheme refers to a method for improving the reliability of a message signal by using two or more communication channels with different characteristics. Diversity plays an important role in combating fading effect and co-channel interference and avoiding errors [4]-[6]. It is based on the fact that individual channels experience different levels of fading and interference. Multiple versions of the same signal may be transmitted or received and combined in the receiver. Diversity techniques may exploit the multipath propagation, resulting in a diversity gain, often measured in decibels.

When space diversity is used the signal is transmitted over several different propagation paths. In the case of wired transmission, this can be achieved by transmitting via multiple wires. In the case of wireless transmission, it can be achieved by antenna diversity using multiple transmitter antennas (transmit diversity) and/or multiple receiving antennas (reception diversity). In the latter case, a diversity combining technique is applied before further signal processing takes place.

Diversity combining is the technique applied to combine the multiple received signals of a diversity reception device into a single improved signal. Various diversity combining techniques can be distinguished:

Selection combining (SC): Of the N received signals, the strongest signal is selected [7]. When the N signals are independent and Rayleigh distributed, the expected diversity gain has been shown to be inversely proportional to the number of antennas [8, 9]. Therefore, any additional gain diminishes rapidly with the increasing number of channels.

Switched combining: The receiver switches to another signal when the currently selected signal drops below a predefined threshold [10, 11]. This is a less efficient technique than selection combining.

Equal-gain combining (EGC): All the received signals are summed coherently [12].

Maximal-ratio combining (MRC) is often used in large phased-array systems. The received signals are weighted with respect to their SNR and then summed [13].

The authors determined earlier the probability density functions and joint probability density functions for SSC combiner output signals at two time instants in the presence of different fading distributions and used these expressions for obtaining better system performances, such as the bit error rate and the outage probability, for complex systems sampling at two time instants. Performance analysis of SSC/SC combiner in the presence of Rayleigh and log-normal fading are performed in [14] and [15], respectively.

In this paper, the probability density functions (PDFs) of derivatives for Switch and Stay Combiner (SSC) output signals at two time instants in the presence of Rician fading will be determined. The dual branch SSC combiner will be

 ISBN: 978-1-61208-203-5

considered. Subsequently, the second-order characteristics can be determined using these PDF [16].

The remainder of the document is organized in the following way: Section II introduces the model of the SSC combiner observed and basic assumptions of the problem under consideration. After that, in Section III, the probability density function of derivative is derived and graphicaly presented. Last section gives some conclusions.

II. SYSTEM MODEL

This section discusses the SSC combiner with two branches in two time moments. The model is shown in Figure 1. The input signals are r_{11} and r_{21} in the first time moment, and r_{12} and r_{22} in the second time moment. The signals at the output are r_1 and r_2. The derivatives are $\dot{r}_{11}$ and $\dot{r}_{21}$ at the first time moment, and $\dot{r}_{12}$ and $\dot{r}_{22}$ at the second time moment. The derivatives at the SSC combiner output are $\dot{r}_1$ and $\dot{r}_2$.

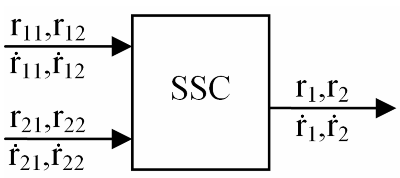

Figure 2. Model of the SSC combiner with two inputs at two time instants

The indices for input signals and their derivatives are: the first index represents the branch ordinal number and the other one signs the time instant observed. The indices for the output signal correspond to the time instants considered.

The probability that combiner examines first the signal from the first branch is P_1 and P_2 for the second. The values of P_1 and P_2 for SSC combiner are obtained in [1].

