Performance of macrodiversity system with Selection Combining and three microdiversity MRC receivers in the presence of various fading

Dragana Krstić, Radmila Gerov, Zoran Popović, Miloš Perić, Vladimir Veličković and Mihajlo Stefanović

Abstract— Macrodiversity with macrodiversity selection reception and three microdiversity (MID) Maximum Ratio Combining (MRC) receivers in the presence of long term fading and short term fading is considered in this paper. Received signal in the first MRC receiver experiences Gamma long term fading and Nakagami-m short term fading, in the second MID MRC receiver Gamma long term fading and Rician short term fading are present, and received signal in the third MID MRC receiver is under Gamma long term fading and κ-μ short term fading. Cumulative distribution functions (CDF) and level crossing rates of signals at outputs of MID receivers are determined. Based on them, the level crossing rate (LCR) of MAD Selection Combining (SC) receiver output signal is calculated. Some figures are presented to show the influence of severity parameter of Nakagami-*m* short term fading, Rician factor of Rician fading, Rician factor of κ-μ fading, severity parameter and correlation coefficient of Gamma long term fading on LCR.

***Keywords*—**Cumulative distribution function (CDF), macrodiversity reception, microdiversity reception, Gamma fading, κ-μ short term fading, Nakagami-m short term fading, Rician fading, level crossing rate.

I. INTRODUCTION

MACRODIVERSITY reception can be used to reduce long term fading effects and short term fading effects on system performance such as outage probability, bit error probability or level crossing rate [1][2]. Macrodiversity (MAD) receiver reduces long term fading effects and microdiversity (MID) receivers mitigate short term fading effects [3]. Macrodiversity with macrodiversity Selection Combining (SC) reception and three microdiversity Maximum Ratio Combining (MRC) receivers in the presence of long term fading and short term fading is considered in this paper.

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The received signal in the first microdiversity MRC experiences Gamma long term fading and Nakagami-*m* short term fading, the received signal in the second microdiversity MRC receiver experiences Gamma long term fading and Rician short term fading and received signal in the third microdiversity MRC experiences Gamma long term fading and κ-μ short term fading.

The Nakagami-*m* distribution has severity parameter *m* [4]. For parameter m=1, Nakagami-*m* distribution reduces to Rayleigh distribution and for m= 0,5 Nakagami-*m* distribution reduces to one sided Gaussian distribution. When severity parameter goes to infinity, Nakagami-*m* short term channel becomes no fading channel. Parameter *m* takes values from 0,5 to infinity. Rician distribution has parameter κ known as Rician factor [5]. The Rician factor is defined as ratio of dominant component power and scattering components power. When Rician factor is zero, Rician distribution reduces to Rayleigh distribution. When κ goes to infinity, Rician multipath fading channel becomes no fading channel. Rician factor goes to infinity when dominant component power goes to infinity or scattering components power goes to zero. The κ-μ distribution has two parameters κ and μ [6]. Parameter κ is Rician factor and parameter μ is in relation to the number of clusters in propagation environment. When parameter μ=1, the κ-μ distribution reduces to Rician distribution, when Rician factor κ=0, the κ-μ distribution reduces to Nakagami-*m* distribution, and when parameter μ=1 and Rician factor κ=0, the κ-μ distribution reduces to Rayleigh distribution. When Rician factor goes to infinity, the κ-μ short term fading becomes no fading channel, and when parameter μ goes to infinity, the κ-μ short term fading also becomes no fading channel. The parameter μ is known as the κ-μ short term fading severity parameter. The κ-μ multipath fading is more severe for lower values of severity parameter.

The level crossing rate is the second order performance measure of wireless communication system which is defined as the number of crossings of random process at determined level and can be calculated as mean of the first time derivative of random process [3]. Average fade duration is also the second order performance measure of wireless communication system which is defined as average time that signal envelope falls below the determined threshold and can be calculated as ratio of outage probability and level crossing rate. Outage probability is defined as probability that signal envelope fall below the determined threshold and can be evaluated for cumulative distribution [3].

There are more works in open technical literature considering the second order performance measures of wireless mobile communication systems. In paper [7], level crossing rate and average fade duration of output signal of MAD system with MAD SC receiver and two MID MRC receivers operated over Gamma shadowed Nakagami-m short term fading channel are evaluated.

MAD system including MAD SC receiver and two MID SC receivers is considered in [8]. Received signal experiences, simultaneously, both, long term fading and short term fading. MID SC receivers reduce Rayleigh fading effects on system performance and MAD SC receiver mitigates Gamma shadowing effects on the level crossing rate. MAD system with MAD SC receiver and two MID SC receivers is considered in [9]. Received signal is affected simultaneously to Gamma long term fading and Rician short term fading resulting in system performance degradation. MAD SC receiver reduces Gamma shadowing effects and MID SC receivers reduce multipath fading effects on bit error probability. Closed form expression for average LCR of MAD SC receiver output signal envelope is evaluated.

Level crossing rate and average fade duration of MAD reception, in the presence of correlated Gamma long term fading and Rician short term fading, are calculated in [10]. In [11], wireless system with MAD reception and three branches MID MRC systems in gamma-shadowed Ricean fading channels is considered. An exact and rapidly converging infinite-series expression for the average level crossing rate (LCR) at the output of the system is provided. In paper [12], the second-order statistics (LCR and AFD) of SC MAD working over Gamma shadowed Nakagami-*m* fading channels are derived. MAD SC system consists of two MID systems and switching is based on their output signal power values. Each MID is of MRC type with arbitrary number of branches in the presence of correlative Nakagami-*m* fading. Also, in paper [13], MAD system with MAD SC receiver and two MID MRC receivers is considered. Level crossing rate and average fade duration are evaluated for the case when proposed system operating over shadowed κ-μ multipath fading channel.

In this paper, CDF and LCR of signal at output of MRC receiver output signal operating over Gamma shadowed 1) Nakagami-m small scale fading channel, 2) Rician fading and 3) κ-μ short term fading are determined. These expressions are used for calculation the level crossing rate of MAD SC receiver output signal envelope. Such kind of characteristics of MAD system in the presence of mixed fading is not reported in available literature.

II. Model of Macrodiversity System with Three Microdiversity Receivers

Model of macrodiversity system with three microdiversity receivers is shown in Fig. 1.

