Level Crossing Rate of Macrodiversity in the Presence of Short Term Fading and Long Term Fading with Different Average Powers

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***Abstract*—The macrodiversity system reduces long term fading effects and short term fading effects on wireless system performances simultaneously. The received signal is subjected to Nakagami-m short term fading and Gamma correlated long term fading resulting in signal envelope and envelope average power variation, respectively. The macrodiversity considered in this paper has macrodiversity selection combining (SC) receiver and two microdiversity SC receivers. Signal envelope average power at inputs in microdiversity SC receivers have correlated Gamma distribution with different average values. Level crossing rate of macrodiversity SC receiver output signal envelope is evaluated for the case that the user is at different distances of microdiversity SC receivers.**

Keywords- Gamma correlated long term fading; Nakagami-m short term fading; level crossing rate; selection combining (SC).

I. INTRODUCTION

Gamma long term fading and Nakagami-*m* short term fading degrade the bit error probability and the outage probability of wireless mobile communication radio system [1]. Macrodiversity technique can be applied to mitigate small scale fading effects and large scale fading effects on the outage probability, average bit error probability, the level crossing rate and average fade duration [2].

There are several diversity techniques which reduce fading effects on the bit error probability, the outage probability and the channel capacity. Maximal ratio combining (MRC), equal gain combining (EGC) and selection combining (SC) are the most widely used diversity combining schemes. In the scenario where Gaussian noise power is equally distributed in each branch of MRC receiver, squared output signal can be calculated as a sum of squared signals from its inputs [3]. Signal envelope at the EGC receiver output is a sum of signal envelopes from its inputs [4]. The SC receiver selects the branch with the highest signal envelope from input to provide service to user [5]-[7]. MRC is the optimal combining scheme, but its price and complexity are the highest. MRC and EGC combiners require knowing of all or some of the fading channel information and separate receiver for each branch of the diversity system, which increase the complexity of the system.

The macrodiversity, considered in this paper, consists of macrodiversity SC reception and two microdiversity SC receptions. The macrodiversity SC reception selects the microdiversity with the highest signal envelope average power to enable transmission to the user and microdiversities select the branch with the highest signal envelope. Microdiversity receivers use antennas at one base station and macrodiversity receiver uses antennas at two or more base stations.

Nakagami-*m* distribution describes small scale signal envelope in non line of sight multipath fading channels. For the case when parameter *m* is 1, shadowed Nakagami-*m* fading channel becomes shadowed Rayleigh fading channel, and when *m* goes to infinity, shadowed Nakagami-*m* channel becomes shadowed fading channel. When Gamma long term fading severity parameter goes to infinity and Nakagami-*m* short term fading severity parameter goes to infinity, Gamma shadowed Nakagami-*m* multipath fading channel becomes no fading channel [8].

The first order performance measures of wireless mobile radio systems are average symbol error probability, the channel capacity and the outage probability, and the second order performance measures are the level crossing rate (LCR) and average fade duration (AFD). The level crossing rate can be evaluated as mean of the first order of random process and average fade duration can be calculated as the ratio of the outage probability and the level crossing rate.

There are more works considering LCR of wireless macrodiversity communication system operating over shadowed multipath fading channel. In [5], LCR and AFD of macrodiversity, with macrodiversity SC receiver and two microdiversity maximal ratio combining (MRC) receivers, operating over correlated Gamma long term fading and Nakagami-*m* short term fading channel are calculated. On the other side, the authors in [6] derived the infinite-series expressions for the second-order statistics (LCR and AFD) at the output of SC macrodiversity consisting of two microdiversity systems of MRC type with arbitrary number of branches, which is operating over Gamma shadowed Nakagami-m fading channel.

The macrodiversity system with macrodiversity SC receiver and three microdiversity SC receivers working over Gamma shadowed Nakagami-m multipath fading environment is studied in [7]. The level crossing rate of

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signals at outputs of microdiversity SC receivers are calculated and based on these formulas, the closed form expression for average LCR of macrodiversity SC receiver output signal is calculated.

The second order statistics of macrodiversity in Gamma shadowed Rician fading channel is analyzed in [3]. In paper [9], macrodiversity, with macrodiversity SC receiver and two microdiversity SC receivers, is studied and LCR of macrodiversity SC receiver output signal is calculated for the presence of Gamma shadowed k-μ multipath fading.

