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The Statistical Characteristics of the MRC Diversity System Output Signal

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Introduction

In the paper [1] the outage probability of the MRC combiner output signal in the presence of Rice channel and big interference power is calculated. In the paper [2] M-QAM signal in the Nakagami channel, with MRC combiner, is considered. In [3] and [4] the Hybrid Selection/Maximal-Ratio Combining in Rayleigh Fading is used.

In this paper the MRC diversity system with two branches will be considered. The predetection MRC combining will be used. The statistical characteristics of the combiner output signal at two and more time instants will be determined. These characteristics are important when the signals at the combiner input are correlated. The signals at the combiner input are correlated when the Gaussian noise at the diversity system input is correlated. Because of that the determination of the joint probability density function of the signals at two time instants is necessary. In the paper the probability density function of the combiner output signal at two and more time instants will be calculate. The joint probability density function of the signal and its derivative at two and more time instants will be calculated also.

The characteristics of the combiner output signal at two time instants

The MRC diversity system with two branches is observed. It is shown at Fig. 1. The signal at the combiner output will be derived at two independent time instants t_1 and t_2. SNR on the combiner output is γ_1 at time instant t_1 and γ_2 at time instant t_2 SNR at the first antenna output, at the moment t_1, is γ_{11}, and at the second antenna it is γ_{21}. At time moment t_2 SNR at the output from the first antenna is γ_{12}, and from the other is γ_{22}. Their joint probability density function is known. This is valid for the SNRs γ_{21} and γ_{22}, also. The SNRs γ_{11} and γ_{21} are corelated at the same time instant and their joint probability density function is known. That is valid for the SNRs γ_{12} and γ_{22}, also.

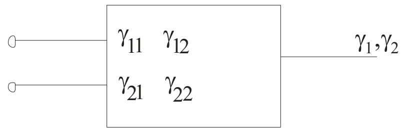

Fig. 1. The MRC diversity system with two inputs at two time instants

The MRC diversity system is observed. For this sheme of the combining the SNRs γ_1 and γ_2 are:

$$\gamma_1 = \gamma_{11} + \gamma_{21},$$
$$\gamma_2 = \gamma_{12} + \gamma_{22}. \quad (1)$$

From these two equations we have:

$$\gamma_{11} = \gamma_1 - \gamma_{21},$$
$$\gamma_{12} = \gamma_2 - \gamma_{22}. \quad (2)$$

The joint probability density function of the variables γ_1 and γ_2 is:

$$p_{\gamma_1\gamma_2}(\gamma_1,\gamma_2) = \int d\gamma_{21} \int d\gamma_{22} \times$$
$$\times\, p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}}(\gamma_1 - \gamma_{21}, \gamma_2 - \gamma_{22}, \gamma_{21}, \gamma_{22}). \quad (3)$$

The derivatives of the variables γ_1 and γ_2 are:

$$\dot\gamma_1 = \dot\gamma_{11} + \dot\gamma_{21},$$
$$\dot\gamma_2 = \dot\gamma_{12} + \dot\gamma_{22}. \quad (4)$$

From the previous equations it is:

$$\dot\gamma_{11} = \dot\gamma_1 - \dot\gamma_{21},$$
$$\dot\gamma_{12} = \dot\gamma_2 - \dot\gamma_{22}. \quad (5)$$

If the joint probability density function of the variables $\gamma_{11},\gamma_{12},\gamma_{21},\gamma_{22}$ and their derivatives $\dot\gamma_{11},\dot\gamma_{12},\dot\gamma_{21},\dot\gamma_{22}$ is:
$p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}\dot\gamma_{11}\dot\gamma_{12}\dot\gamma_{21}\dot\gamma_{22}}(\gamma_{11},\gamma_{12},\gamma_{21},\gamma_{22},\dot\gamma_{11},\dot\gamma_{12},\dot\gamma_{21},\dot\gamma_{22}),$

the joint probability density function of the variables $\gamma_1, \dot{\gamma}_1, \gamma_2, \dot{\gamma}_2$ is then:

