First and Second Order Statistical Characteristics of the SSC Combiner Output Signal in the Presence of Rice fading

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***Abstract*— The level crossing rate, the outage probability, the average time of fade duration and the bit error rate of the Switch and Stay Combiner (SSC) output signal, in the presence of Rice fading at the input, are determined in this paper. The results are shown graphically for different variance values, decision threshold values and signal and fading parameters values.**

Keywords- probability density function, level crossing rate, outage probability, average fade duration, bit error rate, Switch and Stay Combiner, Rice fading

I. INTRODUCTION

The most important obstruction in wireless telecommunication systems is fading. When a received signal experiences fading during transmission, its envelope and phase both fluctuate over time. The fading appears because of signals extending by more paths and shadow effects. Last few years, with development of wireless and mobile communication systems, this problem is considered in the literature [2], [3].

Many of the wireless communication systems use some form of diversity combining in order to reduce multupath fading appeared in the channel. Upgrading transmission reliability and increasing channel capacity without increasing transmission power and bandwidth is the main goal of diversity techniques.

The most useful are space diversity with two or more branches. The receiver combines signals from different antenna and makes the decision from combined signal on the optimal manner. The most popular of them are maximal ratio combining (MRC), equal gain combining (EGC), selection combining (SC) and switch and stay combining (SSC).

Maximal-Ratio Combining (MRC) is one of the most widely used diversity combining schemes whose SNR is the sum of the SNR's of each individual diversity branches. MRC is the optimal combining scheme, but its price and complexity are higher. Also, MRC requires cognition of all channel parameters and admit in the same phase all input signals, because it is the most complicated for realization ([4]-[6]).

Signal at the EGC diversity system output is equal to the sum of its' input signals. The input signals should be admitted in the same phase, but it is not necessary to know the channel parameters. Therefore, EGC provides comparable performances to MRC technique, but has lower implementation complexity, so it is an intermediate solution [7].

Among the simpler diversity combining schemes, selection combining (SC) and switch and stay combining (SSC) are the two most popular. With SC receiver, the processing is performed at only one of the diversity branches, which is selectively chosen, and no channel information is required. That is why SC is much simpler for practical realization. In general, selection combining, assuming that noise power is equally distributed over branches, selects the branch with the highest signal-to-noise ratio (SNR) that is the branch with the strongest signal ([7]-[9]).

SSC is an attempt to simplify the complexity of the system with loss in performance. In this case, rather than continually connecting the antenna with the best fading conditions, the receiver selects a particular antenna until its quality drops below a predetermined threshold. When this happens, the receiver switches to another antenna and stays with it for the next time slot, regardless of whether or not the channel quality of that antenna is above or below the predetermined threshold.

The consideration of SSC systems in the literature has been restricted to low-complexity mobile units where the number of diversity antennas is typically limited to two ([10]-[12]). Furthermore, in all these publications, only predetection SSC has thus far been considered wherein the switching of the receiver between the two receiving antennas is based on a comparison of the instantaneous signal to noise ratio (SNR) of the connected antenna with a predetermined threshold. This results in a reduction of complexity relative to SC in that the simultaneous and continuous monitoring of both branches SNRs is no longer necessary. In [13] the moment generating function (MGF) of the signal power at the output of dual-branch switch and stay selection diversity (SSC) combiners is derived.

The fading influence to the system performances is considered in [2]. The most often Rayleigh, Rice, Nakagami, Weibull and log-normal fading are considered.

The Rice fading is present very often in wireless telecommunication systems with direct line of site. When the fading appeared in the channel because of signal propagation by more paths, and dominate component exists because of optical visibility from transmitter to receiver, signal amplitude is modeled by Rice distribution. Therefore, *Rice distribution* is often used to model propagation paths consisting of one strong direct LOS component and many random weaker components.

Abu-Dayya and Beaulieu in [14] consider switched diversity on microcellular Ricean channels.

The performances of the SSC combiner output signal in the presence of Nakagami-m fading are assigned in [15] and in the presence of log-normal fading in [16]. The level crossing rate of the SSC combiner output signal in the presence of Rayleigh fading is observed in [17].

The probability density function of dual branch SSC combiner output signal and the joint probability density function of this combiner output signal at two time instants in the presence of Rice fading are settled in [18].

The level crossing rate of the SSC combiner output signal in the presence of Rice fading is calculated and presented in [19] and the outage probability and the average time of fade duration of the SSC combiner output signal in the presence of Rice fading at the input are determined in [1].

Because the switch and stay combining (SSC) is very popular combining model due to its simplicity, their performances in the presence of Rice fading are summed up in this paper. Whereas the level crossing rate, the outage probability and the average fade duration for dual SSC combiner are determined earlier, the bit error rate of the SSC combiner output signal in the presence of Rice fading for coherent BPSK modulation sheme will be determined in this paper. The results will be shown graphically for different signal and fading parameters values and the decision threshold values.

The structure of the paper is as follows: after Introduction in Section II the model of the SSC combiner is given. Then, in Section III, the system performances are derived. In Section IV the numerical results for all performances are given in the case that BPSK modulation scheme is considered. The last Section is Conclusion.

II. SYSTEM MODEL

With SSC combiner with great number of branches we can minimize the bit error rate (BER). We will analyze in this paper the SSC combiner with two inputs because the gain is the greatest when instead of one-channel system at least the dual SSC combiner is used. With the enlarging of the number of inputs (branches) the gain becomes less. Because of that it is more economic using dual SSC combiner.

The model of the SSC combiner with two inputs, considered in this paper, is shown in Figure 1.

The signals at the combiner input are r_1 and r_2, and r is the combiner output signal. The predetection combining is observed.

The probability of the event that the combiner first examines the signal at the first input is P_1, and for the second input to be examined first it is P_2.

