MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

TRANSMITTER DIVERSITY FOR BINARY PSK MOBILE RADIO

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ABSTRACT

To combat the effects of multipath fading in mobile radio, a transmitter diversity scheme for binary PSK is investigated. In the transmitter, three carriers with uniform separation equal to the bit rate and three separate antennas are used.

I. INTRODUCTION

Digital modulation schemes have become of interest in UHF and microwave radio communications [1]. Diversity is an effective technique for combating multipath Rayleigh fading encountered in these channels [2]-[4]. Transmitter diversity with no feedback control loops is suitable for transmission systems requiring simplified receiver structure [5].

In this paper, a transmitter diversity scheme employing binary PSK modulation is considered. In this scheme, three PSK signals, with the same binary information but different carrier frequencies, are transmitted from separate antennas.

II. SYSTEM MODEL DESCRIPTION

Consider a binary PSK system in which the transmitter has three branches as shown in Fig. 1. The input binary data (± 1) is used to modulate simultaneously three carriers (ω_c and $\omega_c \pm \Delta\omega$) and the modulated carriers are transmitted from separate antennas through multipath channels.

Within any signaling interval of length T, the receiver composite input signal and its components can be represented as follows :

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$$r(t) = r_c(t) + n(t) \tag{1}$$

$$\begin{aligned} r_c(t) &= r_1(t) + r_2(t) + r_3(t) \\ &= A_c(t) \cos \varkappa(t) \end{aligned} \tag{2}$$

$$r_1(t) = \rho_1 A \cos (\omega_c t + \phi_s + \theta_1) \tag{3}$$

$$r_2(t) = \rho_2 kA \cos [(\omega_c+\Delta\omega)t + \phi_s + \theta_2] \tag{4}$$

$$r_3(t) = \rho_3 kA \cos [(\omega_c-\Delta\omega)t + \phi_s + \theta_3] \tag{5}$$

$$\varkappa(t) = \omega_c t + \phi_s + \psi_c(t) \tag{6}$$

$$A_c(t) = A \Big[\rho_1^2 + k^2(\rho_2^2+\rho_3^2) + 2\rho_1\rho_2 k \cos (\Delta\omega t+\theta_2-\theta_1) + 2\rho_1\rho_3 k \cos (-\Delta\omega t+\theta_3-\theta_1) + 2\rho_2\rho_3 k^2 \cos (2\Delta\omega t+\theta_2-\theta_3)\Big]^{1/2} \tag{7}$$

$$\psi_c(t)=\text{arc tan}\left[\frac{\rho_1\sin\theta_1+\rho_2 k\sin(\Delta\omega t+\theta_2)+\rho_3 k\sin(-\Delta\omega t+\theta_3)}{\rho_1\cos\theta_1+\rho_2 k\cos(\Delta\omega t+\theta_2)+\rho_3 k\cos(-\Delta\omega t+\theta_3)}\right] \tag{8}$$

n(t) is the additive white Gaussian zero-mean noise with single sided power spectral density N_o. ϕ_s(0 or π) is the carrier phase modulation caused by the input data. ρ_1, ρ_2, and ρ_3 are statistically independent identically distributed random processes assumed constant (slowly varying) over the considered signaling interval T each with Rayleigh probability density function (pdf). θ_1, θ_2, and θ_3 are statistically independent identically distributed random processes assumed constant (slowly varying) over the considered signaling interval each with uniform pdf over a range of 2π. The factor k controls the transmitter power distribution between the central and the two side carriers.

The carrier recovery can be performed using a squarer followed by a band pass filter and divider as shown in Fig. 1(c). If we neglect noise the squarer output will be

$$\begin{aligned} r_c^2(t) &= A_c^2(t) \cos^2 \varkappa(t) \\ &= 0.5\, A_c^2(t) \Big\{1 + \cos [2\omega_c t + 2\psi_c(t)]\Big\} \end{aligned} \tag{9}$$

since $2\phi_s$ = 0 or 2π. The BPF passes only the double frequency component and the divider output can be written in the form