$$p_{\gamma_1\dot{\gamma}_1\gamma_2\dot{\gamma}_2}(\gamma_1, \dot{\gamma}_1, \gamma_2, \dot{\gamma}_2) = \int d\gamma_{21} \int d\gamma_{22} \int d\dot{\gamma}_{21} \int d\dot{\gamma}_{22} \times$$
$$\times\, p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}\dot{\gamma}_{11}\dot{\gamma}_{12}\dot{\gamma}_{21}\dot{\gamma}_{22}}(\gamma_1 - \gamma_{21}, \gamma_2 - \gamma_{22}, \gamma_{21}, \gamma_{22},$$
$$\dot{\gamma}_1 - \dot{\gamma}_{21}, \dot{\gamma}_2 - \dot{\gamma}_{22}, \dot{\gamma}_{21}, \dot{\gamma}_{22}). \quad (6)$$

The joint probability density function of the variables γ_1 and γ_2 is:

$$p_{\gamma_1\gamma_2}(\gamma_1, \gamma_2) = \int d\gamma_{21} \int d\gamma_{22} \times$$
$$\times\, p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}}(\gamma_1 - \gamma_{21}, \gamma_2 - \gamma_{22}, \gamma_{21}, \gamma_{22}). \quad (7)$$

The diversity system with L branches is shown at Fig. 2. At the time instant t_1 SNRs at the antennas output are $\gamma_{11}, \gamma_{21}, \ldots, \gamma_{L1}$, and at the time instant t_2 they are $\gamma_{12}, \gamma_{22}, \ldots, \gamma_{L2}$. SNRs at the combiner output at time instants t_1 and t_2 are:

$$\gamma_1 = \gamma_{11} + \gamma_{21} + \cdots + \gamma_{L1},$$
$$\gamma_2 = \gamma_{12} + \gamma_{22} + \cdots + \gamma_{L2}. \quad (8)$$

SNRs γ_{11} and γ_{12} are:

$$\gamma_{11} = \gamma_1 - \gamma_{21} - \cdots - \gamma_{L1},$$
$$\gamma_{12} = \gamma_2 - \gamma_{22} - \cdots - \gamma_{L2}. \quad (9)$$

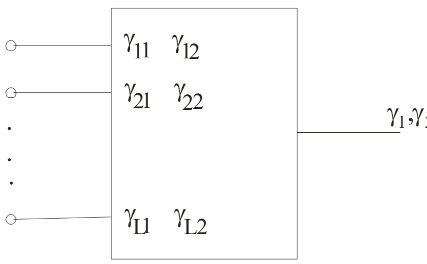

Fig. 2. The MRC diversity system with L branches at two time instants

The joint probability density function of the variables γ_1 and γ_2 is:

$$p_{\gamma_1\gamma_2}(\gamma_1, \gamma_2) = \int d\gamma_{21} \cdots \int d\gamma_{L2} \times$$
$$\times\, p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}\cdots\gamma_{L1}\gamma_{L2}}(\gamma_1 - \gamma_{21} - \cdots - \gamma_{L1},$$
$$\gamma_2 - \gamma_{22} - \cdots - \gamma_{L2}, \gamma_{21}, \gamma_{22}, \ldots, \gamma_{L1}, \gamma_{L2}),$$
$$p_{\gamma_1\gamma_2}(\gamma_1, \gamma_2) = \int d\gamma_{21} \cdots \int d\gamma_{L2} \cdot p_{\gamma_{11},\gamma_{12},\gamma_{21},\gamma_{22},\ldots,\gamma_{L1},\gamma_{L2}}(\gamma_1 - \gamma_{21} - \cdots - \gamma_{L1},$$
$$\gamma_2 - \gamma_{22} - \cdots - \gamma_{L2}, \gamma_{21}, \gamma_{22}, \ldots, \gamma_{L1}, \gamma_{L2}). \quad (10)$$

