A B S T R A C T

This paper considers the average probability of error for various modulation schemes with diversity and adaptable slow Rayleigh fading in Gaussian noise.

The average is formed over the instantaneous receiver signal-to-noise ratio after combining. Binary constant amplitude digital modulation schemes described by Aulin and Sundberg are considered. The signals CMP - continuous phase modulation, are transmitted over an adaptable slow nonselective Rayleigh fading channel - exponential model with bound conditions. The detection is assumed with coherent MSK-type receivers. Diversity is used and the branch fading is assumed independent. The error probability is calculated for several modulation schemes, including TFM 5, Gaussian MSK and 3RC for diversity with selection combining. The obtained results are significant and have practical appliations in the case of newly designed digital land mobile radio systems.

1. INTRODUCTION

In the last years the application of bandwidth efficient constant amplitude modulation schemes to digital land mobile radio have been taken into consideration.

The transmission of information over radio channels with multiple changing propagation paths is typically subject to random time variation, or fading, of the received signal strengh. When digital information is to be transmitted over such a channel, the fading produces random variation of probabilities of error.

In this paper, we will consider adaptable slow Rayleigh fading, i. e, exponential model with bound conditions. are digital land mobile radio links which must consider "depth fading" events. By slow fading we mean that the time varying signal-to-noise ratio is approximately constant over couple of transmitted bits (symbols), say 5-10 bits. The density function for that signal-to-noise ratio is

$$R(\eta) = \begin{cases} \dfrac{1}{\eta_0 - \eta^*} \exp\left[-\dfrac{\eta - \eta^*}{\eta_0 - \eta^*}\right] & \eta \geq \eta^* \\ 0 & \eta < \eta^* \end{cases}$$

with bound conditions

$$\eta_0 = F . \eta^* = \int_{\eta^*}^{\infty} \eta . R(\eta) . d\eta \qquad \text{and} \qquad \int_{\eta^*}^{\infty} R(\eta) . d\eta = 1$$

where F is the limiting parameter of the "depth fading", and the values to consider are limited to 30 or 40 dB. With this model is possible to consider unlikely isolated fades.[1]

Coherent transmission will be considered. A family of binary constant amplitude digital modulation schemes are defined by the transmitted signal

$$s(t,\underline{\alpha}) = \sqrt{\frac{2E}{T}} \cos\left(2\pi f_0 t + \varphi(t,\underline{\alpha})\right)$$

where $E = E_b$ is the symbol energy, T is the symbol time and f_0 is the carrier frequency. The information carrying phase is

$$\varphi(t,\underline{\alpha}) = 2\pi h \sum_{i=-\infty}^{i=+\infty} \alpha_i \cdot q(t-iT)$$

where $\underline{\alpha} = \alpha_{n-2}, \alpha_{n-1}, \alpha_n, \alpha_{n+1}, \alpha_{n+2}, \ldots\ldots$ is a sequence of independent binary symbols and h is the modulation index. The phase response is defined by

$$q(t) = \int_{-\infty}^{t} g(\tau)\, d\tau$$

where g (t) is a time limited pulse defined in instantaneous frequency.

It is shown in the literature that the $h = 1/2$ schemes can be detected with good efficiency in an MSK-type detector and MSK receiver with modified filter were proposed for partial response schemes by Aulin and Sundberg [2].

The average error probably P for the partial response scheme is

$$P(\eta) = P(E_b/N_0) = \sum_{i=1}^{i=m} C_i/\sqrt{2} \cdot \int_{\sqrt{d_i^2 E_b/N_0}}^{\infty} \exp(-t^2/2)\, dt$$

where d_i^2 is the squared normalized Euclidean "distance" associated with a signal corresponding to data sequence

We have used $m = 2^{N_T + L-2}$ in the calculations below and independent data symbols with $p(-1)=p(+1)= 1/2$, then $C_i = 1/m$. The parameters d_i^2 are independent of signal-to-noise ratio. They only depend on the data sequence. We derive analytical average BER for the adaptable fading case. Examples for specific transmitted signal formats - Tamed Frequency Modulation pulse, Raised cosine pulse and the Gaussian MSK pulse, and comparisons with other works are illustrated.

2. ERROR PROBABILITY FOR DIVERSITY WITH SELECTION COMBINING.

We assume ideal selection combining. Let η_k be the instantaneous signal-to-noise ratio in branch k.

In this case, the probabily density function for the ideal selection combiner output signal-to-noise ratio η is

$$f(\eta)= \begin{cases} \dfrac{M}{\eta_0-\eta^*} \cdot \exp\left(-\dfrac{\eta-\eta^*}{\eta_0-\eta^*}\right)\left[1-\exp\left(-\dfrac{\eta-\eta^*}{\eta_0-\eta^*}\right)\right]^{M-1} & ; \eta>\eta^* \\ 0 & ; \eta<\eta^* \end{cases}$$

where η_0 is the average signal-to-noise ratio per branch and M is the number of branches. The average receiver output signal-to-noise ratio is in this case

$$E\{\eta\}= (\eta_0-\eta^*) \sum_{k=1}^{k=M} \frac{1}{k} + \eta^*$$

The average error probability is

$$P= \int_{\eta^*}^{\infty} f(\eta).P(\eta).d\eta$$

$$= \sum_{i=1}^{i=m} \left\{ \frac{C_i}{2} \sqrt{\frac{d_i^2}{2}} \cdot \sum_{t=0}^{t=M} \left[(-1)^t \cdot \binom{M}{t} \cdot \frac{\exp\left(\frac{t \cdot \eta^*}{\eta_0 - \eta^*}\right) \cdot \operatorname{erfc} \sqrt{\left(\frac{t}{\eta_0 - \eta^*} + \frac{d_i^2}{2}\right) \eta^*}}{\sqrt{\frac{t}{\eta_0 - \eta^*} + \frac{d_i^2}{2}}} \right] \right\} \qquad (1)$$

with $\operatorname{erfc}(x) \cong \dfrac{\exp(-x^2)}{x\sqrt{\pi}} \qquad (x > 3)$