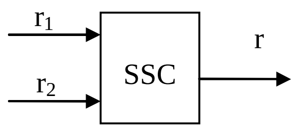

Figure. 1. Model of the SSC combiner with two inputs

If the combiner examines first the signal at the first input and if the value of the signal at the first input is above the decision treshold, r_T, SSC combiner forwards this signal to the circuit for the decision. If the value of the signal at the first input is below the decision treshold r_T, SSC combiner forwards the signal from the other input to the circuit for the decision. If the SSC combiner first examines the signal from the second combiner input it works in the similar way.

The decision threshold value can be selected so that one of three parameters has to be minimal: the error probability, fade duration or average signal value (or signal to noise/interference ratio (SNR/SIR) when noise or interference is significant) [2].

The average SNR at the SSC output can be obtained by averaging γ over $p_{\gamma SSC}(\gamma)$ as given by [2, Eq. 9.274], yielding

$$\overline{\gamma}_{SSC} = p_\gamma(\gamma_T)\int_0^\infty \gamma\, p_\gamma(\gamma)\,d\gamma + \int_{\gamma_T}^\infty \gamma\, p_\gamma(\gamma)\,d\gamma =$$

$$= p_\gamma(\gamma_T)\overline{\gamma} + \int_{\gamma_T}^\infty \gamma\, p_\gamma(\gamma)\,d\gamma$$

Differentiating previous equation with respect to γ_T and setting the result to zero, it can be easily shown that $\overline{\gamma}_{SSC}$ is maximized when the switching threshold is set to $\gamma_T^* = \overline{\gamma}$.

It can be shown that the MGF associated with appropriate fading model is given by [2, Eq. 2.17], and the moments are given by [2, Eq. (2.18)]

$$E\left(\gamma^k\right)=\frac{\Gamma(1+k)}{\left(1+n^2\right)^k}\,{}_1F_1\,(\text{-k},1;\,\text{-n}^2)\,\bar{\gamma}^{k}$$

where ${}_1F_1\,(\cdot,\ \cdot;\ \cdot)$ is the Kummer confluent hypergeometric function and parameter $k=1$ for the presence of Rice fading.

III. SYSTEM PERFORMANCES

The determination of the probability density of the combiner output signal is important for the receiver performance determination.

The probability density functions (PDFs) of the combiner input signals, r_1 and r_2 , in the presence of Rice fading, are [20]:

$$p_{r_i}(r_i)=\frac{r_i}{\sigma_i^2}e^{-\frac{r_i^2+A^2}{2\sigma_i^2}}I_0\left(\frac{r_iA}{\sigma_i^2}\right)$$

$$r_i\geq 0 \tag{1}$$

where i =1,2; A is the signal amplitude, σ_1 and σ_2 are variances.

The cumulative probability densities (CDFs) are given by [2]:

$$F_{r_i}(r_T)=\int_0^{r_T}p_{r_i}(x)\,dx \tag{2}$$

where i =1,2 and r_T is the decision treshold.

If we put the expression (1) into (2), we obtain the CDFs in the presence of Rice fading as:

$$F_{r_i}(r_T)=\int_0^{r_T}\frac{x}{\sigma_i^2}e^{-\frac{x^2+A^2}{2\sigma_1^2}}I_0\left(\frac{xA}{\sigma_i^2}\right)dx=$$

$$=1-Q\left(A/\sigma_i,r_T/\sigma_i\right) \tag{3}$$

for i =1,2. $Q(a,b)$ is the Marcum Q function defined as [2]:

$$Q\left(a,b\right)=\int_b^{\infty}t\exp\left[-\frac{t^2+a^2}{2}\right]I_0(at)\,dt\ .$$

The joint probability densities of the combiner input signals, r_1 and r_2, and their derivatives $\dot{r}_1$ and $\dot{r}_2$, in the presence of Rice fading, are [3]:

$$p_{r_1\dot{r}_1}(r_1,\dot{r}_1)=\frac{r_1}{\sigma_1^2}e^{-\frac{r_1^2+A^2}{2\sigma_1^2}}\cdot$$

$$\cdot I_0\left(\frac{r_1A}{\sigma_1^2}\right)\cdot\frac{1}{\sqrt{2\pi}\,\beta_1}e^{-\frac{\dot{r}_1^2}{2\beta_1^2}},\qquad r_1\geq 0 \tag{4}$$

$$p_{r_2\dot{r}_2}(r_2,\dot{r}_2)=\frac{r_2}{\sigma_2^2}e^{-\frac{r_2^2+A^2}{2\sigma_2^2}}\cdot$$

$$\cdot I_0\left(\frac{r_2A}{\sigma_2^2}\right)\cdot\frac{1}{\sqrt{2\pi}\,\beta_2}e^{-\frac{\dot{r}_2^2}{2\beta_2^2}},\qquad r_2\geq 0 \tag{5}$$

where β_1 and β_2 are variances.

The expression for the joint probability density function of the SSC combiner output signal and its derivative will be determined first for the case $r<r_T$:

$$p_{r\dot{r}}(r\dot{r})=P_1\cdot F_{r_1}(r_T)\cdot p_{r_2\dot{r}_2}(r\dot{r})+$$

$$+P_2\cdot F_{r_2}(r_T)\cdot p_{r_1\dot{r}_1}(r\dot{r}) \tag{6}$$

and then for $r\geq r_T$:

$$p_{r\dot{r}}(r\dot{r})=P_1\cdot F_{r_1}(r_T)\cdot p_{r_2\dot{r}_2}(r\dot{r})+$$

$$+P_1\cdot_{r_1\dot{r}_1}(r\dot{r})+P_2\cdot_{r_2\dot{r}_2}(r\dot{r})+$$

$$+P_2\cdot F_{r_2}(r_T)\cdot p_{r_1\dot{r}_1}(r\dot{r}) \tag{7}$$

The expressions for the obtainment of the probabilities P_1 and P_2 are [19]:

$$P_1=P_1\left(1-F_{r_1}(r_T)\right)+P_2F_{r_2}(r_T) \tag{8}$$

$$P_2=P_2\left(1-F_{r_2}(r_T)\right)+P_1F_{r_1}(r_T) \tag{9}$$

Then, after arrangement, the probabilities P_1 and P_2 are:

$$P_1=\frac{F_{r_2}(r_T)}{F_{r_1}(r_T)+F_{r_2}(r_T)} \tag{10}$$

$$P_2=\frac{F_{r_1}(r_T)}{F_{r_1}(r_T)+F_{r_2}(r_T)} \tag{11}$$

After changing (3) into (10), i.e. (11), it is valid [16]:

$$P_1=\frac{1-Q\left(A/\sigma_2,r_T/\sigma_2\right)}{2-\left[Q\left(A/\sigma_1,r_T/\sigma_1\right)+Q\left(A/\sigma_2,r_T/\sigma_2\right)\right]} \tag{12}$$

$$P_2=\frac{1-Q\left(A/\sigma_1,r_T/\sigma_1\right)}{2-\left[Q\left(A/\sigma_1,r_T/\sigma_1\right)+Q\left(A/\sigma_2,r_T/\sigma_2\right)\right]} \tag{13}$$

The expression for the joint probability density function (pdf) of the SSC combiner output signal and its derivative, in the presence of Rice fading, after substitutions of the expressions (3), (12) and (13) into (6) for the case $r<r_T$ is:

$$p_{r\dot{r}}(r\dot{r}) = B \cdot \frac{r}{\sigma_2{}^2} e^{-\frac{r^2+A^2}{2\sigma_2{}^2}} I_0\left(\frac{rA}{\sigma_2{}^2}\right) \cdot$$

$$\cdot \frac{1}{\sqrt{2\pi}\,\beta_2} e^{-\frac{\dot{r}^2}{2\beta_2^2}} + B \cdot \frac{r}{\sigma_1{}^2} e^{-\frac{r^2+A^2}{2\sigma_1{}^2}} \cdot$$

$$\cdot I_0\left(\frac{rA}{\sigma_1{}^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta_1} e^{-\frac{\dot{r}^2}{2\beta_1^2}} \tag{14}$$

where:

$$B = \frac{\left(1 - Q(A/\sigma_1, r_T/\sigma_1)\right)\left(1 - Q(A/\sigma_2, r_T/\sigma_2)\right)}{2 - \left[Q(A/\sigma_1, r_T/\sigma_1) + Q(A/\sigma_2, r_T/\sigma_2)\right]} \tag{15}$$

For $r \geq r_T$ the joint pdf of the SSC combiner output signal and its derivative, in the presence of Rice fading, after substitutions of the expressions (3), (12) and (13) into (7), is:

$$p_{r\dot{r}}(r\dot{r}) = \frac{1 - Q(A/\sigma_2, r_T/\sigma_2)}{2 - \left[Q(A/\sigma_1, r_T/\sigma_1) + Q(A/\sigma_2, r_T/\sigma_2)\right]} \cdot$$

$$\cdot \frac{r}{\sigma_1{}^2} e^{-\frac{r^2+A^2}{2\sigma_1{}^2}} I_0\left(\frac{rA}{\sigma_1{}^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta_1} e^{-\frac{\dot{r}^2}{2\beta_1^2}} +$$

$$+ B \cdot \frac{r}{\sigma_2{}^2} e^{-\frac{r^2+A^2}{2\sigma_2{}^2}} I_0\left(\frac{rA}{\sigma_2{}^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta_2} e^{-\frac{\dot{r}^2}{2\beta_2^2}} +$$

$$+ \frac{1 - Q(A/\sigma_1, r_T/\sigma_1)}{2 - \left[Q(A/\sigma_1, r_T/\sigma_1) + Q(A/\sigma_2, r_T/\sigma_2)\right]} \cdot$$

$$\cdot \frac{r}{\sigma_2{}^2} e^{-\frac{r^2+A^2}{2\sigma_2{}^2}} I_0\left(\frac{rA}{\sigma_2{}^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta_2} e^{-\frac{\dot{r}^2}{2\beta_2^2}} +$$

$$+ B \cdot \frac{r}{\sigma_1{}^2} e^{-\frac{r^2+A^2}{2\sigma_1{}^2}} I_0\left(\frac{rA}{\sigma_1{}^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta_1} e^{-\frac{\dot{r}^2}{2\beta_1^2}} \tag{16}$$

For the channels with identical parameters: $\beta_1 = \beta_2 = \beta$ and $\sigma_1 = \sigma_2, = \sigma$ and for $r < r_T$ the joint probability density function of the SSC combiner output signal and its derivative is:

$$p_{r\dot{r}}(r\dot{r}) = \left(1 - Q(A/\sigma, r_T/\sigma)\right) \cdot \frac{r}{\sigma^2} e^{-\frac{r^2+A^2}{2\sigma^2}} \cdot$$

$$\cdot I_0\left(\frac{rA}{\sigma^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta} e^{-\frac{\dot{r}^2}{2\beta^2}} \tag{17}$$

and for $r \geq r_T$ the joint pdf is:

$$p_{r\dot{r}}(r\dot{r}) = \left(2 - Q(A/\sigma, r_T/\sigma)\right) \frac{r}{\sigma^2} e^{-\frac{r^2+A^2}{2\sigma^2}} \cdot$$

$$\cdot I_0\left(\frac{rA}{\sigma^2}\right) \cdot \frac{1}{\sqrt{2\pi}\,\beta} e^{-\frac{\dot{r}^2}{2\beta^2}} \tag{18}$$