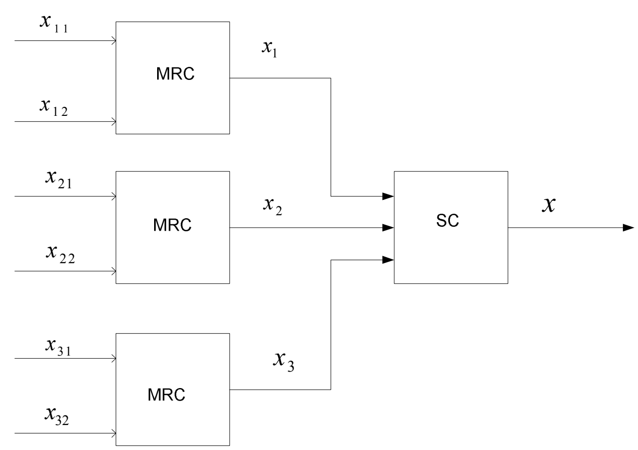

Fig.1. System model

Random variables x_{11} and x_{12} follow Nakagami-m distribution [4]:

$$p_{x_{1i}}\left(x_{1i}\right)=\frac{2}{\Gamma(m)}\cdot\left(\frac{m}{\Omega_1}\right)^m x_{1i}^{2m-1}e^{-\frac{m}{\Omega_1}x_{1i}^2},\ x_{1i}\geq 0,\ i=1,\ 2 \tag{1}$$

where *m* is severity parameter and Ω_1 is average power of x_{1i}.

Random signal envelopes x_{21} and x_{22} follow Rician distribution [5]:

$$p_{x_{2i}}\left(x_{2i}\right)=\frac{2(k+1)x_{2i}}{e^k\Omega_2}\cdot e^{-\frac{(k+1)}{\Omega_2}x_{2i}^2} I_0\left(2\sqrt{\frac{k(k+1)}{\Omega_2}}x_{2i}\right)=$$

$$=\frac{2(k+1)}{e^k\Omega_2}\cdot\sum_{i_1=0}^{\infty}\left(\frac{k(k+1)}{\Omega_2}\right)^{i_1}\frac{1}{\left(i_1!\right)^2}x_{2i}^{2i_1+1}e^{-\frac{(k+1)}{\Omega_2}x_{2i}^2},$$

$$x_{2i}\geq 0,\ i=1,2\ ; \tag{2}$$

here *k* is Rician factor, Ω_2 is average power of x_{2i}.

Random variables x_{31} and x_{32} follow κ-μ distribution [6]:

$$p_{x_{3i}}\left(x_{3i}\right)=\frac{2\mu\left(k_1+1\right)^{\frac{\mu+1}{2}}}{k_1^{\frac{\mu-1}{2}}e^{k_1\mu}\Omega_3^{\frac{\mu+1}{2}}}x_{3i}^{\mu}\cdot e^{-\frac{\mu\left(k_1+1\right)}{\Omega_3}x_{3i}^2}.$$

$$\cdot I_{\mu-1}\left(2\mu\sqrt{\frac{k_1\left(k_1+1\right)}{\Omega_3}}x_{3i}\right)=\frac{2\mu\left(k_1+1\right)^{\frac{\mu+1}{2}}}{k_1^{\frac{\mu-1}{2}}e^{k_1\mu}\Omega_3^{\frac{\mu+1}{2}}}$$

$$\cdot\sum_{i_2=0}^{\infty}\left(\mu\sqrt{\frac{k_1\left(k_1+1\right)}{\Omega_3}}\right)^{2i_2+\mu-1}\cdot\frac{1}{i_2!\Gamma\left(i_2+\mu\right)}\cdot$$

$$x_{3i}^{2i_2+2\mu-1}\cdot e^{-\frac{\mu\left(k_1+1\right)}{\Omega_3}x_{3i}^2},\ x_{3i}\geq 0,\ i=1,2, \tag{3}$$

where k_1 is Rician factor, Ω_3 is average power of x_{3i} and μ is severity parameter of κ-μ multipath fading.

The first MID MRC output signal envelope x_1 is:

$$x_1^2 = x_{11}^2 + x_{12}^2 \quad . \tag{4}$$

It follows distribution:

$$p_{x_1}(x_1) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m} x_1^{4m-1} e^{-\frac{m}{\Omega_1}x_1^2},\ x_1 \geq 0 . \tag{5}$$

Probability density function (PDF) of the second MID MRC output signal envelope x_2 is:

$$p_{x_2}(x_2) = \frac{4(k+1)^{3/2} x_2}{e^{2k}\Omega_2^{3/2} k^{1/2}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_1+3} \frac{1}{i_1!\Gamma(i_1+2)} x_2^{2i_1+3} e^{-\frac{2(k+1)}{\Omega_2}x_2^2},\ x_2 \geq 0 ; \tag{6}$$

Ω_2 is average power of x_2.

The PDF of the third MID MRC output signal envelope x_3 is:

$$p_{x_3}(x_3) = \frac{4\mu(k_1+1)^{\frac{2\mu+1}{2}}}{k_1^{1/2} e^{2k_1\mu}\Omega_3^{\frac{2\mu+1}{2}}} \cdot$$

$$\cdot \sum_{i_2=0}^{\infty}\left(4\mu\sqrt{\frac{k_1(k_1+1)}{\Omega_3}}\right)^{2i_2+4\mu-1} \cdot \frac{1}{i_2!\Gamma(i_2+2\mu)} \cdot$$

$$x_3^{2i_2+4\mu-1} \cdot e^{-\frac{2\mu(k_1+1)}{\Omega_3}x_{3i}^2},\ x_3 \geq 0 \tag{7}$$

Cumulative distribution function of x_1 is:

$$F_{x_1}(x_1) = \frac{1}{\Gamma(2m)}\gamma\left(2m, \frac{m}{\Omega_1}x_1^2\right),\ x_1 \geq 0 \tag{8}$$

Cumulative distribution function of x_2 is:

$$F_{x_2}(x_2) = \frac{4(k+1)^{3/2}}{k^{1/2}e^{2k}\Omega_2^{3/2}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_1+3} \frac{1}{i_1!\Gamma(i_1+2)} \cdot$$

$$\frac{1}{2}\left(\frac{\Omega_2}{2(k+1)}\right)^{i_1+2} \gamma\left(i_1+2, \frac{2\mu(k+1)}{\Omega_2}x_2^2\right),\ x_2 \geq 0 ; \tag{9}$$

Cumulative distribution function of x_3 is:

$$F_{x_3}(x_3) = \frac{4\mu(k_1+1)^{\frac{2\mu+1}{2}}}{k_1^{1/2}e^{2k_1\mu}\Omega_3^{\frac{2\mu+1}{2}}} \cdot$$

$$\cdot \sum_{i_2=0}^{\infty}\left(4\mu\sqrt{\frac{k_1(k_1+1)}{\Omega_3}}\right)^{2i_2+2\mu-1} \cdot \frac{1}{i_2!\Gamma(i_2+2\mu)} \cdot$$

$$\frac{1}{2}\left(\frac{\Omega_3}{2\mu(k_1+1)}\right)^{i_2+2\mu} \gamma\left(i_2+2\mu, \frac{2\mu(k_1+1)}{\Omega_3}x_3^2\right),\ x_3 \geq 0 \tag{10}$$

The joint probability density function (JPDF) of signal envelope average powers at inputs of MID MRC receivers Ω_1, Ω_2 and Ω_3 is:

$$p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3) = \frac{2}{\Gamma(c)(1-\rho^2)^2 \rho^{2(c-1)}\Omega_0^{c+2}} \cdot$$

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1} \frac{1}{i_3!\Gamma(i_3+c)}$$

$$\sum_{i_4=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_4+c-1} \frac{1}{i_4!\Gamma(i_4+c)}$$

$$\Omega_1^{i_3+c-1}\Omega_2^{i_3+i_4+c-1}\Omega_3^{i_4+c-1} \cdot e^{-\frac{\Omega_1+(1+\rho^2)\Omega_2+\Omega_3}{\Omega_0(1-\rho^2)}}, \tag{11}$$

where c is Gamma long term fading severity parameter, Ω_0 is average power of Ω_1, Ω_2 or Ω_3, and ρ is Gamma long term fading correlation coefficient.