3. NUMERICAL RESULTS

The receiver considered here is S.P.A.M. type (Aulin). We present numerical results about

- TFM 5 with $N_T = 6$
- Gaussian MSK with $N_T = 6$ and $B_b \cdot T = 0.20$
- 3 RC with $N_T = 5$

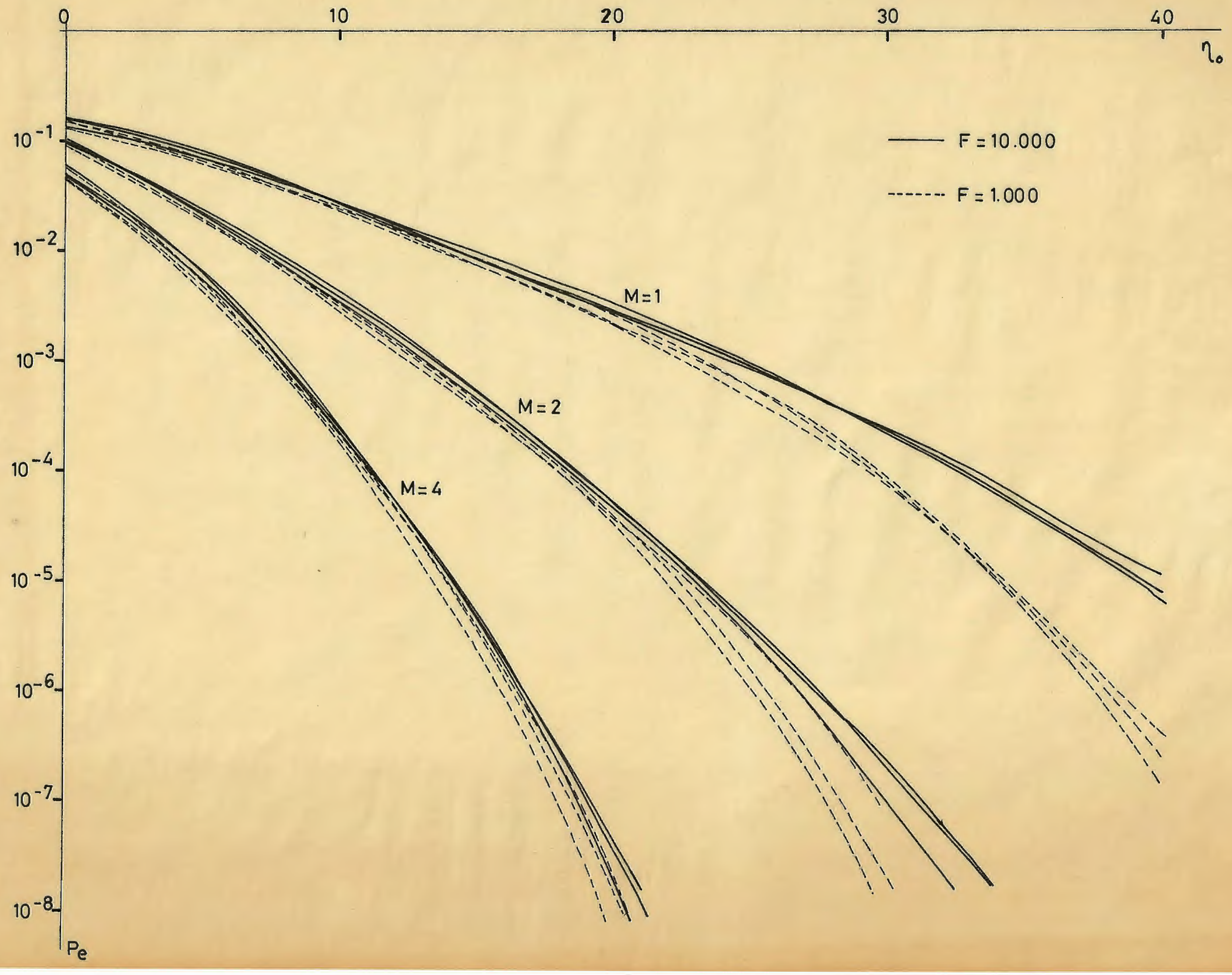
The average probability of error is obtained for two cases: F = 1000 and F = 10000 (30 dB and 40 dB, respectivaly).

4. DISCUSSION AND CONCLUSION

Comparisons are made of $\mathcal{P}$ among the three schemes and for M = 1,2, and 4 Sundberg's results [3].

The curves of performance of 3RC, GMSK and TFM 5 was obtained by equation (1). These curves are computed for twenty different values of average BER from 10 dB to 40 dB.

From this analysis, an ideal system working in "squelch conditions" with CPM schemes have a BER better than CPFSK (rational modulation index "h") schemes in the same fading conditions. For reliable transmission with M=4 and with any one of three schemes, 3RC, GMSK, and TFM 5 are posible digital land mobile radio systems.



0
10
20
30
40
η₀
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
Pe
F = 10.000
F = 1.000
M = 1
M = 2
M = 4

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