$$u_{ref}(t) = 2 \cos [\omega_c t + \psi_c(t)] \tag{10}$$

III. BER PERFORMANCE ANALYSIS

The decision variable is given by

$$v = \int_0^T r(t)\, u_{ref}(t)\, dt$$
$$= v_s + v_n \tag{11}$$

where

$$v_s = \int_0^T A_c(t) \cos\left[\omega_c t+\phi_s+\psi_c(t)\right]\, 2\cos\left[\omega_c t+\psi_c(t)\right] dt$$
$$= \pm\ \alpha AT \quad \text{if } \omega_c T = 2m\pi \quad (m \text{ integer}) \text{ and } \Delta\omega T = 2\pi \tag{12}$$
$$\alpha^2 = \rho_1^2 + k^2(\rho_2^2 + \rho_3^2) \tag{13}$$
$$v_n = \int_0^T n(t)\, 2\cos\left[\omega_c t + \psi_c(t)\right] dt \tag{14}$$

v_n is a Gaussian variable with zero mean and variance $N_o T$.

The bit error rate (BER) is given by

$$P_e = \Pr\left(v < 0 \,/\, \phi_s = 0\right)$$
$$= 0.5\ \mathrm{erfc}\left(\sqrt{\gamma_b}\right) \tag{15}$$

where

$$\gamma_b = \alpha^2 E_b / N_o, \qquad E_b = A^2 T/2 \tag{16}$$

Let us define

$$Z_1 = \rho_1^2,\ Z_2 = k^2 \rho_2^2,\ Z_3 = k^2 \rho_3^2,\ Z = Z_1+Z_2+Z_3 = \alpha^2 \geq 0 \tag{17}$$

The pdf´s of Z_1, Z_2, and Z_3 are as follows

$$p_{Z_1}(z_1) = (1 / \overline{\rho^2}) \exp(- z_1 / \overline{\rho^2}), \quad z_1 \geq 0 \tag{18}$$
$$p_{Z_2}(z_2) = (1 / k^2\overline{\rho^2}) \exp(- z_2 / k^2\overline{\rho^2}), \quad z_2 \geq 0 \tag{19}$$
$$p_{Z_3}(z_3) = (1 / k^2\overline{\rho^2}) \exp(- z_3 / k^2\overline{\rho^2}), \quad z_3 \geq 0 \tag{20}$$

where $\overline{\rho^2} = \overline{\rho_1^2} = \overline{\rho_2^2} = \overline{\rho_3^2}$. Z_1, Z_2, and Z_3 are independent random variables and $\gamma_b = Z\, E_b / N_o \geq 0$, hence we can get the pdf of γ_b

in the following form :

$$p(\gamma_b) = (1/\gamma_c)\ \exp\ (-\gamma_b/\gamma_c), \quad k = 0$$

$$p(\gamma_b) = \left[1/\gamma_c(1-k^2)^2\right]\left[e^{-\gamma_b/\gamma_c} - e^{-\gamma_b/k^2\gamma_c} - (1-k^2)\left(\frac{\gamma_b}{k^2\gamma_c}\right) e^{-\gamma_b/k^2\gamma_c}\right],$$

$$k \neq 0\ , \ k \neq 1$$

$$p(\gamma_b) = (1/2\gamma_c)\ (\gamma_b/\gamma_c)^2\ \exp\ (-\gamma_b/\gamma_c), \quad k = 1 \tag{21}$$

where

$$\gamma_c = \overline{\rho^2}\ E_b\ /\ N_o \tag{22}$$

The average BER is then given by

$$\overline{P_e} = \int_0^{\infty} 0.5\ \mathrm{erfc}\left[\sqrt{\gamma_b}\right]\ p(\gamma_b)\ d\gamma_b$$

$$= 0.5\left[1 - \sqrt{\gamma_c/(1+\gamma_c)}\right], \quad k = 0$$

$$= 0.5\left[1 - \frac{1}{(1-k^2)^2}\sqrt{\gamma_c/(1+\gamma_c)} + \frac{k^2(2-k^2)}{(1-k^2)^2}\sqrt{k^2\gamma_c/(1+k^2\gamma_c)}\right.$$

$$\left. + 0.5\left(\frac{k^2}{1-k^2}\right)\left(\frac{1}{1+k^2\gamma_c}\right)\sqrt{k^2\gamma_c/(1+k^2\gamma_c)}\right], \quad k \neq 0\ , \ k \neq 1$$

$$= 0.5\left\{1 - \sqrt{\gamma_c/(1+\gamma_c)}\left[1 + 0.5(1+\gamma_c)^{-1} + 0.375(1+\gamma_c)^{-2}\right]\right\}, \quad k = 1 \tag{23}$$