Probability density function of x is:

$$p_x(x) = \int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 \int_0^{\Omega_1} d\Omega_3\, p_{x_1}(x/\Omega_1)\, p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3) +$$

$$+\int_0^\infty d\Omega_2 \int_0^{\Omega_2} d\Omega_1 \int_0^{\Omega_2} d\Omega_3\, p_{x_2}(x/\Omega_2)\, p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3) +$$

$$+\int_0^\infty d\Omega_3 \int_0^{\Omega_3} d\Omega_1 \int_0^{\Omega_3} d\Omega_2\, p_{x_3}(x/\Omega_3)\, p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3) =$$

$$= J_1 + J_2 + J_3 \tag{12}$$

The integral J_1 is [14]:

$$J_1 = \frac{2}{\Gamma(2m)} m^{2m} x^{4m-1} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{2(c-1)}\Omega_0^{c+2}} \cdot$$

$$\cdot \sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1} \frac{1}{i_3!\Gamma(i_3+c)}$$

$$\cdot \sum_{i_4=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_4+c-1} \frac{1}{i_4!\Gamma(i_4+c)} \cdot J_{11} \tag{13}$$

$$J_{11}=\int_0^\infty d\Omega_1\Omega_1^{-2m+i_3+c-1}\cdot e^{-\frac{\Omega_1}{\Omega_0\left(1-\rho^2\right)}}$$

$$\int_0^{\Omega_1} d\Omega_2\Omega_2^{i_3+i_4+c-1}\cdot e^{-\frac{\left(1+\rho^2\right)\Omega_2}{\Omega_0\left(1-\rho^2\right)}}\int_0^{\Omega_1} d\Omega_3\Omega_3^{i_4+c-1}\cdot e^{-\frac{\Omega_3}{\Omega_0\left(1-\rho^2\right)}}=$$

$$=\int_0^\infty d\Omega_1\Omega_1^{-2m+i_3+c-1}\cdot e^{-\frac{\Omega_1}{\Omega_0\left(1-\rho^2\right)}}\cdot$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(1+\rho^2\right)}\right)^{i_3+i_4+c}\gamma\left(i_3+i_4+c,\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\Omega_1\right)$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_4+c}\gamma\left(i_4+c,\frac{\Omega_1}{\Omega_0\left(1-\rho^2\right)}\right)=$$

$$=\int_0^\infty d\Omega_1\Omega_1^{-2m+i_3+c-1}\cdot e^{-\frac{\Omega_1}{\Omega_0\left(1-\rho^2\right)}}\cdot$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(1+\rho^2\right)}\right)^{i_3+i_4+c}\frac{1}{i_3+i_4+c}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{i_3+i_4+c}\Omega_1^{i_3+i_4+c}\cdot$$

$$\cdot e^{-\frac{\left(1+\rho^2\right)\Omega_1}{\Omega_0\left(1-\rho^2\right)}}\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(i_3+i_4+c+1\right)\left(j_1\right)}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}\Omega_1^{j_1}\cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_4+c}\frac{\Omega_1^{i_4+c}}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_4+c}}\frac{1}{i_4+c}e^{-\frac{\Omega_1}{\Omega_0\left(1-\rho^2\right)}}$$

$$\cdot\sum_{j_2=0}^{\infty}\frac{1}{\left(i_4+c+1\right)\left(j_2\right)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\Omega_1^{j_2}=$$

$$=\frac{1}{i_3+i_4+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(i_3+i_4+c+1\right)\left(j_1\right)}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_4+c+1\right)\left(j_2\right)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\cdot\int_0^\infty d\Omega_1\Omega_1^{-2m+i_3+c-1+i_3+i_4+c+i_4+c+j_1+j_2}\cdot e^{-\frac{\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\Omega_1}=$$

$$=\frac{1}{i_3+i_4+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(i_3+i_4+c+1\right)\left(j_1\right)}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_4+c+1\right)\left(j_2\right)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(3+\rho^2\right)}\right)^{-2m+2i_3+2i_4+3c+j_1+j_2}\Gamma\left(-2m+2i_3+2i_4+3c+j_1+j_2\right)\tag{14}$$

After substitution, the integral J_1 is:

$$J_1=\frac{2}{\Gamma\left(2m\right)}m^{2m}x^{4m-1}\frac{1}{\Gamma\left(c\right)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

$$\cdot\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\cdot\sum_{i_4=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_4+c-1}\frac{1}{i_4!\Gamma\left(i_4+c\right)}\cdot$$

$$\cdot\frac{1}{i_3+i_4+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(i_3+i_4+c+1\right)\left(j_1\right)}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_4+c+1\right)\left(j_2\right)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(3+\rho^2\right)}\right)^{-2m+2i_3+2i_4+3c+j_1+j_2}\Gamma\left(-2m+2i_3+2i_4+3c+j_1+j_2\right)\tag{15}$$

$\Gamma(n)$ is the (complete) gamma function [15].

The integral J_2 is [14]:

$$J_2=\frac{4\left(k+1\right)^{3/2}}{k^{1/2}e^{2k}}\cdot\sum_{i_1=0}^{\infty}\left(2\sqrt{k\left(k+1\right)}\right)^{2i_1+3}\frac{1}{i_1!\Gamma\left(i_1+1\right)}$$

$$\frac{1}{\Gamma\left(c\right)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

$$\cdot\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\cdot\sum_{i_4=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_4+c-1}\frac{1}{i_4!\Gamma\left(i_4+c\right)}\cdot J_{21}\tag{16}$$

$$J_{21}=\int_0^\infty d\Omega_2\Omega_2^{i_3+i_4+c-1-3/2-i_1-3/2}\cdot e^{-\frac{(1+\rho^2)\Omega_2}{\Omega_0(1-\rho^2)}}\cdot$$

$$\int_0^{\Omega_2} d\Omega_1\Omega_1^{i_3+c-1}\cdot e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\int_0^{\Omega_1} d\Omega_3\Omega_3^{i_4+c-1}\cdot e^{-\frac{\Omega_3}{\Omega_0(1-\rho^2)}}=$$