The four different cases are discussed here:

1) $r_1<r_T$, $r_2<r_T$

In this case all signals are less then threshold r_T, i.e.: $r_{11}<r_T$, $r_{12}<r_T$ $r_{21}<r_T$, and $r_{22}<r_T$. Let combiner considers first the signal r_{11}. Because $r_{11}<r_T$, then $\dot{r}_1=\dot{r}_{21}$, and because of $r_{22}<r_T$, then $\dot{r}_2=\dot{r}_{12}$. The probability of this event is P_1. If combiner examines first the signal r_{21}, then $r_{21}<r_T$, $\dot{r}_1=\dot{r}_{11}$, as $r_{21}<r_T$, $\dot{r}_2=\dot{r}_{22}$. The probability of this event is P_2.

2) $r_1\geq r_T$, $r_2<r_T$

The possible combinations are:

- $r_{11}\geq r_T$, $r_{12}<r_T$, $r_{22}<r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{22}$ P_1

- $r_{11}<r_T$, $r_{21}\geq r_T$ $r_{22}<r_T$, $r_{12}<r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{12}$ P_1

- $r_{21}\geq r_T$, $r_{22}<r_T$, $r_{12}<r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{12}$ P_2

- $r_{21}<r_T$, $r_{11}\geq r_T$, $r_{12}<r_T$, $r_{22}<r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{22}$ P_2

3) $r_1<r_T$, $r_2\geq r_T$

The possible combinations for this case are:

- $r_{11}<r_T$, $r_{21}<r_T$, $r_{22}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{22}$ P_1

- $r_{11}<r_T$, $r_{21}<r_T$, $r_{22}<r_T$, $r_{12}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{12}$ P_1

- $r_{21}<r_T$, $r_{11}<r_T$, $r_{12}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{12}$ P_2

- $r_{21}<r_T$, $r_{11}<r_T$, $r_{12}<r_T$, $r_{22}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{22}$ P_2

4) $r_1\geq r_T$, $r_2\geq r_T$

Now, the possible combinations are:

- $r_{11}\geq r_T$, $r_{12}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{12}$ P_1

- $r_{11}\geq r_T$, $r_{12}<r_T$, $r_{22}\geq r_T$ $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{22}$ P_1

- $r_{11}<r_T$, $r_{21}\geq r_T$, $r_{22}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{22}$ P_1

- $r_{11}<r_T$, $r_{21}\geq r_T$, $r_{22}<r_T$, $r_{12}<r_T$ $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{12}$ P_1

- $r_{21}\geq r_T$, $r_{22}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{22}$ P_2

- $r_{21}\geq r_T$, $r_{22}<r_T$, $r_{12}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{21}$ $\dot{r}_2=\dot{r}_{12}$ P_2

- $r_{21}<r_T$, $r_{11}\geq r_T$, $r_{12}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{12}$ P_2

- $r_{21}<r_T$, $r_{11}\geq r_T$, $r_{12}<r_T$, $r_{22}\geq r_T$, $\quad \dot{r}_1=\dot{r}_{11}$ $\dot{r}_2=\dot{r}_{22}$ P_2

III. PROBABILITY DENSITY FUNCTIONS OF DERIVATIVES

The joint probability density functions of signal derivatives are:

$r_1<r_T$, $r_2<r_T$

$$p_{r_1 r_2 \dot{r}_1 \dot{r}_2}(r_1, r_2, \dot{r}_1, \dot{r}_2) = P_1 \int_0^{r_T} dr_{11} \int_0^{r_T} dr_{22}\, p_{r_{11} r_{22} r_{21} r_{12} \dot{r}_{21} \dot{r}_{12}}(r_{11}, r_{22}, r_1, r_2, \dot{r}_1, \dot{r}_2) +$$

$$+ P_2 \int_0^{r_T} dr_{21} \int_0^{r_T} dr_{12}\, p_{r_{21} r_{12} r_{11} r_{22} \dot{r}_{11} \dot{r}_{22}}(r_{21}, r_{12}, r_1, r_2, \dot{r}_1, \dot{r}_2) \tag{1}$$