In the previous expression $p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}\cdots\gamma_{L1}\gamma_{L2}}(\gamma_{11}, \gamma_{12}, \gamma_{21}, \gamma_{22}, \ldots, \gamma_{L1}, \gamma_{L2})$ is the joint probability density function of the variables $\gamma_{11}, \gamma_{12}, \gamma_{21}, \gamma_{22}, \ldots, \gamma_{L1}, \gamma_{L2}$. The joint probability density function of these variables and theirs derivatives $\dot{\gamma}_{11}, \dot{\gamma}_{12}, \dot{\gamma}_{21}, \dot{\gamma}_{22}, \ldots, \dot{\gamma}_{L1}, \dot{\gamma}_{L2}$ is:

$$p_{\gamma_{11}\gamma_{12}\gamma_{21}\gamma_{22}\cdots\gamma_{L1}\gamma_{L2}\dot{\gamma}_{11}\dot{\gamma}_{12}\dot{\gamma}_{21}\dot{\gamma}_{22}\cdots\dot{\gamma}_{L1}\dot{\gamma}_{L2}}(\gamma_{11}, \gamma_{12}, \gamma_{21},$$
$$\gamma_{22}, \ldots, \gamma_{L1}, \gamma_{L2}, \dot{\gamma}_{11}, \dot{\gamma}_{12}, \dot{\gamma}_{21}, \dot{\gamma}_{22}, \dot{\gamma}_{L1}, \dot{\gamma}_{L2}).$$

The derivatives of the variables γ_1 and γ_2 are:

$$\dot{\gamma}_1 = \dot{\gamma}_{11} + \dot{\gamma}_{21} + \cdots + \dot{\gamma}_{L1},$$
$$\dot{\gamma}_2 = \dot{\gamma}_{12} + \dot{\gamma}_{22} + \cdots + \dot{\gamma}_{L2}. \quad (11)$$

From the previous relations it can be obtained:

$$\dot{\gamma}_{11} = \dot{\gamma}_1 - \dot{\gamma}_{21} - \cdots - \dot{\gamma}_{L1},$$
$$\dot{\gamma}_{12} = \dot{\gamma}_2 - \dot{\gamma}_{22} - \cdots - \dot{\gamma}_{L2}. \quad (12)$$

The joint probability density function of the variables γ_1 and γ_2 and theirs derivatives is

$$p_{\gamma_1\dot{\gamma}_1\gamma_2\dot{\gamma}_2}(\gamma_1, \dot{\gamma}_1, \gamma_2, \dot{\gamma}_2) = \int d\gamma_{21} \int d\gamma_{31} \cdots \int d\gamma_{L1}$$
$$\times \int d\gamma_{22} \int d\gamma_{32} \cdots\cdots d\gamma_{L2} \times$$
$$\times \int d\dot{\gamma}_{21} \int d\dot{\gamma}_{31} \cdots \int d\dot{\gamma}_{L1} \cdot \int d\dot{\gamma}_{22} \int d\dot{\gamma}_{32} \cdots \int d\dot{\gamma}_{L2} \times$$
$$\times\, p_{\gamma_{11}\gamma_{21}\cdots\gamma_{L1}\gamma_{12}\gamma_{22}\cdots\gamma_{L2}\dot{\gamma}_{11}\dot{\gamma}_{21}\cdots\dot{\gamma}_{L1}\dot{\gamma}_{12}\dot{\gamma}_{22}\cdots\dot{\gamma}_{L2}}($$
$$\gamma_1 - \gamma_{21} - \cdots - \gamma_{L1}, \gamma_{21}, \gamma_{L1}, \gamma_2 - \gamma_{22} - \cdots - \gamma_{L2},$$
$$\gamma_{22}, \gamma_{32}, \ldots, \gamma_{L2}, \dot{\gamma}_1 - \dot{\gamma}_{21} - \cdots - \dot{\gamma}_{L1},$$
$$\dot{\gamma}_{21}, \ldots, \dot{\gamma}_{L1}, \dot{\gamma}_2 - \dot{\gamma}_{22} - \cdots - \dot{\gamma}_{L2}, \dot{\gamma}_{22}, \dot{\gamma}_{32}, \ldots, \dot{\gamma}_{L2}). \quad (13)$$