$$=\int_0^\infty d\Omega_2\Omega_2^{i_3+i_4+c-1-i_1-3}\cdot e^{-\frac{(1+\rho^2)\Omega_2}{\Omega_0(1-\rho^2)}}\cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}\gamma\left(i_3+c,\frac{\Omega_2}{\Omega_0\left(1-\rho^2\right)}\right)\cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_4+c}\gamma\left(i_4+c,\frac{\Omega_2}{\Omega_0\left(1-\rho^2\right)}\right)=$$

$$=\int_0^\infty d\Omega_2\Omega_2^{i_3+i_4+c-1-3/2-i_1-3/2}\cdot e^{-\frac{(1+\rho^2)\Omega_2}{\Omega_0(1-\rho^2)}}\cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}\gamma\left(i_3+c,\frac{\Omega_2}{\Omega_0\left(1-\rho^2\right)}\right)\cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}\cdot\frac{1}{i_3+c}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{i_3+c}\cdot\Omega_2^{i_3+c}$$

$$\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_3+c+1)(j_1)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}\Omega_2^{j_1}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_4+c}\cdot\frac{1}{i_4+c}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{i_4+c}\cdot\Omega_2^{i_4+c}$$

$$\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_4+c+1)(j_2)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot\Omega_2^{j_2}=$$

$$=\frac{1}{i_3+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_3+c+1)(j_1)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_4+c+1)(j_2)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\cdot\int_0^\infty d\Omega_2\Omega_2^{i_3+i_4+c-1-i_1-3+i_3+c+i_4+c+j_1+j_2}\cdot e^{-\frac{(3+\rho^2)}{\Omega_0(1-\rho^2)}\Omega_2}=$$

$$=\frac{1}{i_3+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_3+c+1)(j_1)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_4+c+1)(j_2)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\cdot\left(\frac{\Omega_0(1-\rho^2)}{(3+\rho^2)}\right)^{2i_3+2i_4+3c-i_1-3+j_1+j_2}\Gamma\left(2i_3+2i_4+3c-i_1-3+j_1+j_2\right) \tag{17}$$

The integral J_2 is, after replacement:

$$J_2=\frac{4(k+1)^{3/2}}{k^{1/2}e^{2k}}x^{2i_1+3}\cdot\sum_{i_1=0}^{\infty}\left(2\sqrt{k(k+1)}\right)^{2i_1+3}\frac{1}{i_1!\Gamma(i_1+1)}$$

$$\frac{1}{\Gamma(c)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

$$\cdot\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma(i_3+c)}$$

$$\cdot\sum_{i_4=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_4+c-1}\frac{1}{i_4!\Gamma(i_4+c)}\cdot$$

$$\frac{1}{i_3+c}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_3+c+1)(j_1)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot\frac{1}{i_4+c}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_4+c+1)(j_2)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}\cdot$$

$$\cdot\left(\frac{\Omega_0(1-\rho^2)}{(3+\rho^2)}\right)^{2i_3+2i_4+3c-i_1-3+j_1+j_2}\Gamma\left(2i_3+2i_4+3c-i_1-3+j_1+j_2\right) \tag{18}$$

The integral J_3 is [14]:

$$J_3=\frac{4\mu\left(k_1+1\right)^{\frac{2\mu+1}{2}}}{k_1^{\frac{2\mu-1}{2}}e^{k_1\mu}}\cdot x^{2i_2+4\mu-1}$$

$$\cdot\sum_{i_2=0}^{\infty}\left(4\mu\sqrt{k_1\left(k_1+1\right)}\right)^{2i_2+2\mu-1}\cdot\frac{1}{i_2!\Gamma\left(i_2+2\mu\right)}\cdot J_{31} \tag{19}$$

$$J_{31} = \int_0^\infty d\Omega_3 \Omega_3^{i_4+c-1-\mu-1/2-i_2-\mu+1/2} \, e^{-\frac{\Omega_3}{\Omega_0(1-\rho^2)} - \frac{2\mu(k_1+1)x^2}{\Omega_3}}$$

$$\int_0^{\Omega_3} d\Omega_1 \Omega_1^{i_3+c-1} \cdot e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}} \int_0^{\Omega_3} d\Omega_2 \Omega_2^{i_3+i_4+c-1} \cdot e^{-\frac{(1+\rho^2)\Omega_2}{\Omega_0(1-\rho^2)}} =$$

$$= \int_0^\infty d\Omega_3 \Omega_3^{i_4+c-1-2\mu-i_2} e^{-\frac{\Omega_3}{\Omega_0(1-\rho^2)} - \frac{2\mu(k_1+1)x^2}{\Omega_3}}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c} \gamma\left(i_3+c, \frac{\Omega_3}{\Omega_0\left(1-\rho^2\right)}\right) \cdot$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+i_4+c} \gamma\left(i_3+i_4+c, \frac{\left(1+\rho^2\right)\Omega_3}{\Omega_0\left(1-\rho^2\right)}\right) =$$

$$= \frac{1}{i_3+c} \cdot \sum_{j_1=0}^\infty \frac{1}{(i_3+c+1)(j_1)} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot \frac{1}{(i_3+i_4+c)} \cdot \sum_{j_2=0}^\infty \frac{1}{(i_3+i_4+c+1)(j_2)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2} \cdot$$

$$\cdot \int_0^\infty d\Omega_3 \Omega_3^{2i_3+2i_4+3c-1-2\mu-i_2+j_1+j_2} e^{-\frac{\mu(k_1+1)x^2}{\Omega_3} - \frac{\Omega_3(3+\rho^2)}{\Omega_0(1-\rho^2)}} =$$

$$= \frac{1}{i_3+c} \cdot \sum_{j_1=0}^\infty \frac{1}{(i_3+c+1)(j_1)} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot \frac{1}{(i_3+i_4+c)} \cdot \sum_{j_2=0}^\infty \frac{1}{(i_3+i_4+c+1)(j_2)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2} \cdot$$

$$\left(\frac{\mu(k_1+1)x^2\Omega_0(1-\rho^2)}{(3+\rho^2)}\right)^{i_3+i_4+3c/2+j_1/2++j_2/2-\mu-i_2/2}$$

$$\cdot K_{2i_3+2i_4+3c-2\mu-i_2+j_1+j_2}\left(2\sqrt{\frac{\mu(k_1+1)x^2(3+\rho^2)}{\Omega_0(1-\rho^2)}}\right) \tag{20}$$

After changing, the integral J_2 is obtained in the form:

$$J_3 = \frac{4\mu(k_1+1)^{\frac{2\mu+1}{2}}}{k_1^{\frac{2\mu-1}{2}} e^{2k_1\mu}} \cdot x^{2i_2+4\mu-1}$$

$$\cdot \sum_{i_2=0}^\infty \left(4\mu\sqrt{k_1(k_1+1)}\right)^{2i_2+2\mu-1} \cdot \frac{1}{i_2!\Gamma(i_2+2\mu)} \cdot$$

$$\cdot \frac{1}{i_3+c} \cdot \sum_{j_1=0}^\infty \frac{1}{(i_3+c+1)(j_1)} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\cdot \frac{1}{(i_3+i_4+c)} \cdot \sum_{j_2=0}^\infty \frac{1}{(i_3+i_4+c+1)(j_2)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2} \cdot$$

$$\left(\frac{\mu(k_1+1)x^2\Omega_0(1-\rho^2)}{(1+\rho^2)}\right)^{i_3+i_4+3c/2+j_1/2++j_2/2-\mu-i_2/2}$$

$$\cdot K_{2i_3+2i_4+3c-2\mu-i_2+j_1+j_2}\left(2\sqrt{\frac{\mu(k_1+1)x^2\Omega_0(1-\rho^2)}{(1+\rho^2)}}\right) \tag{21}$$

$K_n(x)$ denotes the modified Bessel function of the second kind [16], order n and argument x.