In this paper, macrodiversity, with macrodiversity SC receiver and two microdiversity SC receivers, in the presence of Nakagami-*m* small scale fading and correlated Gamma long term fading is considered. Average powers of Gamma distribution are different. The distances of user and microdiversity receivers are different. The closed form expression for LCR of proposed wireless macrodiversity system is calculated. The level crossing rate of macrodiversity, when distances of user from microdiversity receivers are different, is not considered in open technical literature.

This paper consists of five sections. After the first section, Introduction, where the topic is introduced and related papers analyzed, in the second section the system model is described. The expression for level crossing rate of macrodiversity SC receiver output signal is derived in the third section. In the forth section, numerical results are analyzed. Then, Conclusion is given with some final comments. In the Appendix, the integrals, which appear in the expressions for LCR, are solved.

II. MODEL OF MACRODIVERSITY SYSTEM

The macrodiversity has macrodiversity SC receiver and two microdiversity SC receivers. Macrodiversity operates in the presence of Gamma long term fading and Nakagami-*m* short term fading. This macrodiversity SC receiver selects microdiversity with the highest signal envelope average power and microdiversity SC receiver selects the branch with the strongest signal envelope. Model of considered system is shown in Figure 1.

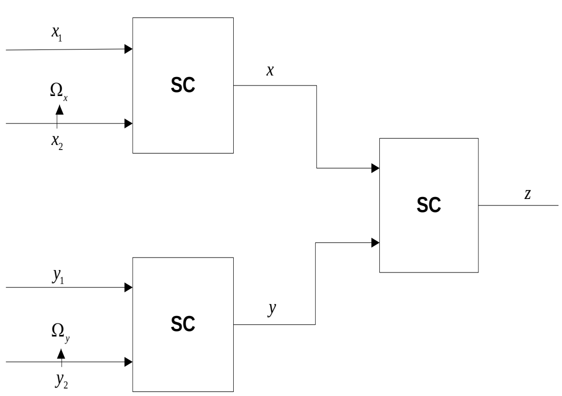

Figure 1. Model of considered system

Probability density function (PDF) of x_1 and x_2 is:

$$p_{x_i}(x_i) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_x}\right)^m x_i^{2m-1} e^{-\frac{m}{\Omega_x}x_i^2}, \; x_i \ge 0, \quad i = 1,2 \quad (1)$$

Probability density function of y_1 and y_2 is:

$$p_{y_i}(y_i) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_y}\right)^m y_i^{2m-1} e^{-\frac{m}{\Omega_y}y_i^2}, \; y_i \ge 0, \quad i = 1,2 . \quad (2)$$

Cumulative distribution function (CDF) of x_i is:

$$F_{x_i}(x_i) = \frac{1}{\Gamma(m)}\gamma\left(m, \frac{m}{\Omega_x}x_i^2\right), \quad x_i \ge 0, \quad i = 1,2 , \quad (3)$$

and cumulative distribution function of y_i is:

$$F_{y_i}(y_i) = \frac{1}{\Gamma(m)}\gamma\left(m, \frac{m}{\Omega_y}y_i^2\right), \quad y_i \ge 0, \quad i = 1,2 , \quad (4)$$

where $\gamma(n,x)$ is incomplete Gamma function.

The level crossing rate of x_i random process is:

$$N_{x_1} = \frac{f_m\sqrt{2\pi}}{\Gamma(m)}\left(\frac{m}{\Omega_x}\right)^{m-1/2} x_1^{2m-1} e^{-\frac{m}{\Omega_x}x_i^2}, \; x_i \ge 0; \; i = 1,2 . \quad (5)$$

The level crossing rate of y_i is:

$$N_{y_1} = \frac{f_m\sqrt{2\pi}}{\Gamma(m)}\left(\frac{m}{\Omega_y}\right)^{m-1/2} y_1^{2m-1} e^{-\frac{m}{\Omega_y}y_i^2}, \; y_i \ge 0; \; i = 1,2 . \quad (6)$$