The characteristics of the combiner output signal at more time instants

The diversity system with L branches is shown in Fig. 3. SNR at the combiner output is observed at p time instants. The SNRs at the time instant t_1 are $\gamma_{11}, \gamma_{21}, \ldots, \gamma_{L1}$, at the time instant t_2 they are $\gamma_{12}, \gamma_{22}, \ldots, \gamma_{L2}$, and at the time instant t_p they are $\gamma_{1p}, \gamma_{2p}, \ldots, \gamma_{Lp}$. The joint probability density function of these variables is:

$$p_{\gamma_{11}\gamma_{21}\cdots\gamma_{L1}\gamma_{12}\gamma_{22}\cdots\gamma_{L2}\cdots\gamma_{1p}\gamma_{2p}\cdots\gamma_{Lp}}(\gamma_{11}, \gamma_{21}, \ldots, \gamma_{L1},$$
$$\gamma_{12}, \gamma_{22}, \ldots, \gamma_{L2}, \ldots, \gamma_{1p}, \gamma_{2p}, \ldots, \gamma_{Lp}).$$

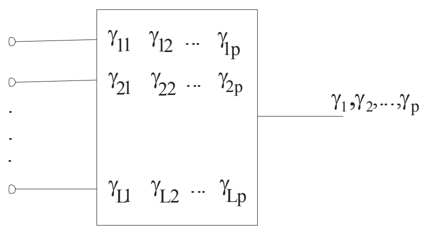

Fig. 3. The MRC diversity system with L inputs at p time instants

SNRs at the combiner output are:

$$\gamma_1 = \gamma_{11} + \gamma_{21} + \cdots + \gamma_{L1},$$

$$\gamma_2 = \gamma_{12} + \gamma_{22} + \cdots + \gamma_{L2},$$

$$\gamma_p = \gamma_{1p} + \gamma_{2p} + \cdots + \gamma_{Lp}. \qquad (14)$$

Now it follows from the previous:

$$\gamma_{11} = \gamma_1 - \gamma_{21} - \cdots - \gamma_{L1},$$

$$\gamma_{12} = \gamma_2 - \gamma_{22} - \cdots - \gamma_{L2},$$

$$\gamma_{1p} = \gamma_p - \gamma_{2p} - \cdots - \gamma_{Lp}. \qquad (15)$$

The joint probability density function of the variables γ_1, γ_2 and γ_p is:

$$p_{\gamma_1\gamma_2\cdots\gamma_p}(\gamma_1,\gamma_2,\ldots,\gamma_p) = \int d\gamma_{21}\int d\gamma_{31}\cdots\int d\gamma_{L1}\int d\gamma_{22}\int d\gamma_{32}\cdots$$

$$\cdots\int d\gamma_{L2}\int d\gamma_{2p}\int d\gamma_{3p}\cdots\int d\gamma_{Lp}\times$$

$$\times\, p_{\gamma_{11},\gamma_{21},\ldots,\gamma_{L1},\gamma_{12},\gamma_{22},\ldots,\gamma_{L2},\gamma_{p1},\gamma_{2p},\ldots,\gamma_{Lp}}(\gamma_1 - \gamma_{21} - \cdots -$$

$$-\gamma_{L1},\gamma_{21},\ldots,\gamma_{L1},\gamma_2 - \gamma_{22} - \cdots - \gamma_{L2},\gamma_{22},\ldots,\gamma_{L2},$$

$$\gamma_p - \gamma_{2p} - \cdots - \gamma_{Lp},\gamma_{2p},\ldots,\gamma_{Lp}) \qquad (16)$$