Now, PDF of x is obtained as the sum of expressions given by (15), (18) and (21).

III. Level Crossing Rate of MID MRC Receivers Output Signals

Random variable $\dot{x}_1$ also has Nakagami-m distribution. The joint probability density function of x_1 and $\dot{x}_1$ is:

$$p_{x_1\dot{x}_1}(x_1\dot{x}_1) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m} x_1^{4m-1} e^{-\frac{m}{\Omega_1}x_1^2} \frac{1}{\sqrt{2\pi}\beta_1} e^{-\frac{\dot{x}_1^2}{2\beta_1^2}} \tag{22}$$

where $\beta_1^2 = \pi^2 f_m^2 \frac{\Omega_1}{m}$, and f_m is maximal Doppler frequency.

Level crossing rate of x_1 random process is [3]:

$$N_{x_1} = \int_0^\infty d\dot{x}_1 \dot{x}_1 p_{x_1\dot{x}_1}(x_1\dot{x}_1) =$$

$$= \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m} x_1^{4m-1} e^{-\frac{m}{\Omega_1}x_1^2} \int_0^\infty d\dot{x}_1 \dot{x}_1 \frac{1}{\sqrt{2\pi}\beta_1} e^{-\frac{\dot{x}_1^2}{2\beta_1^2}} =$$

$$= \frac{\sqrt{2\pi} f_m}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m-1/2} x_1^{4m-1} e^{-\frac{m}{\Omega_1}x_1^2}. \tag{23}$$

JPDF of x_2 and $\dot{x}_2$ is:

$$p_{x_2\dot{x}_2}(x_2\dot{x}_2) = \frac{4(k+1)^{3/2} x_2}{k^{1/2} e^{2k} \Omega_2^{3/2}} \cdot e^{-\frac{2(k+1)}{\Omega_2}x_2^2}$$

$$I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}}x_2\right) \frac{1}{\sqrt{2\pi}\beta_2} e^{-\frac{\dot{x}_2^2}{2\beta_2^2}} \tag{24}$$

with $\beta_2^2 = \pi^2 f_m^2 \frac{\Omega_2}{2(k+1)}$.

Level crossing rate of x_2 random process is:

$$N_{x_2} = \int_0^\infty d\dot{x}_2 \dot{x}_2 p_{x_2\dot{x}_2}\left(x_2\dot{x}_2\right) =$$

$$= \frac{4(k+1)^{3/2} x_2}{k^{1/2} e^{2k} \Omega_2^{3/2}} \cdot e^{-\frac{2(k+1)}{\Omega_2}x_2^2} I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}} x_2\right)$$

$$\int_0^\infty d\dot{x}_2 \dot{x}_2 \frac{1}{\sqrt{2\pi}} \pi f_m \frac{\Omega_2^{1/2}}{2^{1/2}(k+1)^{1/2}} e^{-\frac{\dot{x}_2^2}{2\beta_2^2}} =$$

$$= \frac{2\sqrt{\pi} f_m (k+1) x_2}{k^{1/2} e^{2k} \Omega_2} e^{-\frac{2(k+1)}{\Omega_2}x_2^2} I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}} x_2\right). \quad (25)$$

JPDF of x_3 and $\dot{x}_3$ is:

$$p_{x_3\dot{x}_3}\left(x_3\dot{x}_3\right) = \frac{4\mu(k+1)^{\frac{2\mu+1}{2}} x_3^{2\mu}}{k^{\frac{2\mu-1}{2}} e^{2k\mu} \Omega_3^{\frac{2\mu+1}{2}}} \cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu \frac{\sqrt{k(k+1)}}{2\Omega_3} x_3^2\right) \frac{1}{\sqrt{2\pi}\beta_3} e^{-\frac{\dot{x}_3^2}{2\beta_3^2}}, \quad x_3 \geq 0, \quad (26)$$

where $\beta_3^2 = \pi^2 f_m^2 \frac{\Omega_3}{\mu(k+1)}$.

Level crossing rate of x_3 random process is:

$$N_{x_3} = \int_0^\infty d\dot{x}_3 \dot{x}_3 p_{x_3\dot{x}_3}\left(x_3\dot{x}_3\right) = \frac{4\mu(k+1)^{\frac{2\mu+1}{2}} x_3^{2\mu}}{k^{\frac{2\mu-1}{2}} e^{2k\mu} \Omega_3^{\frac{2\mu+1}{2}}} \cdot$$

$$e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2} I_{2\mu-1}\left(4\mu \frac{\sqrt{k(k+1)}}{2\Omega_3} x_3^2\right)$$

$$\int_0^\infty d\dot{x}_3 \dot{x}_3 \frac{1}{\sqrt{2\pi}\beta_3} e^{-\frac{\dot{x}_3^2}{2\beta_3^2}} = \frac{4\mu(k+1)^{\frac{2\mu+1}{2}} x_3^{2\mu}}{k^{\frac{2\mu-1}{2}} e^{2k\mu} \Omega_3^{\frac{2\mu+1}{2}}} \cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu \frac{\sqrt{k(k+1)}}{2\Omega_3} x_3^2\right) \cdot \frac{1}{\sqrt{2\pi}} \frac{\pi f_m \Omega_3^{1/2}}{\mu^{1/2}(k+1)^{1/2}} =$$

$$= \frac{\sqrt{2\pi} f_m \mu^{1/2} (k+1)^{\mu} x_3^{2\mu}}{k^{2\mu-1/2} e^{2k\mu} \Omega_3^{\mu}} \cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu \frac{\sqrt{k(k+1)}}{2\Omega_3} x_3^2\right), x_3 \geq 0. \quad (27)$$