$r_1\geq r_T$, $r_2<r_T$

$$p_{r_1 r_2 \dot{r}_1 \dot{r}_2}(r_1, r_2, \dot{r}_1, \dot{r}_2) = P_1 \int_0^{r_T} dr_{12}\, p_{r_{12} r_{11} r_{22} \dot{r}_{11} \dot{r}_{22}}(r_{12}, r_1, r_2, \dot{r}_1, \dot{r}_2) +$$

$$+P_1\int_0^{r_T}dr_{11}\int_0^{r_T}dr_{22}\,p_{r_{11}r_{22}r_{21}r_{12}\dot{r}_{21}\dot{r}_{12}}(r_{11},r_{22},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{22}\,p_{r_{22}r_{21}r_{12}\dot{r}_{21}\dot{r}_{12}}(r_{22},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\int_0^{r_T}dr_{12}\,p_{r_{21}r_{12}r_{11}r_{22}\dot{r}_{11}\dot{r}_{22}}(r_{21},r_{12},r_1,r,\dot{r}_1,\dot{r}_2) \tag{2}$$

$r_1<r_T,\ r_2\geq r_T$

$$p_{r_1r_2\dot{r}_1\dot{r}_2}(r_1,r_2,\dot{r}_1,\dot{r}_2)=P_1\int_0^{r_T}dr_{11}\,p_{r_{11}r_{21}r_{22}\dot{r}_{21}\dot{r}_{22}}(r_{11},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{11}\int_0^{r_T}dr_{22}\,p_{r_{11}r_{22}r_{21}r_{12}\dot{r}_{21}\dot{r}_{12}}(r_{11},r_{22},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\,p_{r_{21}r_{11}r_{12}\dot{r}_{11}\dot{r}_{12}}(r_{21},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\int_0^{r_T}dr_{12}\,p_{r_{21}r_{12}r_{11}r_{22}\dot{r}_{11}\dot{r}_{22}}(r_{21},r_{12},r_1,r,\dot{r}_1,\dot{r}_2) \tag{3}$$

$r_1\geq r_T,\ r_2\geq r_T$

$$p_{r_1r_2\dot{r}_1\dot{r}_2}(r_1,r_2,\dot{r}_1,\dot{r}_2)=P_1\,p_{r_{11}r_{12}\dot{r}_{11}\dot{r}_{12}}(r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{12}\,p_{r_{12}r_{11}r_{22}\dot{r}_{11}\dot{r}_{22}}(r_{12},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{11}\,p_{r_{11}r_{21}r_{22}\dot{r}_{21}\dot{r}_{22}}(r_{11},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{11}\int_0^{r_T}dr_{22}\,p_{r_{11}r_{22}r_{21}r_{12}\dot{r}_{21}\dot{r}_{12}}(r_{11},r_{22},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\,p_{r_{21}r_{22}\dot{r}_{21}\dot{r}_{22}}(r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{22}\,p_{r_{22}r_{21}r_{12}\dot{r}_{21}\dot{r}_{12}}(r_{22},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\,p_{r_{21}r_{11}r_{12}\dot{r}_{11}\dot{r}_{12}}(r_{21},r_1,r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\int_0^{r_T}dr_{12}\,p_{r_{21}r_{12}r_{11}r_{22}\dot{r}_{11}\dot{r}_{22}}(r_{21},r_{12},r_1,r,\dot{r}_1,\dot{r}_2) \tag{4}$$

For the case that signal and its derivative are not correlated, after integrating of the whole range of signal values and some mathematical manipulations, the joint PDF of derivative can be expressed as:

$$p_{\dot{r}_1\dot{r}_2}(\dot{r}_1,\dot{r}_2)=P_1\int_0^{r_T}dr_{11}\int_0^{r_T}dr_{22}\,p_{r_{11}r_{22}\dot{r}_{21}\dot{r}_{12}}(r_{11},r_{22},\dot{r}_1,\dot{r}_2)+$$