The joint probability density function of the variables γ_{mn}, $m=1,2,\ldots,L$; $n=1,2,\ldots,p$ and theirs derivatives is:

$$p_{\gamma_{11}\gamma_{21}\cdots\gamma_{L1}\dot\gamma_{11}\dot\gamma_{21}\cdots\dot\gamma_{L1}\gamma_{12}\gamma_{22}\cdots\gamma_{L2}\dot\gamma_{12}\dot\gamma_{22}\cdots\dot\gamma_{L2}\cdots\gamma_{1p}\gamma_{2p}\cdots\gamma_{Lp}\dot\gamma_{1p}\dot\gamma_{2p}\cdots\dot\gamma_{Lp}}(\gamma_{11},\gamma_{21},\ldots,\gamma_{L1},\dot\gamma_{11},\dot\gamma_{21},\ldots,\dot\gamma_{L1},\gamma_{12},\gamma_{22},\ldots,\gamma_{L2},$$

$$\dot\gamma_{12},\dot\gamma_{22},\ldots,\dot\gamma_{L2},\ldots,\gamma_{1p},\gamma_{2p},\ldots,\gamma_{Lp},\dot\gamma_{1p},\dot\gamma_{2p},\ldots,\dot\gamma_{Lp}).$$

SNRs at the combiner output, γ_1, γ_2 i γ_p, and theirs derivatives are:

$$\gamma_1 = \gamma_{11} + \gamma_{21} + \cdots + \gamma_{L1}$$

$$\dot\gamma_1 = \dot\gamma_{11} + \dot\gamma_{21} + \cdots + \dot\gamma_{L1} \qquad (17)$$

$$\gamma_2 = \gamma_{12} + \gamma_{22} + \cdots + \gamma_{L2}$$

$$\dot\gamma_2 = \dot\gamma_{12} + \dot\gamma_{22} + \cdots + \dot\gamma_{L2} \qquad (18)$$

$$\cdots$$

$$\gamma_p = \gamma_{1p} + \gamma_{2p} + \cdots + \gamma_{Lp}$$

$$\dot\gamma_p = \dot\gamma_{1p} + \dot\gamma_{2p} + \cdots + \dot\gamma_{Lp} \qquad (19)$$

From the previous equations it is obtained:

$$\gamma_{11} = \gamma_1 - \gamma_{21} - \cdots - \gamma_{L1}$$

$$\dot\gamma_{11} = \dot\gamma_1 - \dot\gamma_{21} - \cdots - \dot\gamma_{L1} \qquad (20)$$

$$\gamma_{12} = \gamma_2 - \gamma_{22} - \cdots - \gamma_{L2}$$

$$\dot\gamma_{12} = \dot\gamma_2 - \dot\gamma_{22} - \cdots - \dot\gamma_{L2} \qquad (21)$$

$$\cdots$$

$$\gamma_{1p} = \gamma_p - \gamma_{2p} - \cdots - \gamma_{Lp}$$

$$\dot\gamma_{1p} = \dot\gamma_p - \dot\gamma_{2p} - \cdots - \dot\gamma_{Lp} \qquad (22)$$

The joint probability density function of SNRs $\gamma_1,\gamma_2,\ldots,\gamma_p$ and their derivatives $\dot\gamma_1,\dot\gamma_2,\ldots,\dot\gamma_p$ is:

$$p_{\gamma_1\gamma_2\cdots\gamma_p\dot\gamma_1\dot\gamma_2\cdots\dot\gamma_p}(\gamma_1,\gamma_2,\ldots,\gamma_p,\dot\gamma_1,\dot\gamma_2,\ldots,\dot\gamma_p) =$$

$$= \int d\gamma_{21}\int d\dot\gamma_{21}\int d\gamma_{31}\int d\dot\gamma_{31}\cdots\int d\gamma_{L1}\int d\dot\gamma_{L1}\times$$

$$\times\int d\gamma_{22}\int d\dot\gamma_{22}\int d\gamma_{32}\int d\dot\gamma_{32}\cdots\int d\gamma_{L2}\int d\dot\gamma_{L2}\times$$

$$\cdots\int d\gamma_{2p}\int d\dot\gamma_{2p}\int d\gamma_{3p}\int d\dot\gamma_{3p}\cdots\int d\gamma_{Lp}\int d\dot\gamma_{Lp}\times$$