The level crossing rate is [2]:

$$N(r_{th}) = \int_0^\infty \dot{r}\, p_{r\dot{r}}(r_{th}, \dot{r})\, d\dot{r} \tag{19}$$

After some calculations the expressions for the level crossing rate are obtained in [16]. These expressions for the channels with identical parameters are, for $r_{th} < r_T$:

$$N(r_{th}) = \left(1 - Q(A/\sigma, r_T/\sigma)\right) \cdot$$

$$\cdot \frac{r_{th}}{\sigma^2} e^{-\frac{r_{th}{}^2+A^2}{2\sigma^2}} \cdot I_0\left(\frac{r_{th}A}{\sigma^2}\right) \frac{\beta}{\sqrt{2\pi}} \tag{20}$$

and for $r_{th} \geq r_T$:

$$N(r_{th}) = \left(2 - Q(A/\sigma, r_T/\sigma)\right) \cdot$$

$$\cdot \frac{r_{th}}{\sigma^2} e^{-\frac{r_{th}{}^2+A^2}{2\sigma^2}} \cdot I_0\left(\frac{r_{th}A}{\sigma^2}\right) \frac{\beta}{\sqrt{2\pi}} \tag{21}$$

The probability density function is used for the system error probability and for the outage probability determination. The probability density functions of the output signal is, for $r < r_T$:

$$p_r(r) = P_1 \cdot F_{r_1}(r_T) \cdot p_{r_2}(r) +$$

$$+ P_2 \cdot F_{r_2}(r_T) \cdot p_{r_1}(r) \tag{22}$$

and for $r \geq r_T$ the pdf is:

$$p_r(r) = P_1 \cdot p_{r_1}(r) + P_1 \cdot F_{r_1}(r_T) \cdot p_{r_2}(r) +$$

$$+ P_2 \cdot p_{r_2}(r) + P_2 \cdot F_{r_2}(r_T) \cdot p_{r_1}(r) \tag{23}$$

After some substitutions of the expressions (3), (12) and (13) into (22), i.e. (23), the pdf, for $r < r_T$, is:

$$p_r(r) = B \cdot \frac{r}{\sigma_2^2} e^{-\frac{r^2+A^2}{2\sigma_2^2}} I_0\left(\frac{rA}{\sigma_2^2}\right) + + B \cdot \frac{r}{\sigma_1^2} e^{-\frac{r^2+A^2}{2\sigma_1^2}} I_0\left(\frac{rA}{\sigma_1^2}\right) \quad (24)$$

where B is defined in (15).

For $r \geq r_T$ the pdf is:

$$p_r(r) = P_1 \cdot \frac{r}{\sigma_1^2} e^{-\frac{r^2+A^2}{2\sigma_1^2}} I_0\left(\frac{rA}{\sigma_1^2}\right) + + B \cdot \frac{r}{\sigma_2^2} e^{-\frac{r^2+A^2}{2\sigma_2^2}} I_0\left(\frac{rA}{\sigma_2^2}\right) + + P_2 \cdot \frac{r}{\sigma_2^2} e^{-\frac{r^2+A^2}{2\sigma_2^2}} I_0\left(\frac{r\,A}{\sigma_2^2}\right) + + B \cdot \frac{r}{\sigma_1^2} e^{-\frac{r^2+A^2}{2\sigma_1^2}} \cdot I_0\left(\frac{rA}{\sigma_1^2}\right) \quad (25)$$

P_1 and P_2 are given by (12) and (13).

The outage probability P_{out} is standard performance criterion of communication systems operating over fading channels. This performance measure is commonly used to control the noise or co-channel interference level, helping the designers of wireless communication systems to meet the quality-of-service (QoS) and grade of service (GoS) demands.

The outage probability P_{out} is defined as the probability that the combiner output SNR falls below a given threshold γ_{th} and is therefore obtained by replacing γ with γ_{th} in the CDF expressions given previously.

The outage probability $P_{out}(r_{th})$ is defined as [2]:

$$P_{out}(r_{th}) = \int_0^{r_{th}} p_r(r)dr \quad (26)$$

After appropriate substitutions the outage probabilities are, for $r_{th} < r_T$ [1]:

$$P_{out}(r_{th}) = B \cdot \left(1 - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + + B \cdot \left(1 - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right) \quad (27)$$

and for $r_{th} \geq r_T$:

$$P_{out}(r_{th}) = P_1 \cdot \left(Q\left(A/\sigma_1, r_T/\sigma_1\right) - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + + B \cdot \left(1 - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + + P_2 \cdot \left(Q\left(A/\sigma_2, r_T/\sigma_2\right) - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right) + + B \cdot \left(1 - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right) + \quad (28)$$

For the channels with identical parameters it is valid, for $r_{th} < r_T$:

$$P_{out}(r_{th}) = \left(1 - Q\left(A/\sigma, r_T/\sigma\right)\right)\left(1 - Q\left(A/\sigma, r_{th}/\sigma\right)\right) \quad (29)$$

and for $r_{th} \geq r_T$:

$$P_{out}(r_{th}) = \left(1 - Q\left(A/\sigma, r_T/\sigma\right)\right)\left(1 - Q\left(A/\sigma, r_{th}/\sigma\right)\right) + + Q\left(A/\sigma_1, r_T/\sigma_1\right) - Q\left(A/\sigma_1, r_{th}/\sigma_1\right) \quad (30)$$

The average time of fade duration can be obtained from the expression [2]:

$$T(r_{th}) = \frac{P_{out}(r_{th})}{N(r_{th})} \quad (31)$$

Substituting (20) and (27) in (31), the average fade duration $T(r_{th})$ can be obtained for $r_{th} < r_T$ as:

$$T(r_{th}) = = \frac{B \cdot \left(1 - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + B \cdot \left(1 - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right)}{\left(1 - Q\left(A/\sigma, r_T/\sigma\right)\right) \frac{r_{th}}{\sigma^2} e^{-\frac{r_{th}^2+A^2}{2\sigma^2}} \cdot I_0\left(\frac{r_{th}A}{\sigma^2}\right) \frac{\beta}{\sqrt{2\pi}}} \quad (32)$$