$$+P_2\int_0^{r_T}dr_{21}\int_0^{r_T}dr_{12}\,p_{r_{21}r_{12}\dot{r}_{11}\dot{r}_{22}}(r_{21},r_{12},\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{12}\int_{r_T}^{\infty}dr_1\,p_{r_{12}r_{11}\dot{r}_{11}\dot{r}_{22}}(r_{12},r_1,\dot{r}_1,\dot{r}_2)+P_2\int_0^{r_T}dr_{22}\int_{r_T}^{\infty}dr_1\,p_{r_{22}r_{21}\dot{r}_{21}\dot{r}_{12}}(r_{22},r_1,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_0^{r_T}dr_{11}\int_{r_T}^{\infty}dr_2\,p_{r_{11}r_{22}\dot{r}_{21}\dot{r}_{22}}(r_{11},r_2,\dot{r}_1,\dot{r}_2)+P_2\int_0^{r_T}dr_{21}\int_{r_T}^{\infty}dr_2\,p_{r_{21}r_{12}\dot{r}_{11}\dot{r}_{12}}(r_{21},r_2,\dot{r}_1,\dot{r}_2)+$$

$$+P_1\int_{r_T}^{\infty}dr_1\int_{r_T}^{\infty}dr_2\,p_{r_{11}r_{12}\dot{r}_{11}\dot{r}_{12}}(r_1,r_2,\dot{r}_1,\dot{r}_2)+P_2\int_{r_T}^{\infty}dr_1\int_{r_T}^{\infty}dr_2\,p_{r_{21}r_{22}\dot{r}_{21}\dot{r}_{22}}(r_1,r_2,\dot{r}_1,\dot{r}_2) \tag{5}$$

The signal derivatives PDFs can be found from joint PDF based on:

$$p_{\dot{r}_1}(\dot{r}_1)=\int_{-\infty}^{\infty}p_{\dot{r}_1\dot{r}_2}(\dot{r}_1,\dot{r}_2)d\dot{r}_2 \tag{6}$$

$$p_{\dot{r}_2}(\dot{r}_2)=\int_{-\infty}^{\infty}p_{\dot{r}_1\dot{r}_2}(\dot{r}_1,\dot{r}_2)d\dot{r}_1 \tag{7}$$

By replacing (5) in (6) and (7), obtained:

$$p_{\dot{r}_1}(\dot{r}_1)=P_1p_{\dot{r}_{11}}(\dot{r}_1)+P_2p_{\dot{r}_{21}}(\dot{r}_1)+$$

$$+\left(P_2F_{r_{21}}(r_T)-P_1F_{r_{11}}(r_T)\right)p_{\dot{r}_{11}}(\dot{r}_1)+$$

$$+\left(P_1F_{r_{11}}(r_T)-P_2F_{r_{21}}(r_T)\right)p_{\dot{r}_{21}}(\dot{r}_1) \tag{8}$$

$$p_{\dot{r}_2}(\dot{r}_2)=P_1F_{r_{11}}(r_T)F_{r_{22}}(r_T)p_{\dot{r}_{12}}(\dot{r}_2)+P_2F_{r_{21}}(r_T)F_{r_{12}}(r_T)p_{\dot{r}_{22}}(\dot{r}_2)+$$

$$+P_1B_1(r_T)p_{\dot{r}_{22}}(\dot{r}_2)+P_2B_2(r_T)p_{\dot{r}_{12}}(\dot{r}_2)+$$

$$+P_1F_{r_{11}}(r_T)\left(1-F_{r_{22}}(r_T)\right)p_{\dot{r}_{22}}(\dot{r}_2)+P_2F_{r_{21}}(r_T)\left(1-F_{r_{12}}(r_T)\right)p_{\dot{r}_{12}}(\dot{r}_2)+$$

$$+P_1C_1(r_T)p_{\dot{r}_{12}}(\dot{r}_2)+P_2C_2(r_T)p_{\dot{r}_{22}}(\dot{r}_2) \tag{9}$$

where $F_{r_{ij}}(r_T)$ are signals' CDFs and $F_{r_{i1}}(r_T)=F_{r_{i2}}(r_T)$, while $B_i(r_T)$ and $C_i(r_T)$ are obtained based on [(11), 17]