$$\times\, p_{\gamma_{11}\gamma_{21}\cdots\gamma_{L1}\gamma_{12}\gamma_{22}\cdots\gamma_{L2}\cdots\gamma_{1p}\gamma_{2p}\cdots\gamma_{Lp}\dot\gamma_{11}\dot\gamma_{21}\cdots\dot\gamma_{L1}\dot\gamma_{12}\dot\gamma_{22}\cdots\dot\gamma_{L2}\cdots\dot\gamma_{1p}\dot\gamma_{2p}\cdots\dot\gamma_{Lp}}(\gamma_1 - \gamma_{21} - \cdots - -\gamma_{L1},\gamma_{21},\ldots,\gamma_{L1},\gamma_2 - \gamma_{22} - \cdots - \gamma_{L2},$$

$$\gamma_{22},\gamma_{32},\ldots,\gamma_{L2},\ldots,\gamma_p - \gamma_{2p} - \cdots - \gamma_{Lp},\gamma_{2p},\ldots,\gamma_{Lp},$$

$$\dot\gamma_1 - \dot\gamma_{21} - \cdots - \dot\gamma_{L1},\dot\gamma_{21},\ldots,\dot\gamma_{L1},$$

$$\dot\gamma_2 - \dot\gamma_{22} - \cdots - \dot\gamma_{L2},\dot\gamma_{22},\dot\gamma_{32},\ldots,\dot\gamma_{L2},\ldots,$$

$$\dot\gamma_p - \dot\gamma_{2p} - \cdots - \dot\gamma_{Lp},\dot\gamma_{2p},\ldots,\dot\gamma_{Lp}). \qquad (23)$$

Conclusions

In this paper the diversity system with two and *L* branches and predetection MRC combining is considered. The statistical characteristics of the signal at the combiner output at two and more time instants are derived. These characteristics are important when the signals at the combiner input are correlated in time. That is the case the Gaussian noise at the combiner input is correlated. Because of that it is necessary to determine the joint probability density functions of the symbols at the input at two time instants.

The probability density of the signal at the combiner output at two and more time instants is calculated. The joint probability density of the signal and its derivative at the combiner output at two and more time instants is calculated also. The autocorrelation function at the combiner output can be calculated by the joint probability density of the signal at two time instants. The spectral power density can be calculated by the autocorrelation function if we use Winer-Hichin theorem. The autocorrelation function and the spectral power density are the Fourier transformation peer. The joint probability density function of the signals and theirs derivatives can be used for the different coded signals calculations, also.

References

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4. Analysis of Hybrid Selection/Maximal-Ratio Combining in Rayleigh Fading // IEEE Transactions on Communications. – December 1999. – Vol. 47, No. 12.

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The MRC diversity system with two and L branches will be considered. The signal at the combiner output will be observed at two and more time instants. This is important in the case the noise is correlated. The joint probability density function of the signal at two and more time instants will be calculated. The joint probability density function of the signal and its derivative at two and more time instants will be calculated also. Ill. 3, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

Д. Крстич, М. Стефанович. Статистические характеристики выходного сигнала системы диверсификации MRC // Электроника и электротехника. – Каунас: Технология, 2007. – № 1(73). – С. 45–48.

Анализируется система диверсификации MRC с двумя выходами. Сигнал на входе суммирующего элемента исследуется в двух и более моментах времени. Это важно, когда помехи имеют корреляционный характер. Вычисляется суммарная функция плотности вероятности сигнала в различных моментах времени. Также вычисляется суммарная функция плотности вероятности сигнала и его производной. Ил. 3, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Krstić, M. Stefanović. MRC diversifikavimo sistemos išėjimo signalo statistinės charakteristikos // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 1(73). – P. 45–48.

Nagrinėjama MRC diversifikavimo sistema su dviem ir L išsišakojimų. Signalas sumuojančiojo elemento įėjime nagrinėjamas dviem ir daugiau laiko momentais. Tai svarbu, kai triukšmas yra koreliacinio pobūdžio. Apskaičiuojama bendra signalo tikimybės tankio funkcija įvairiais laiko momentais. Taip pat apskaičiuojama bendra signalo ir jo išvestinės tikimybės tankio funkcija. Il. 3, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).