Substituting (21) and (28) in (31), the average fade duration $T(r_{th})$ is, for $r_{th} \geq r_T$:

$$T(r_{th}) = = \frac{1}{\left(2 - Q\left(A/\sigma, r_T/\sigma\right)\right) \frac{r_{th}}{\sigma^2} e^{-\frac{r_{th}^2+A^2}{2\sigma^2}} \cdot I_0\left(\frac{r_{th}A}{\sigma^2}\right) \frac{\beta}{\sqrt{2\pi}}} \cdot \cdot \left(P_1 \cdot \left(Q\left(A/\sigma_1, r_T/\sigma_1\right) - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + + B \cdot \left(1 - Q\left(A/\sigma_1, r_{th}/\sigma_1\right)\right) + + P_2 \cdot \left(Q\left(A/\sigma_2, r_T/\sigma_2\right) - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right) + + B \cdot \left(1 - Q\left(A/\sigma_2, r_{th}/\sigma_2\right)\right) + \quad (33)$$

The bit error rate (BER) is given by [2]:

$$P_b(e)=\int_0^\infty P_b(e/r)p_r(r)dr \tag{34}$$

where, *Pb(e/r)* is conditional BER and *p(r)* is the pdf of the combiner output signal *r* [2]

$$P_b(e/\gamma)=Q\left(\sqrt{2g\gamma}\right) \tag{35}$$

and Q is the one-dimensional Gaussian Q-function [2]

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-t^2/2}dt \tag{36}$$

Gaussian Q-function can be defined using alternative form as [2, 21]:

$$Q(x)=\frac{1}{\pi}\int_0^{\pi/2}\exp\left(-\frac{x^2}{2\sin^2\phi}\right)d\phi \tag{37}$$

After putting (35) and (37) in (34), $P_b(e)$ is obtained as

$$P_b(e)=\frac{1}{\pi}\int_0^\infty\int_0^{\pi/2}\exp\left(-\frac{gr}{\sin^2\phi}\right)p_r(r)d\phi dr\,. \tag{38}$$

For coherent BPSK parameter g is determined as $g=1$ [22] and *Pb(e)* is given by

$$P_b(e)=\frac{1}{\pi}\int_0^\infty\int_0^{\pi/2}\exp\left(-\frac{r}{\sin^2\phi}\right)p_r(r)d\phi dr\,. \tag{39}$$

For SSC combiner output signal in the presence of Rice fading, BER is:

$$P_b(e)=\frac{1}{\pi}\int_0^\infty\int_0^{\pi/2}\exp\left(-\frac{r}{\sin^2\phi}\right)\cdot$$

$$\cdot\left[B\cdot\frac{r}{\sigma_1^2}e^{-\frac{r^2+A^2}{2\sigma_1^2}}I_0\left(\frac{rA}{\sigma_1^2}\right)+\right.$$

$$\left.+B\frac{r}{\sigma_2^2}e^{-\frac{r^2+A^2}{2\sigma_2^2}}I_0\left(\frac{rA}{\sigma_2^2}\right)\right]d\phi dr+$$

$$+\frac{1}{\pi}\int_{r_T}^\infty\int_0^{\pi/2}\exp\left(-\frac{r}{\sin^2\phi}\right)\cdot$$

$$\cdot\left[P_1\cdot\frac{r}{\sigma_1^2}e^{-\frac{r^2+A^2}{2\sigma_1^2}}I_0\left(\frac{rA}{\sigma_1^2}\right)+\right.$$

$$\left.+P_2\cdot\frac{r}{\sigma_2^2}e^{-\frac{r^2+A^2}{2\sigma_2^2}}I_0\left(\frac{r\,A}{\sigma_2^2}\right)\right]d\phi dr \tag{40}$$

IV. Numerical Results

The joint probability density functions (PDFs) of the SSC combiner output signal and its derivative $p_{r\dot{r}}(r,\dot{r})$ are shown in Figures 2. and 3.

The parameters of curves are some diferent values of the decision threshold r_T, variances σ and β and the signal amplitude *A*.

The probability density functions are used for the system error probability and for the outage probability determination.

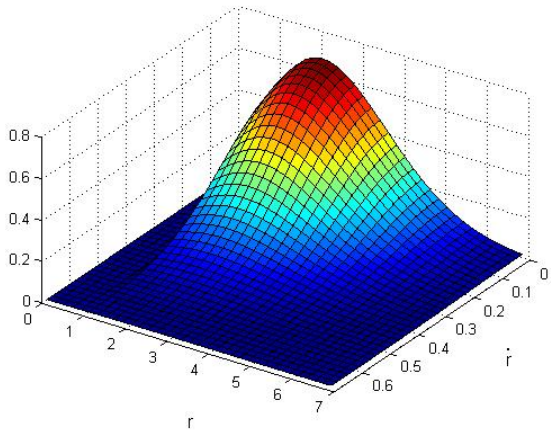

Figure 2. The joint PDF of the SSC combiner output signal and its derivative for r_T $=1$, $\sigma=2$, $A=0.5$ and $\beta=0.2$

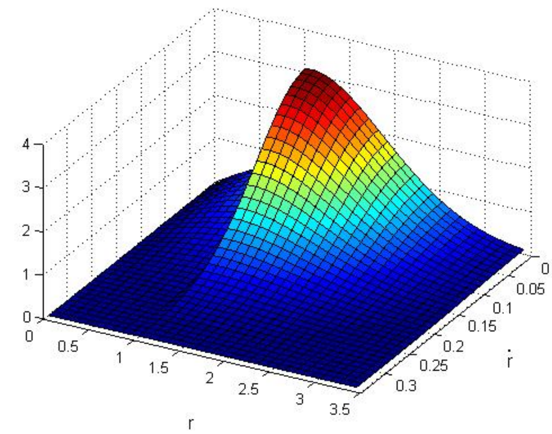

Figure 3. The joint PDF of the SSC combiner output signal and its derivative for r_T $=1$, $\sigma=1$, $A=0.5$ and $\beta=0.1$