IV. Level Crossing Rate of Signal Envelope at Output of MAD SC Receiver

MAD SC receiver selects MID MRC receiver with the highest signal envelope average power at its input. Consequently, level crossing rate of signal envelope at output of MAD SC receiver output signal envelope is:

$$N_x = \int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 \int_0^{\Omega_1} d\Omega_3 N_{x_1/\Omega_1} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) +$$

$$+ \int_0^\infty d\Omega_2 \int_0^{\Omega_2} d\Omega_1 \int_0^{\Omega_2} d\Omega_3 N_{x_2/\Omega_2} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) +$$

$$+ \int_0^\infty d\Omega_3 \int_0^{\Omega_3} d\Omega_1 \int_0^{\Omega_3} d\Omega_2 N_{x_3/\Omega_3} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) =$$

$$= J_4 + J_5 + J_6 \quad (28)$$

The integrals J_4, J_5 and J_6 can be solved similar as integrals J_1, J_2 and J_3. So, the integral J_4 is [14]:

$$J_4 = \int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 \int_0^{\Omega_1} d\Omega_3 N_{x_1/\Omega_1} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) =$$

$$= \frac{\sqrt{2\pi} f_m}{\Gamma(2m)} m^{2m} x^{4m-1} \cdot \frac{2}{\Gamma(c)\left(1-\rho^2\right)^2 \rho^{2(c-1)} \Omega_0^{c+2}} \cdot$$

$$\sum_{i_1=0}^\infty \left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_1+c-1} \frac{1}{i_1!\Gamma(i_1+c)}$$

$$\sum_{i_2=0}^\infty \left(\frac{2\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1} \frac{1}{i_2!\Gamma(i_2+c)}$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{1+\rho^2}\right)^{i_1+i_2+c} \Omega_1^{i_1+c-1} \Omega_2^{i_1+i_2+c-1} \Omega_3^{i_2+c-1} \cdot e^{-\frac{\Omega_1+\left(1+\rho^2\right)\Omega_2+\Omega_3}{\Omega_0\left(1-\rho^2\right)}}$$

$$\frac{1}{(i_1+i_2+c)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{i_1+i_2+c}$$

$$\sum_{j_1=0}^\infty \frac{1}{(i_1+i_2+c+1)(j_1)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{i_2+c} \frac{1}{i_2+c} \cdot$$

$$\sum_{j_2=0}^\infty \frac{1}{(i_2+c+1)(j_2)} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}$$

$$\int_0^\infty d\Omega_1 \Omega_1^{i_1+c-1+i_1+i_2+c+j_1+i_2+c+j_2-2m+1/2} e^{-\frac{m}{\Omega_1}x^2-\frac{\left(3+\rho^2\right)\Omega_1}{\Omega_0\left(1-\rho^2\right)}} =$$

$$= \frac{\sqrt{2\pi} f_m}{\Gamma(2m)} m^{2m} x^{4m-1} \cdot \frac{2}{\Gamma(c)\left(1-\rho^2\right)^2 \rho^{2(c-1)} \Omega_0^{c+2}} \cdot$$

$$\sum_{i_1=0}^{\infty} \left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_1+c-1} \frac{1}{i_1!\Gamma(i_1+c)}$$

$$\sum_{i_2=0}^{\infty} \left(\frac{2\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1} \frac{1}{i_2!\Gamma(i_2+c)}$$

$$\frac{1}{(i_1+i_2+c)} \sum_{j_1=0}^{\infty} \frac{1}{(i_1+i_2+c+1)(j_1)} \left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\frac{1}{i_2+c} \sum_{j_2=0}^{\infty} \frac{1}{(i_2+c+1)(j_2)} \left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}$$

$$\left(\frac{mx^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_1+i_2+3c/2+j_1/2+j_2/2-m+1/4}$$

$$K_{2i_1+2i_2+3c+j_1+j_2-2m+1/2}\left(2\sqrt{\frac{mx^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \tag{29}$$

with $K_n(x)$ being the modified Bessel function of the second kind.

The integral J_5 is [14]:

$$J_5 = \int_0^\infty d\Omega_2 \int_0^{\Omega_2} d\Omega_1 \int_0^{\Omega_2} d\Omega_3 N_{x_2/\Omega_2} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) =$$

$$= \frac{2\sqrt{\pi} f_m (k+1) x}{k^{1/2} e^{2k}} \cdot \sum_{i_1=0}^{\infty} \left(2\sqrt{\frac{k(k+1)}{2}}\right)^{2i_1} \frac{1}{i_1!\Gamma(i_1)} x^{2i_1}$$

$$\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2 \rho^{2(c-1)} \Omega_0^{c+2}}$$

$$\sum_{i_2=0}^{\infty} \left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1} \frac{1}{i_2!\Gamma(i_2+c)}$$

$$\sum_{i_3=0}^{\infty} \left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1} \frac{1}{i_3!\Gamma(i_3+c)}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c} \frac{1}{i_2+c} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}} \cdot$$

$$\sum_{j_1=0}^{\infty} \frac{1}{(i_2+c+1)(j_1)} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_1}}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c} \frac{1}{i_3+c} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}} \cdot$$

$$\sum_{j_2=0}^{\infty} \frac{1}{(i_3+c+1)(j_2)} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_2}}$$

$$\int_0^\infty d\Omega_2 \Omega_2^{-1+i_1+i_2+i_3+c-1+i_2+c+i_3+c+j_1+j_2} \cdot e^{-\frac{2(k+1)}{\Omega_2}x^2-\frac{\left(3+\rho^2\right)\Omega_2}{\Omega_0\left(1-\rho^2\right)}} =$$

$$= \frac{2\sqrt{\pi} f_m (k+1) x}{k^{1/2} e^{2k}} \cdot \sum_{i_1=0}^{\infty} \left(2\sqrt{\frac{k(k+1)}{2}}\right)^{2i_1} \frac{1}{i_1!\Gamma(i_1)} x^{2i_1}$$

$$\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2 \rho^{2(c-1)} \Omega_0^{c+2}}$$

$$\sum_{i_2=0}^{\infty} \left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1} \frac{1}{i_2!\Gamma(i_2+c)}$$

$$\frac{1}{i_2+c} \sum_{j_1=0}^{\infty} \frac{1}{(i_2+c+1)(j_1)} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_1}}$$

$$\frac{1}{i_3+c} \sum_{j_2=0}^{\infty} \frac{1}{(i_3+c+1)(j_2)} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_2}}$$

$$\left(\frac{2(k+1)x^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_1/2+i_2+i_3+3c/2+j_1/2+j_2/2}$$

$$K_{i_1+2i_2+2i_3+3c+j_1+j_2}\left(2\sqrt{\frac{2(k+1)x^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \tag{30}$$

The integral J_3 is:

$$J_3 = \int_0^\infty d\Omega_3 \int_0^{\Omega_3} d\Omega_1 \int_0^{\Omega_3} d\Omega_2 N_{x_3/\Omega_3} p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right) =$$

$$= \frac{\sqrt{2\pi} f_m \mu^{1/2} (k+1)^{\mu} x^{2\mu}}{k^{\mu-1/2} e^{2k\mu}}$$

$$\sum_{i_1=0}^{\infty} \left(2\mu\sqrt{\frac{k(k+1)}{2}}x\right)^{2i_1+2\mu-1} \frac{1}{i_1!\Gamma(i_1+2\mu)}$$

$$\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2 \rho^{2(c-1)} \Omega_0^{c+2}}$$

$$\sum_{i_2=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1}\frac{1}{i_2!\Gamma\left(i_2+c\right)}$$