The LCR of x random process is:

$$N_x = 2N_{x_1}F_{x_2}(x) = \frac{2\sqrt{2\pi}f_m}{\Gamma(m)}\left(\frac{m}{\Omega_x}\right)^{m-1/2} x^{2m-1} e^{-\frac{m}{\Omega_x}x^2} \cdot$$

$$\cdot\frac{1}{\Gamma(m)}\gamma\left(m, \frac{m}{\Omega_x}x^2\right), \; x \ge 0 . \quad (7)$$

The LCR of y random process is:

$$N_y = 2N_{y_1}F_{y_2}(y) = \frac{2\sqrt{2\pi}f_m}{\Gamma(m)}\left(\frac{m}{\Omega_y}\right)^{m-1/2} y^{2m-1} e^{-\frac{m}{\Omega_y}y^2} \cdot$$

$$\cdot\frac{1}{\Gamma(m)}\gamma\left(m, \frac{m}{\Omega_y}y^2\right), \; y \ge 0 . \quad (8)$$

The powers Ω_x and Ω_y follow correlated Gamma distribution:

$$p_{\Omega_x\Omega_y}(\Omega_x\Omega_y) = \frac{m_1^{m_1+1}(\Omega_x\Omega_y)^{\frac{m_1-1}{2}}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}} \cdot$$

$$\cdot e^{-\frac{m_1}{(1-\rho)}\left(\frac{\Omega_x}{\Omega_1}+\frac{\Omega_y}{\Omega_2}\right)} I_{m_1-1}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)}\left(\frac{\Omega_x\Omega_y}{\Omega_1\Omega_2}\right)^{1/2}\right)=$$

$$=\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\Omega_x^{i_1+m_1-1}e^{-\frac{m_1}{(1-\rho)\Omega_1}\Omega_x}\Omega_y^{i_1+m_1-1}e^{-\frac{m_1}{(1-\rho)\Omega_2}\Omega_y},\quad \Omega_x\ge 0,\ \Omega_y\ge 0 \qquad (9)$$

where ρ is Gamma long term fading correlation coefficient, m_1 is Gamma long term fading severity parameter and $\Omega_1=\overline{\Omega_x}$ and $\Omega_2=\overline{\Omega_y}$. In this paper, parameters Ω_1 and Ω_2 are different.

III. LEVEL CROSSING RATE OF MACRODIVERSITY SC RECEIVER OUTPUT SIGNAL

Macrodiversity SC receiver selects microdiversity SC receiver with higher signal envelope average power to provide service to user. For that reason, the level crossing rate of macrodiversity SC receiver output signal envelope is:

$$N_z=\int_0^{\infty}d\Omega_x\int_0^{\Omega_x}d\Omega_y N_{x/\Omega_x}p_{\Omega_x\Omega_y}\left(\Omega_x\Omega_y\right)+$$

$$+\int_0^{\infty}d\Omega_y\int_0^{\Omega_y}d\Omega_x N_{y/\Omega_y}p_{\Omega_x\Omega_y}\left(\Omega_x\Omega_y\right)=J_1+J_2\,. \qquad (10)$$

Now, we need to solve the integrals J_1 and J_2. These integrals will be solved in Appendix.

Finally, the LCR of macrodiversity SC receiver output signal envelope is:

$$N_z=\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot$$

$$\cdot m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(m+1)(j_1)}m^{j_1}z^{2^{j_1}}\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\frac{1}{i_1+m_1}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_1+m_1+1)(j_2)}\left(\frac{m_1}{\Omega_2(1-\rho)}\right)^{j_2}\cdot$$

$$\cdot\left(\frac{mz^2(1-\rho)\Omega_1}{m_1}\right)^{i_1+m_1-m+1/4-j_1/2+j_2/2}\cdot$$

$$\cdot K_{2i_1+2m_1-2m+1/2-j_1+j_2}\left(2\sqrt{\frac{4mz^2m_1}{(1-\rho)\Omega_1}}\right)+$$

$$+\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot$$

$$m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(m+1)(j_1)}m^{j_1}z^{2^{j_1}}\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\frac{1}{i_1+m_1}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_1+m_1+1)(j_2)}\left(\frac{m_1}{\Omega_1(1-\rho)}\right)^{j_2}\cdot$$

$$\cdot\left(\frac{mz^2(1-\rho)\Omega_2}{m_1}\right)^{i_1+m_1-m+1/4-j_1/2+j_2/2}\cdot$$

$$\cdot K_{2i_1+2m_1-2m+1/2-j_1+j_2}\left(2\sqrt{\frac{4mz^2m_1}{(1-\rho)\Omega_2}}\right) \qquad (11)$$

where $K_n(x)$ is the modified Bessel function of the second kind, n –th order and argument x [10].