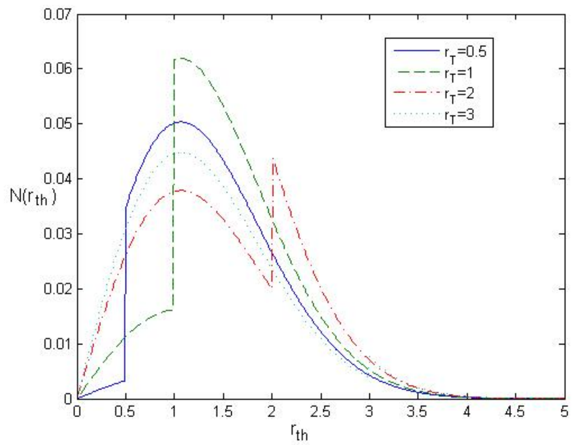

Figure 4. The level crossing rate $N(r_{th})$ for r_T $=0.5; 1; 2; 3$, $\sigma=1$, $A=0.5$ and $\beta=0.2$

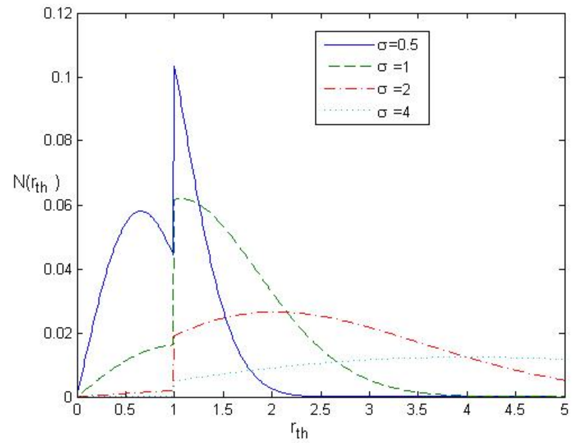

Figure 5. The level crossing rate $N(r_{th})$ for r_T $=1$, $\sigma=0.5; 1; 2; 4$, $A=0.5$ and $\beta=0.2$

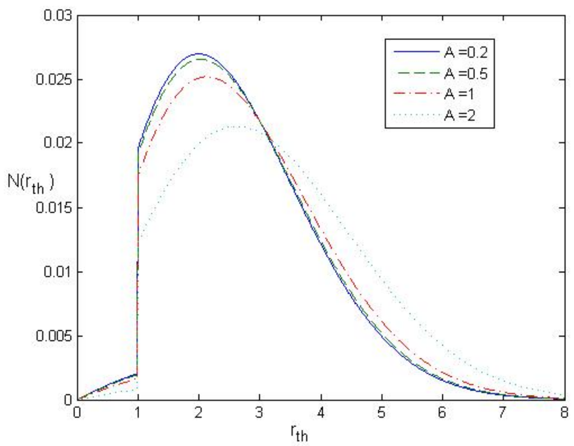

Figure 6. The level crossing rate $N(r_{th})$ for $r_T=1$, $\sigma=2$, $A=0.2; 0.5; 1; 2$ and $\beta=0.2$

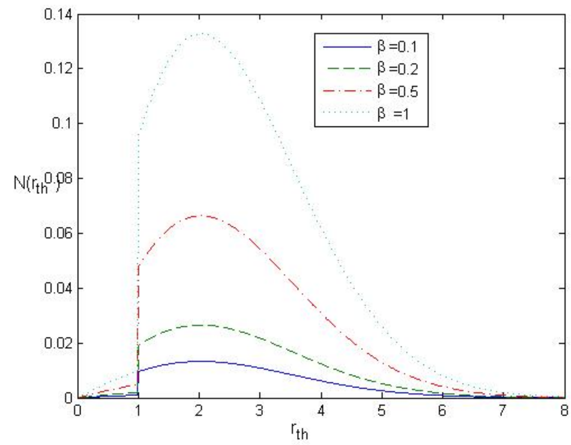

Figure 7. The level crossing rate $N(r_{th})$ for $r_T=1$, $\sigma=2$, $A=0.5$ and $\beta=0.1; 0.2; 0.5; 1$

The level crossing rate curves $N(r_{th})$ versus decision threshold value are given in Figures 4. to 7. for diferent values of variances σ and β, threshold value r_T and amplitude A.

We can notice from the Figures 4. to 7, that all represented curves have the same shape, but there is discontinuities on the level crossing rate curves versus threshold. Numerical values of the threshold determine the discontinuity moment appearance.

The outage probability curves, $P_{OUT}(r_{th})$, versus the threshold, are shown for some parameter values in Figures 8. and 9. The outage probability curves, versus the threshold, given in Figure 8, are with the parameter of curves r_T. The parameter of the curves from Figure 9. is the variance σ.