$$B_i(r_T)=\left(1-\rho_i^{\,2}\right)e^{-\frac{A_i^2}{\sigma_i^2(1+\rho_i)}}\cdot$$

$$\cdot\sum_{k,l_1,l_2,l_3=0}^{\infty}\varepsilon_k\cdot\frac{1}{l_1!\,l_2!\,l_3!\,(k+l_1)!\,(k+l_2)!\,(k+l_3)!}\cdot$$

$$\cdot\rho^{k+2l_1}\left[\left(\frac{1-\rho_i}{1+\rho_i}\right)\left(\frac{A_i}{2\sigma_i^{\,2}}\right)\right]^{k+l_2+l_3}\cdot$$

$$\cdot\gamma\left(k+l_1+l_2+1,\frac{r_T^{\,2}}{2\sigma_i^{\,2}(1-\rho_i^{\,2})}\right)\cdot$$

$$\cdot\left[1-\gamma\left(k+l_1+l_3+1,\frac{r_T^{\,2}}{2\sigma_i^{\,2}(1-\rho_i^{\,2})}\right)\right] \tag{10}$$

$$C_i(r_T)=\left(1-\rho_i^{\,2}\right)e^{-\frac{A_i^2}{\sigma_i^2(1+\rho_i)}}\cdot$$

$$\cdot\sum_{k,l_1,l_2,l_3=0}^{\infty}\varepsilon_k\cdot\frac{1}{l_1!l_2!l_3!(k+l_1)!(k+l_2)!(k+l_3)!}\cdot$$

$$\cdot\rho^{k+2l_1}\left[\left(\frac{1-\rho_i}{1+\rho_i}\right)\left(\frac{A_i}{2\sigma_i^{\,2}}\right)\right]^{k+l_2+l_3}\cdot$$

$$\cdot\left[1-\gamma\left(k+l_1+l_2+1,\frac{r_T^{\,2}}{2\sigma_i^{\,2}(1-\rho_i^{\,2})}\right)\right]\cdot$$

$$\cdot\left[1-\gamma\left(k+l_1+l_3+1,\frac{r_T^{\,2}}{2\sigma_i^{\,2}(1-\rho_i^{\,2})}\right)\right] \tag{11}$$

γ() is incomplete gamma function and ε_k is Neumman factor defined by

$$\varepsilon_k=\begin{cases}1, & k=0\\ 2, & k>0\end{cases}$$

The probability density functions of signal derivatives in the presence of Rician fading at the combiner input has normal distribution with zero mean value [18, 19]:

$$p_{\dot r_i}(\dot r_{i,j})=\frac{1}{\sqrt{2\pi}\dot\sigma_i}e^{-\frac{\dot r_{i,j}^{\,2}}{2\dot\sigma_i^{\,2}}}\qquad ,-\infty<\dot r_{i,j}<\infty \tag{12}$$

where $i=1,2;\ j=1,2$ and $\dot\sigma_i^{\,2}=2\sigma_i^{\,2}\pi^2 f_m^{\,2}$ is the variance and f_m is maximal Doppler frequency.

Probability density function of signal derivatives $\dot r_1$ and $\dot r_2$ at the SSC combiner output at two time moments in the presence of Rician fading is obtained when (12) putting in previously obtained general expressions for PDFs of signal derivatives and replacing of CDF with [20]:

$$F_{r_i}(r_{i,j})=1-Q_1\left(A_i/\sigma_i, r_{i,j}/\sigma_i\right)\ ,\quad r_{i,j}\geq 0 \tag{13}$$

where $Q_1(\ )$ is Marcum Q-function of first order, are obtained as:

$$p_{\dot r_1}(\dot r_1)=P_1\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_1^2}{2\dot\sigma_1^2}}+P_2\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_1^2}{2\dot\sigma_2^2}}+$$