IV. NUMERICAL RESULTS

The level crossing rate curves for the macrodiversity SC receiver output signal versus the SC receiver output signal envelope is presented in Figure 2, for power of Nakagami-m fading in branches: $\Omega_1=\Omega_2=1$, and variable Gamma fading parameter β_2.

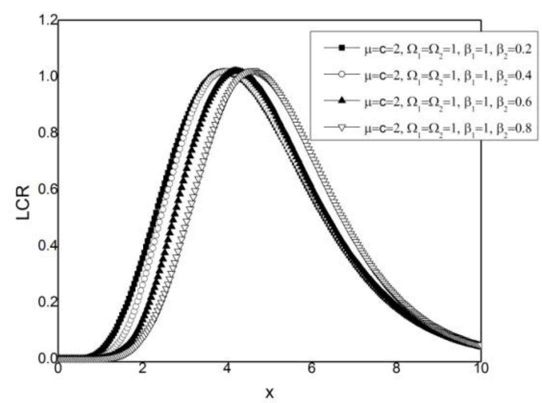

Figure 2. LCR versus macrodiversity SC receiver output signal envelope.

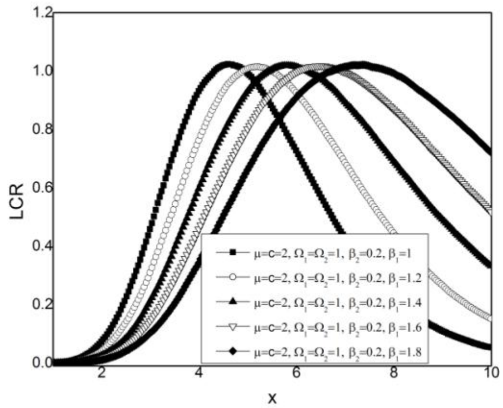

Figure 3. LCR versus macrodiversity SC receiver output signal envelope for variable Gamma fading severity parameter.

It is visible from Figure 2 that LCR is bigger for smaller values of Gamma fading parameter β_2 at low values of the signal envelopes. The system performances are better for lower values of the average level crossing rate.

All these curves have maximums. When the Gamma shadowing severity increases, the maximal values increase also, moving to higher values of the SC receiver output signal envelope.

The LCR takes greater values as the correlation coefficient increases. When the correlation coefficient goes to one, the least values of signal envelope occur at both microdiversity receivers and system has the worst performance.

In Figure 3, the level crossing rate, depending on microdiversity SC receiver output signal envelope, is plotted for a few values of Gamma fading severity parameter. The LCR increases as the parameter β_1 decreases at small values of the signal envelopes. Then, all curves achieve maximums and start to decline. The curves become wider at higher values of the parameter β_1.

V. CONCLUSION

In this paper, macrodiversity with macrodiversity SC receiver and two microdiversity SC receivers is studied. Received signal experiences correlated Gamma long term fading and Nakagami-m short term fading resulting in signal envelope variation and signal envelope average power variation. Performance of macrodiversity system is considered for the case when distances between user and microdiversity SC receivers are different. Macrodiversity SC receiver mitigates Gamma long term fading effects on the level crossing rate and microdiversity SC receivers reduce to Nakagami-m short term fading effects on the outage performance, simultaneously.

The closed form expression for LCR of macrodiversity SC receiver output signal is evaluated. The obtained expression can be used for calculation the level crossing rate at the output of macrodiversity operating over Gamma shadowed Rayleigh multipath fading. The influence of Gamma long term fading severity parameter, Nakagami-*m* short term fading severity and Gamma long term fading correlation coefficient is analyzed and discussed. Also, the influence of distances of the users from microdiversity SC receivers is studied.