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(1+\rho^2\right)}\right)^{i_2+i_3+c}\frac{1}{i_2+i_3+c}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{i_2+i_3+c}\cdot$$

$$\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+i_3+c+1\right)\left(j_1\right)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\frac{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}}\frac{1}{i_3+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_3+c+1\right)\left(j_2\right)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_2}}$$

$$\cdot\int_0^{\infty}d\Omega_3\,\Omega_3^{\,i_3+c-1+i_2+i_3+c+j_1+j_2+i_2+c+\mu-\frac{2i_1+2\mu-1}{2}}$$

$$\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x^2-\frac{\left(3+\rho^2\right)\Omega_3}{\Omega_0\left(1-\rho^2\right)}}=\frac{\sqrt{2\pi}\,f_m\,\mu^{1/2}\left(k+1\right)^{\mu}x^{2\mu}}{k^{\mu-1/2}e^{2k\mu}}$$

$$\sum_{i_1=0}^{\infty}\left(2\mu\sqrt{\frac{k\left(k+1\right)}{2}}x\right)^{2i_1+2\mu-1}\frac{1}{i_1!\Gamma\left(i_1+2\mu\right)}$$

$$\frac{2}{\Gamma\left(c\right)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}$$

$$\sum_{i_2=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_2+c-1}\frac{1}{i_2!\Gamma\left(i_2+c\right)}$$

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\frac{1}{i_2+i_3+c}\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+i_3+c+1\right)\left(j_1\right)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\frac{1}{i_3+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_3+c+1\right)\left(j_2\right)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_2}}$$

$$\left(\frac{\mu\left(k+1\right)x^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_2+i_3+3c/2-\mu-i_1/2+1/4+j_1/2+j_2/2}$$

$$K_{2i_2+2i_3+3c+j_1+j_2-2\mu-1/2-i_1}\left(2\sqrt{\frac{\mu\left(k+1\right)x^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \qquad (31)$$

V. Graphical Results

In Fig. 2, level crossing rate versus MAD SC receiver output signal envelope is shown. Parameters are: Rician factor k_1 of Rician feding, Rician factor k_2 of κ-μ fading, Gamma long term fading severity parameter β, Nakagami-m severity parameter and signal envelope average power.

For lower values of output signal amplitude, level crossing rate increases as signal amplitude increases, and for higher values of signal envelope, level crossing rate decreases as signal envelope increases. The influence of signal envelope on level crossing rate is higher for higher values of signal envelope. Signal envelope increases when Nakagami-m short term fading parameter decreases.

The influence of Nakagami-m severity parameter on level crossing rate is higher for lower values of output signal envelope. Maximums of curves go to higher values of signal envelope as Nakagami-m parameter increases. When Gamma severity parameter decreases, LCR increases; outage probability increases also.

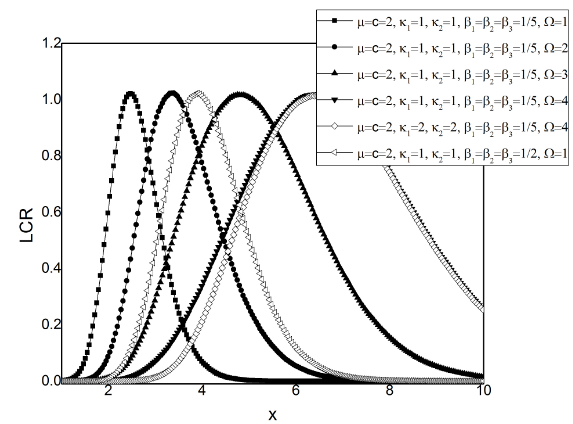

Fig. 2. LCR of MAD SC receiver output signal versus output signal envelope for μ=c=2, variable Gamma fading severity parameter, Rician factors of Rician and κ-μ fading and signal envelope average power.

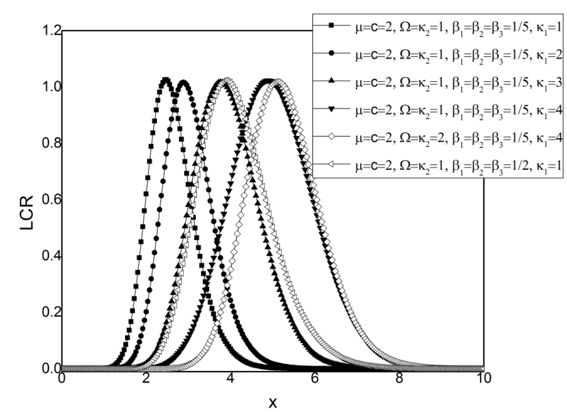

Fig. 3. LCR versus macrodiversity SC receiver output signal envelope for variable Rician factor of Rician fading and Gamma fading severity parameter.

Level crossing rate versus output signal envelope for several values of Rician factor of Rician fading, Rician factor of κ-μ fading and Gamma long term fading severity parameter, is presented in Figs. 3 and 4.

Level crossing rate of output signal envelope increases when Rician factor of Rician fading and Rician factor of κ-μ fading decrease. The influence of Rician factor of Rician fading on LCR is higher for higher values of Rician factor of κ-μ fading and influence of Rician factor of κ-μ fading on LCR is higher for higher values of Rician factor of Rician fading. Maximum of curve goes to lower values of output signal envelope when Rician factor of Rician fading and Rician factor of κ-μ fading increase.

The influence of Gamma fading parameter β on LCR of MAD SC receiver output signal is shown in Fig. 5. It is visible from this figure that LCR for small signal envelopes is bigger for smaller values of Gamma fading parameter β.

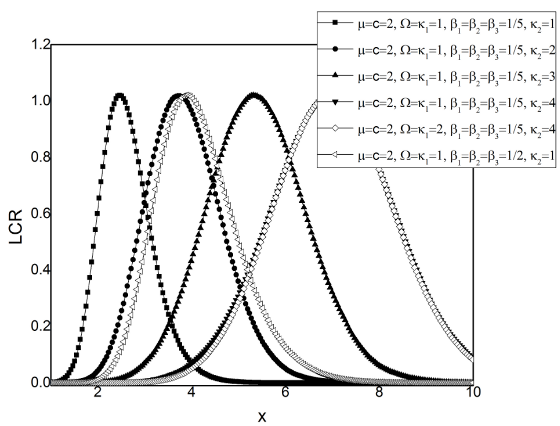

Fig. 4. LCR versus macrodiversity SC receiver output signal envelope.