$$+\left(P_2\left[1-Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\right]-P_1\left[1-Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\right]\right)\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_1^2}{2\dot\sigma_1^2}}+$$

$$+\left(P_1\left[1-Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\right]-P_2\left[1-Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\right]\right)\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_1^2}{2\dot\sigma_2^2}} \tag{14}$$

$$p_{\dot r_2}(\dot r_2)=P_1\left[1-Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\right]\left[1-Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\right]\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_2^2}{2\dot\sigma_1^2}}+$$

$$+P_2\left[1-Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\right]\left[1-Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\right]\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_2^2}{2\dot\sigma_2^2}}+$$

$$+P_1B_1(r_T)\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_2^2}{2\dot\sigma_2^2}}+P_2B_2(r_T)\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_2^2}{2\dot\sigma_1^2}}+$$

$$+P_1\left[1-Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\right]Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_2^2}{2\dot\sigma_2^2}}+$$

$$+P_2\left[1-Q_1\left(\frac{A_2}{\sigma_2},\frac{r_T}{\sigma_2}\right)\right]Q_1\left(\frac{A_1}{\sigma_1},\frac{r_T}{\sigma_1}\right)\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_2^2}{2\dot\sigma_1^2}}+$$

$$+P_1C_1(r_T)\frac{1}{\sqrt{2\pi}\dot\sigma_1}e^{-\frac{\dot r_2^2}{2\dot\sigma_1^2}}+P_2C_2(r_T)\frac{1}{\sqrt{2\pi}\dot\sigma_2}e^{-\frac{\dot r_2^2}{2\dot\sigma_2^2}} \tag{15}$$

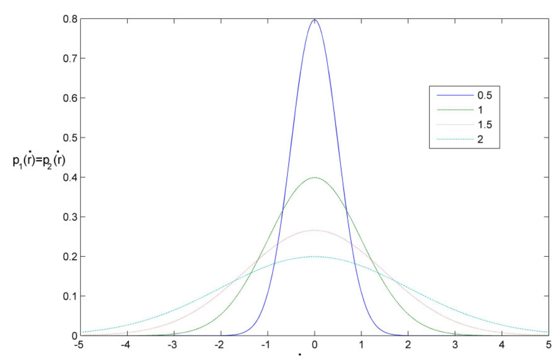

Figure 2. The probability density functions of derivatives at the SSC combiner output at two time instants

The PDFs of signal derivatives are presented in Fig. 2 for different values of parameter $\dot\sigma_i$ in the case of channels with identical distribution.

IV. CONCLUSION

In this paper, the expressions for probability density functions (PDFs) of the time derivatives in two time instants for output signals from dual branch SSC combiner in the presence of Rician fading are obtained. The second order characteristics: the average level crossing rate and the average fade duration for complex combiner who makes the decision based on sampling at two time moments can be calculated by using closed-form expressions derived in this paper.

ACKNOWLEDGMENT

This work has been funded by the Serbian Ministry for Science under the projects III-44006 and TR-33035.

REFERENCES

[1] M. K. Simon, and M. S. Alouni, Digital Communication over Fading Channels, Second Edition, Wiley-Interscience, A John Wiley&Sons, Inc., Publications, New Jersey, 2005.

[2] A. Abdi, C. Tepedelenlioglu, M. Kaveh, and G. Giannakis, “On the estimation of the K parameter for the Rice fading distribution”, IEEE Communications Letters, pp. 92 -94, March 2001.

[3] M. A. Richards, Rice Distribution for RCS, Georgia Institute of Technology, Sep. 2006.

[4] J. Moon and Y. Kim. “Antenna Diversity Strengthens Wireless LANs.”, Communication Systems Design, pp. 15–22, Jan 2003.

[5] S. M. Lindenmeier, L. M. Reiter, D. E. Barie and J. F. Hopf. “Antenna Diversity for Improving the BER in Mobile Digital Radio Reception Especially in Areas with Dense Foliage.” International ITG Conference on Antennas, ISBN 978-3-00-021643-5, pp. 45–48. Mar 30 2007.