The system performance is better for lower values of the level crossing rate. The level crossing rate decreases as Gamma long term fading severity parameter increases and when Nakagami-*m* short term fading severity parameter increases. When Gamma long term fading correlation coefficient goes to one, LCR increases and macrodiversity system has performance as simple microdiversity system.

LCR increases for lower values of the SC receiver output signal, and decreases for higher values of that signal. The influence of SC receiver output signal on the level crossing rate is more pronounced for lower values of this signal.

The biggest contribution of this paper is derivation of LCR of macrodiversity system with different distances between user and microdiversity receivers.

APPENDIX

The integral J_1 is equal to the first addend in the expression for the LCR defined in (10):

$$J_1=\int_0^{\infty} d\Omega_x \int_0^{\Omega_x} d\Omega_y N_{x/\Omega_x} p_{\Omega_x\Omega_y}\left(\Omega_x\Omega_y\right) \qquad (12)$$

Let's solve this integral by putting N_{x/Ω_x} from (7) and $p_{\Omega_x\Omega_y}\left(\Omega_x\Omega_y\right)$ from (9) into (12) [11] [12]:

$$J_1=\int_0^{\infty} d\Omega_x \int_0^{\Omega_x} d\Omega_y \frac{2\sqrt{2\pi}\, f_m}{\Gamma(m)}\left(\frac{m}{\Omega_x}\right)^{m-1/2} z^{2m-1} e^{-\frac{m}{\Omega_x}z^2} \cdot$$

$$\frac{1}{m}\frac{m^m}{\Omega_x^m} z^{2m} e^{-\frac{m}{\Omega_x}z^2} \cdot \sum_{j_1=0}^{\infty} \frac{1}{(m+1)(j_1)} \frac{m^{j_1}}{\Omega_x^{j_1}} z^{2j_1}$$

$$\cdot \frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty}\left(\frac{m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1} \frac{1}{i_1!\,\Gamma(i_1+m_1)}$$

$$\Omega_x^{i_1+m_1-1} e^{-\frac{m_1}{(1-\rho)\Omega_1}\Omega_x} \Omega_y^{i_1+m_1-1} e^{-\frac{m_1}{(1-\rho)\Omega_2}\Omega_y} =$$

$$= \frac{2\sqrt{2\pi}\, f_m}{\Gamma(m)} m^{m-1/2} z^{2m-1} \cdot \frac{1}{m} m^m z^{2m} \cdot \sum_{j_1=0}^{\infty} \frac{1}{(m+1)(j_1)} m^{j_1} z^{2j_1}$$

$$\cdot \frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}} \cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\int_0^{\infty} d\Omega_x \Omega_x^{i_1+m_1-1-m+1/2-m-j_1} e^{-\frac{2m}{\Omega_x}z^2-\frac{m_1}{(1-\rho)\Omega_1}\Omega_x}$$

$$\int_0^{\Omega_x} d\Omega_y \Omega_y^{i_1+m_1-1} e^{-\frac{m_1}{(1-\rho)\Omega_2}\Omega_y} = \frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2} m^{m-1/2} z^{2m-1}\cdot$$

$$m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty} \frac{1}{(m+1)(j_1)} m^{j_1} z^{2j_1}\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\int_0^{\infty} d\Omega_x\Omega_x^{i_1+m_1-2m-1+1/2-m-j_1}e^{-\frac{2m}{\Omega_x}z^2-\frac{m_1}{(1-\rho)\Omega_1}\Omega_x}$$

$$\cdot\left(\frac{(1-\rho)\Omega_2}{m_1}\right)^{i_1+m_1}\cdot\gamma\left(i_1+m_1,\frac{m_1\Omega_x}{\Omega_2(1-\rho)}\right)=$$

$$=\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(m+1)(j_1)}m^{j_1}z^{2j_1}$$

$$\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\int_0^{\infty} d\Omega_x\Omega_x^{i_1+m_1-2m-1/2-m-j_1}e^{-\frac{2m}{\Omega_x}z^2-\frac{m_1}{(1-\rho)\Omega_1}\Omega_x}$$