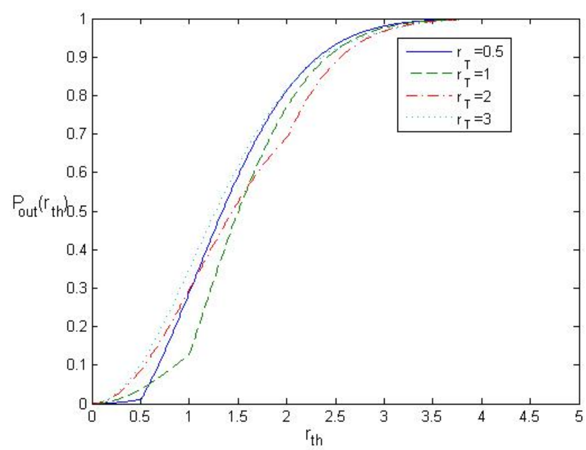

Figure 8. The outage probability $P_{OUT}(r_{th})$ for r_T =0.5;1;2;3, $\sigma=1$, $A=0.5$

From Figure 8. can be seen that the outage probability increases with rising of the threshold. The represented curves have similar shape, but there is discontinuities on them versus the threshold value. Numerical values of the threshold determine the discontinuity moment appearance.

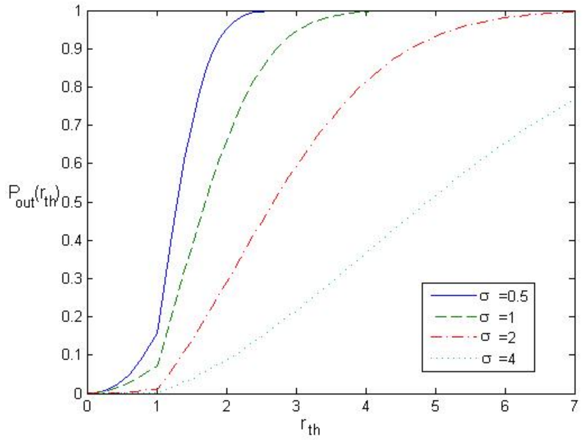

Figure 9. The outage probability $P_{OUT}(r_{th})$ for r_T =1, σ =0.5; 1; 2; 4, A =0.5

From Figure 9. can be seen that the outage probability increases with rising of the threshold. The represented curves have similar shape, but there is also discontinuities on them versus the threshold value. The curves are steeper when variance σ is less.

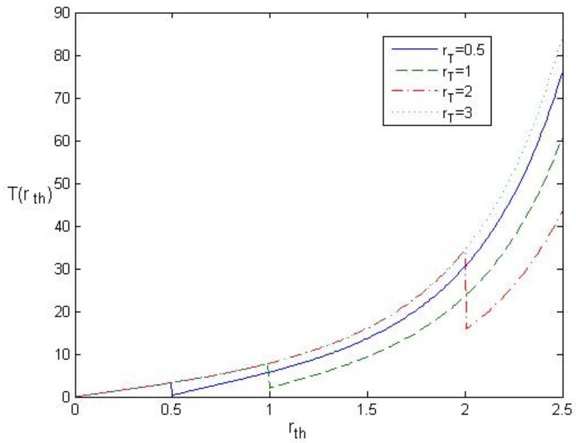

Figure 10. The fade duration $T(r_{th})$ for r_T =0.5; 1; 2; 3, σ =1, A =0.5 and β =0.2

The fade duration curves, $T(r_{th})$, are shown in Figures 10. to 13. versus the decision threshold, for different parameter values.

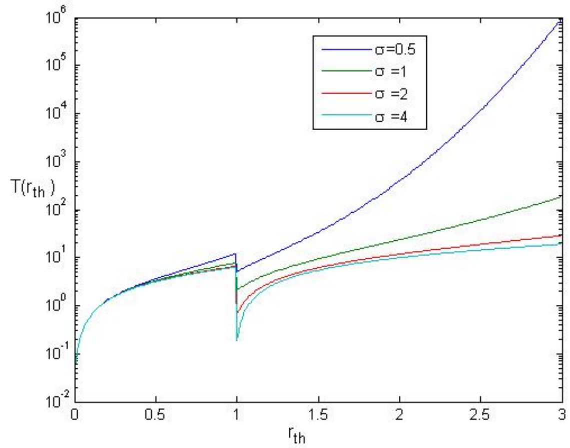

Figure 11. The fade duration $T(r_{th})$ for r_T =1, σ =0.5; 1; 2; 4, A =0.5 and β =0.2

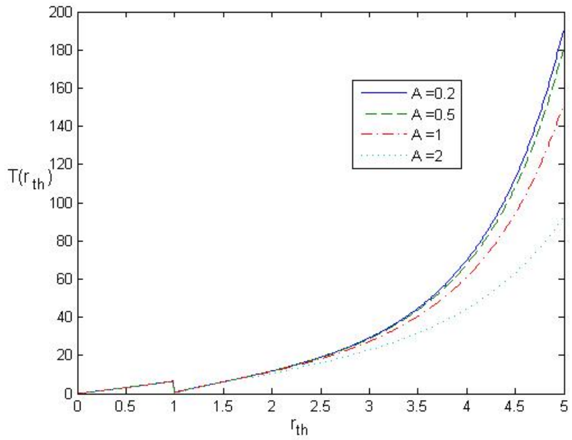

Figure 12. The fade duration $T(r_{th})$ for r_T =1, σ =2, A =0.2; 0.5; 1; 2 and β =0.2

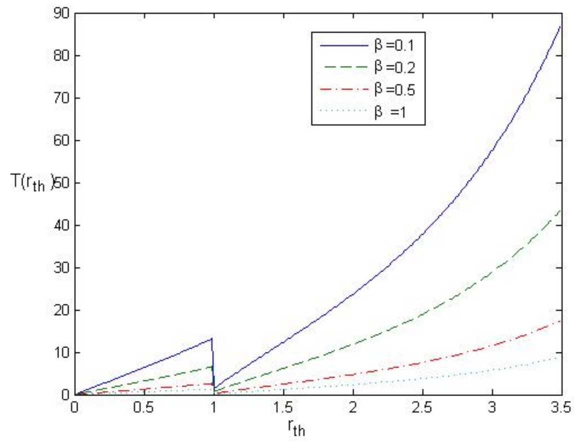

Figure 13. The fade duration $T(r_{th})$ for r_T =1, σ =2, A =0.5 and β =0.1; 0.2; 0.5; 1

We can compare these figures now. It can be observed that all curves, $T(r_{th})$ versus decision threshold, have similar shape, but threshold numerical value influence to the discontinuity moment appearance. Larger rise of fade duration corresponds to larger threshold values and to less variances σ and β, and signal amplitude A.