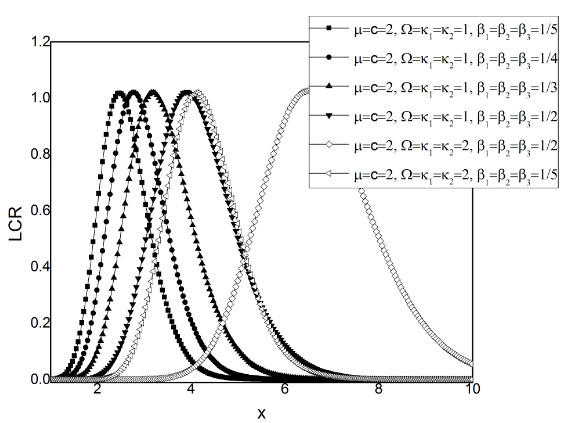

Fig. 5. LCR versus macrodiversity SC receiver output signal envelope for variable Gamma fading severity parameter.

Level crossing rate decreases when Gamma long term fading correlation coefficient goes to one. The influence of Gamma long term fading on level crossing rate is higher for higher values of Nakagami-m short term fading parameter; also, the influence of Nakagami-m severity parameter on level crossing rate is higher for lower values Gamma long term fading correlation coefficient.

VI. CONCLUSION

Macrodiversity technique is applied to reduce simultaneously long term fading and short term fading effects on performance of the wireless communication mobile radio system. Macrodiversity system has MAD selection combining and three MID maximum ratio combinig receptions. At inputs of the first MID receiver, received signal experiences correlated Gamma large scale fading and Nakagami-m small scale fading, at inputs of the second MID reception, received signal experiences correlated Gamma large scale fading and Rician small scale fading and at inputs of the third MID SC receiver, signal envelope experiences correlated Gamma large scale fading and κ-μ small scale fading. The MAD SC receiver reduces Gamma long term fading effects, the first MID MRC receiver reduces Nakagami-m short term fading effects, the second MID MRC receiver reduces Rician short term fading effects, and the third MID MRC reduces Nakagami-m short term fading effects on system performance.

Cumulative distribution function and level crossing rate closed form expressions for MID MRC output signal envelope are calculated in this paper. By using these expressions, in this work, average level crossing rate of MAD SC receiver output signal envelope is efficiently evaluated as expression in the closed form. This expression can be used for evaluation the average fade duration of proposed radio system as ratio of outage probability and level crossing rate.

The influence of Nakagami-m fading severity parameter, Rician factor, κ-μ fading Rician factor, κ-μ short term fading severity parameter, Gamma long term fading severity parameter and Gamma long term fading correlation coefficient on level crossing rate is analyzed. Average fade duration decreases when level crossing rate increases. Level crossing rate decreases when of Rician factor of Rician fading, Rician factor of κ-μ fading, Nakagami-m severity parameter and Gamma severity parameter have higher values. When correlation coefficient goes to zero, level crossing rate decreases and when correlation coefficient goes to one, MAD system becomes MID system.

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REFERENCES

[1] M. K. Simon, M. S. Alouini, *Digital Communication over Fading Channels*, USA: John Wiley & Sons. 2000.

[2] P. M. Shankar, *Fading and Shadowing in Wireless Systems*, Springer, Dec 7, 2011. DOI 10.1007/978-1-4614-0367-8

[3] S. Panic, M. Stefanovic, J. Anastasov, P.Spalevic, *Fading and Interference Mitigation in Wireless Communications*. CRC Press, USA, 2013.

[4] M. Nakagami, "The m-Distribution, a general formula of intensity of rapid fading". In William C. Hoffman, editor, Statistical Methods in Radio Wave Propagation: Proceedings of a Symposium held June 18–20, 1958, pp 3-36. Pergamon Press.

[5] S. O. Rice, Mathematical analysis of random noise, Bell System Tech J. 1944; 23: 282. Reprinted by N. Wax, Selected Papers on Noise and Stochastic Process, Dover Publication, 1954, QA273W3.

[6] M. D. Yacoub, "The κ-μ Distribution: A General Fading Distribution", IEEE Atlantic City Fall Vehicular Technology Conference 2001, Atlantic City, USA, Oct. 2001.

[7] A. D. Cvetković , M. Č. Stefanović , N. M. Sekulović , D. N. Milić , D. M. Stefanović, Z. J. Popović, "Second-order statistics of dual SC macrodiversity system over channels affected by Nakagami-m fading and correlated gamma shadowing", *Przegląd Elektrotechniczny (Electrical Review)*, R. 87 NR 6/2011, pp. 284-288.

[8] B. Jaksic, D. Stefanovic, M. Stefanovic, P. Spalevic, V. Milenkovic, "Level Crossing Rate of Macrodiversity System in the Presence of Multipath Fading and Shadowing", *Radioengineering*, Vol. 24, No. 1, April 2015, pp. 185-191, DOI: 10.13164/re.2015.0185.

[9] S. Panic, D. Bandjur, B. Jaksic, I. Dinic, D.Jaksic, S. Zdravkovic, "Level Crossing Rate of Macrodiversity System Operating over Gamma Shadowed Rician Fading Channel", X International Symposium Industrial Electronics, INDEL 2006, Banja Luka, November 06- 08, 2014, pp. 257-261.

[10] V. Milenković, N. Sekulović, M. Stefanović, M. Petrović, "Effect of microdiversity and macrodiversity on average bit error probability in gamma shadowed Rician fading channels", *ETRI Journal*, vol. 32, no.3, June 2010, pp. 464-467.

[11] D. Aleksic, D. Krstic, N. Vučić, M. M. B. Yassein, P. Zwierzykowski, "Level Crossing Rate of System with Macrodiversity and Three Branches Microdiversity Reception in Gamma Shadowed Rician Fading Channels", The Eleventh International Conference on Wireless and Mobile Communications, ICWMC 2015, St. Julians, Malta, October 11 - 16, 2015, pp. 8-12.

[12] D. M. Stefanović, S. R. Panić, P. Ć. Spalević, "Second-order statistics of SC macrodiversity system operating over Gamma shadowed Nakagami-*m* fading channels", *AEU International Journal of Electronics and Communications*, vol. 65, Issue 5, May 2011, pp. 413-418.

[13] S. R. Panic, D. M. Stefanovic, I. M. Petrovic, M. C. Stefanovic, J. A. Anastasov, D. S. Krstic, "Second order statistics of selection macro-diversity system operating over Gamma shadowed k-μ fading channels", *EURASIP Journal on Wireless Communications and Networking,* 2011, 2011:151, Article ID 631204, doi:10.1186/1687-1499-2011-151.

[14] I. Gradshteyn, I. Ryzhik, *Tables of Integrals, Series, and products*, Academic Press, New York 1994.

[15] Gamma function, Available: http://mathworld.wolfram.com/GammaFunction.html

[16] G. Arfken, "Neumann Functions, Bessel Functions of the Second Kind, $N_\nu(x)$", 11.3 in *Mathematical Methods for Physicists, 3rd ed.*, Orlando, FL: Academic Press, 1985, pp. 596-604.