$$\cdot\left(\frac{(1-\rho)\Omega_2}{m_1}\right)^{i_1+m_1}\cdot\frac{1}{i_1+m_1}\cdot\left(\frac{m_1}{(1-\rho)\Omega_2}\right)^{i_1+m_1}\Omega_x^{i_1+m_1}e^{-\frac{m_1\Omega_x}{\Omega_1(1-\rho)}}\cdot$$

$$\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_1+m_1+1)(j_2)}\left(\frac{m_1\Omega_x}{\Omega_2(1-\rho)}\right)^{j_2}=$$

$$=\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(m+1)(j_1)}m^{j_1}z^{2j_1}$$

$$\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\frac{1}{i_1+m_1}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_1+m_1+1)(j_2)}\left(\frac{m_1}{\Omega_2(1-\rho)}\right)^{j_2}\cdot$$

$$\int_0^{\infty} d\Omega_x\Omega_x^{i2_1+2m_1-2m-1/2-m-j_1+j_2}e^{-\frac{2m}{\Omega_x}z^2-\frac{2m_1\Omega_x}{(1-\rho)\Omega_1}}=$$

$$=\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot m^{m-1}z^{2m}\cdot\sum_{j_1=0}^{\infty}\frac{1}{(m+1)(j_1)}m^{j_1}z^{2j_1}$$

$$\cdot\frac{m_1^{m_1+1}\rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}}\right)^{2i_1+m_1-1}\frac{1}{i_1!\Gamma(i_1+m_1)}$$

$$\frac{1}{i_1+m_1}\cdot\sum_{j_2=0}^{\infty}\frac{1}{(i_1+m_1+1)(j_2)}\left(\frac{m_1}{\Omega_2(1-\rho)}\right)^{j_2}\cdot$$

$$\cdot\left(\frac{mz^2(1-\rho)\Omega_1}{m_1}\right)^{i_1+m_1-m+1/4-j_1/2+j_2/2}\cdot$$

$$\cdot K_{2i_1+2m_1-2m+1/2-j_1+j_2}\left(2\sqrt{\frac{4mz^2m_1}{(1-\rho)\Omega_1}}\right) \quad (13)$$

with $K_n(x)$ as modified Bessel function of the second kind, n –th order and argument x.

Integral J_2 is the second summand in the expression for the LCR in (10):

$$J_2=\int_0^{\infty} d\Omega_y\int_0^{\Omega_y} d\Omega_x N_{y/\Omega_y}\, p_{\Omega_x\Omega_y}(\Omega_x\Omega_y) \quad (14)$$

In the similar way, it is solved by introducing N_{y/Ω_y} from (8) and $p_{\Omega_x\Omega_y}(\Omega_x\Omega_y)$ from (9) in (14) [11] [13]:

$$J_2=\frac{2\sqrt{2\pi}f_m}{\Gamma(m)^2}m^{m-1/2}z^{2m-1}\cdot$$

$$m^{m-1} z^{2m} \cdot \sum_{j_1=0}^{\infty} \frac{1}{(m+1)(j_1)} m^{j_1} z^{2^{j_1}} \cdot \frac{m_1^{m_1+1} \rho^{\frac{1-m_1}{2}}}{\Gamma(m_1)(1-\rho)(\Omega_1\Omega_2)^{\frac{m_1+1}{2}}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty} \left(\frac{2m_1\sqrt{\rho}}{(1-\rho)(\Omega_1\Omega_2)^{1/2}} \right)^{2i_1+m_1-1} \frac{1}{i_1!\,\Gamma(i_1+m_1)}$$

$$\frac{1}{i_1+m_1} \cdot \sum_{j_2=0}^{\infty} \frac{1}{(i_1+m_1+1)(j_2)} \left(\frac{m_1}{\Omega_1(1-\rho)} \right)^{j_2} \cdot$$

$$\cdot \left(\frac{mz^2(1-\rho)\Omega_2}{m_1} \right)^{i_1+m_1-m+1/4-j_1/2+j_2/2} \cdot$$

$$\cdot K_{2i_1+2m_1-2m+1/2-j_1+j_2} \left(2\sqrt{\frac{4mz^2 m_1}{(1-\rho)\Omega_2}} \right). \qquad (15)$$

where $K_n(x)$ is defined earlier.

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