The bit error rate curves, $P_b(e)$, for different parameters, are illustrated in Figures 14. to 17.

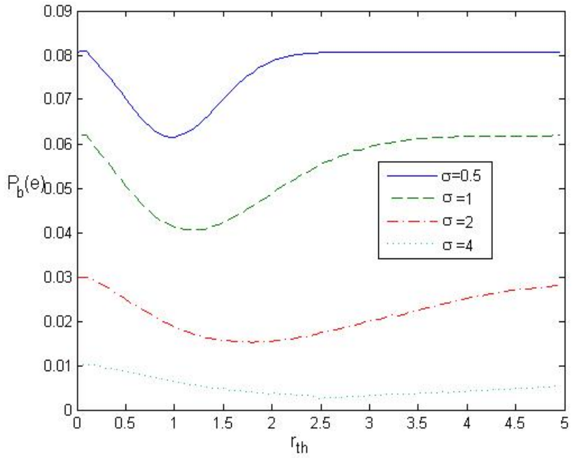

Figure 14. The bit error rate $P_b(e)$ versus the threshold for σ *=0.5; 1; 2; 4, A =1*

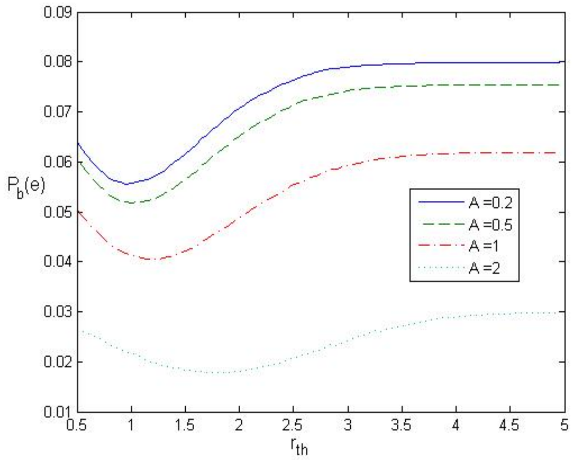

Figure 15. The bit error rate $P_b(e)$ versus the threshold for σ *=1, A =0.2; 0.5; 1; 2*

The bit error rate curves versus the threshold are given in Figures 14. and 15. It is evident from these Figures that bit error rate is less for bigger signal amplitude and variance σ, what is in good coincidence with theoretical recognition.

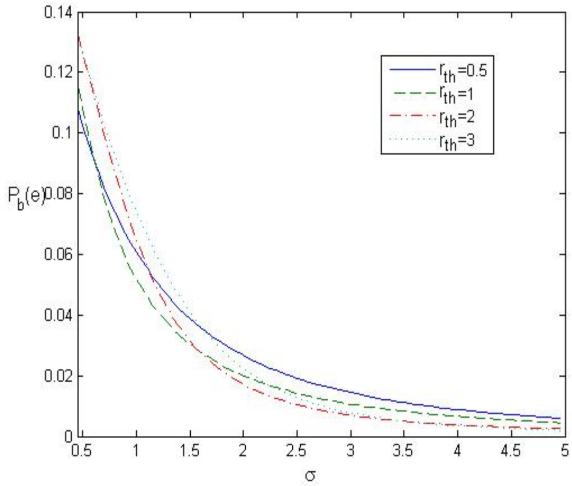

Figure 16. The bit error rate $P_b(e)$ versus variance σ *for* r_T *=0.5; 1; 2; 3, A =0.5*

The bit error rate curves versus variance σ, for diferent values of the threshold, are given in Figure 16. The bit error rate becomes bigger for less values of the threshold when the variances σ is growing up.

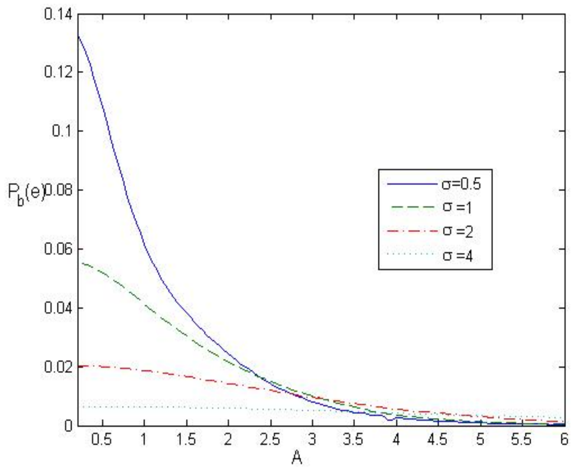

Figure 17. The bit error rate $P_b(e)$ versus signal amplitude A for r_T *=1,* σ *=0.5; 1; 2; 4*

The bit error rate curves versus signal amplitude A, for diferent values of the variance σ, are given in Figure 17. The bit error rate is bigger for less values of the signal amplitude A when the variances σ is less. The curves become wider when variance σ is growing up, and the bit error rate is reduced.

V. CONCLUSION

It is known that the level crossing rate, the outage probability, the average time of fade duration and the bit error rate of combiner output signal are important system performances. In this paper these performances for the dual branch SSC combiner output signal in the presence of Rice fading are integrated and results are shown graphically for different decision threshold values, variances and signal amplitudes. Also, the analysis of the parameters influence on the system performances is done.

In the future work the number of branches could be enlarge and an analysis could be done. Also, the performances of the SSC combiner output signal in the presence of Weibull and Hoyt fading could be determined.

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