[6] C. Dietrich, “Adaptive Arrays and Diversity Antenna Configurations for Handheld Wireless Communication Terminals”, Jr. Feb 15, 2000.

[7] D.G. Brennan, "Linear diversity combining techniques," Proc. IRE, vol.47, no.1, pp.1075–1102, June 1959.

[8] D. Milovic, M. Stefanovic, D. Pokrajac, "Stochastic approach for output SINR computation at SC diversity systems with correlated Nakagami-m fading", European Transactions on Telecommunications, vol. 20, no. 5, pp. 482-486, 2009.

[9] A. Cvetković, M. Stefanović, N. Sekulović, D. Milić, D. Stefanović, Z. Popović, “Second-order statistics of dual SC macrodiversity system over channels affected by Nakagami-*m* fading and correlated gamma shadowing”, Electrical Review (Przeglad Elektrotechniczny), vol. 87, no. 6, pp. 284-288, June 2011.

[10] P. Spalević, S. Panić, Ć. Dolićanin M. Stefanović, A.Mosić, "SSC Diversiity Receiver over Correlated α-μ Fading Channels in the Presence of co-channel interference", EURASIP Journal on Wireless Communications and Networking, vol. 2010, doi:10.1155/2010/142392.

[11] Đ. V. Banđur, M. Stefanović, M. V. Banđur, “Performance analysis of SSC diversity receiver over correlated Ricean fading channels in the presence of co-channel interference”, Electronics Letters, vol. 44, no. 9, pp. 587-588, 2008.

[12] G. T. Djordjevic, D. N. Milic, A. M. Cvetkovic, M. C. Stefanovic, “Influence of Imperfect Cophasing on Performance of EGC Receiver of BPSK and QPSK Signals Transmitted over Weibull Fading Channe”, accepted for publication, European Transactions on Telecommunications, published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ett.1475.

[13] Z. Popovic, S. Panic, J. Anastasov, M. Stefanovic, P.Spalevic, “Cooperative MRC diversity over Hoyt fading channels”, Electrical Review, vol. 87 no. 12, pp. 150-152, Dec. 2011.

[14] P. Nikolić, D. Krstić, M. Milić, and M. Stefanović, “Performance Analysis of SSC/SC Combiner at Two Time Instants in The Presence of Rayleigh Fading”, Frequenz. Vol. 65, Issue 11-12, ISSN (Online) 2191-6349, ISSN (Print) 0016-1136, pp. 319–325, November/2011

[15] M. Stefanović, P. Nikolić, D. Krstić, V. Doljak, “Outage probability of the SSC/SC combiner at two time instants in the presence of lognormal fading”, Przeglad Elektrotechniczny (Electrical Review), ISSN 0033-2097, R. 88 NR 3a/2012, pp.237-240, March 2012.

[16] L. Yang and M. S. Alouini, “Average Level Crossing Rate and Average Outage Duration of Switched Diversity Systems”, Global Telecommunications Conference, GLOBECOM '02. IEEE, vol. 2, Print ISBN: 0-7803-7632-3, pp. 1420-1424, 2002.

[17] M. K. Simon, “Comments on Infinite-Series Representations Associated With the Bivariate Rician Distribution and Their Applications”, IEEE Trans. Commun., vol. 54, no 8, pp. 2149 – 2153, 25-28 Sept.. 2005.

[18] T. S. Rappaport, Wireless Communications: Principles and Practice. Upper Saddle River, NJ: PTR Prentice-Hall, 1996.

[19] L. Yang, and M.-S. Alouini, “Average Level Crossing Rate and Average Outage Duration of Generalized Selection Combining”, IEEE Transactions on Communications, vol. 51, no. 12, pp. 1063-1067, Dec. 2003

[20] S. O. Rice, “Statistical properties of a sine wave plus random noise,” Bell Syst. Tech. J., vol. 27, pp. 109–157, Jan. 1948.