Fig. 2 shows the dependence of the average BER on the average input carrier-to-noise ratio (CNR) given by

$$\gamma_{in} = \gamma_c(1 + 2k^2) \tag{24}$$

for different values of k. The best performance is obtained when the available transmitter power is divided equally between the three carriers (i.e., $k = 1$). The diversity gain for a BER of 10^{-3}, defined as the CNR difference between a diversity and non-diversity case, is about 12.5 dB (for $k = 1$). The diversity gain increases by 7 dB with each BER drop by 10 for BER $\leq 10^{-3}$.

The required values of γ_{in} for BER of 10^{-3} and 10^{-6} are 11 dB and 21.5 dB, respectively (k = 1). The price paid to achieve the diversity gain is the increased complexity in the transmitter and the increased (doubled) bandwidth of the transmitted signal. The conventional binary PSK receiver is applied here.

IV. CONCLUSION

A transmitter diversity scheme has been investigated for binary PSK mobile radio. In this scheme, the same binary information is used to modulate simultaneously three carriers uniformly spaced by the bit rate. The modulated carriers are transmitted by separate antennas. A binary PSK receiver with a single antenna is used to modulate the signal. The BER performance was determined by theoretical analysis. The best performance occurs when the available transmitter power is divided equally between the three carriers. Results show that the diversity scheme has a gain of 12.5 dB and 33.5 dB at BER of 10^{-3} and 10^{-6}, respectively.

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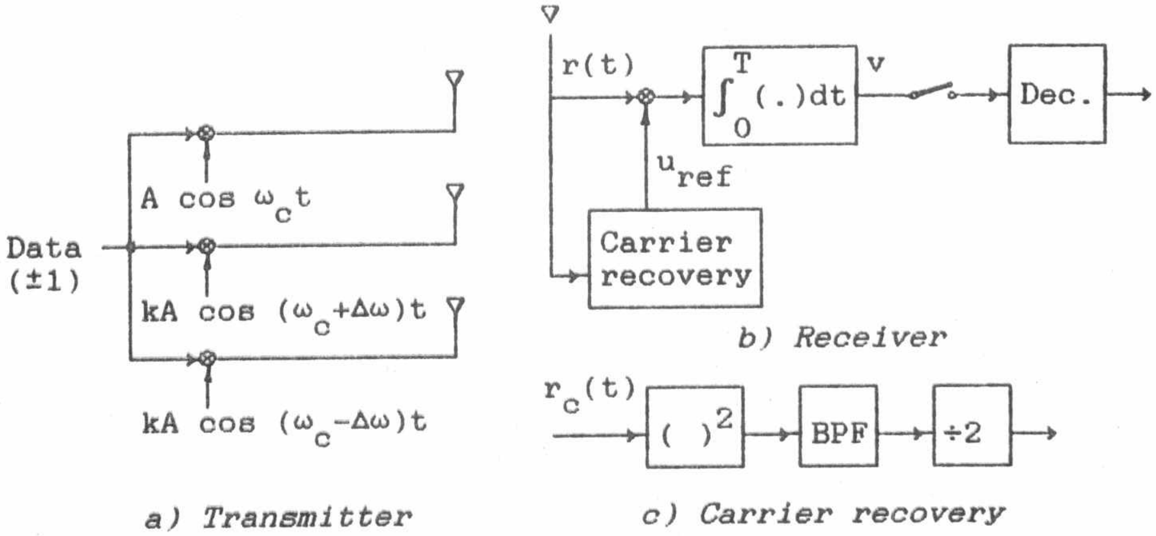

Fig. 1 System model

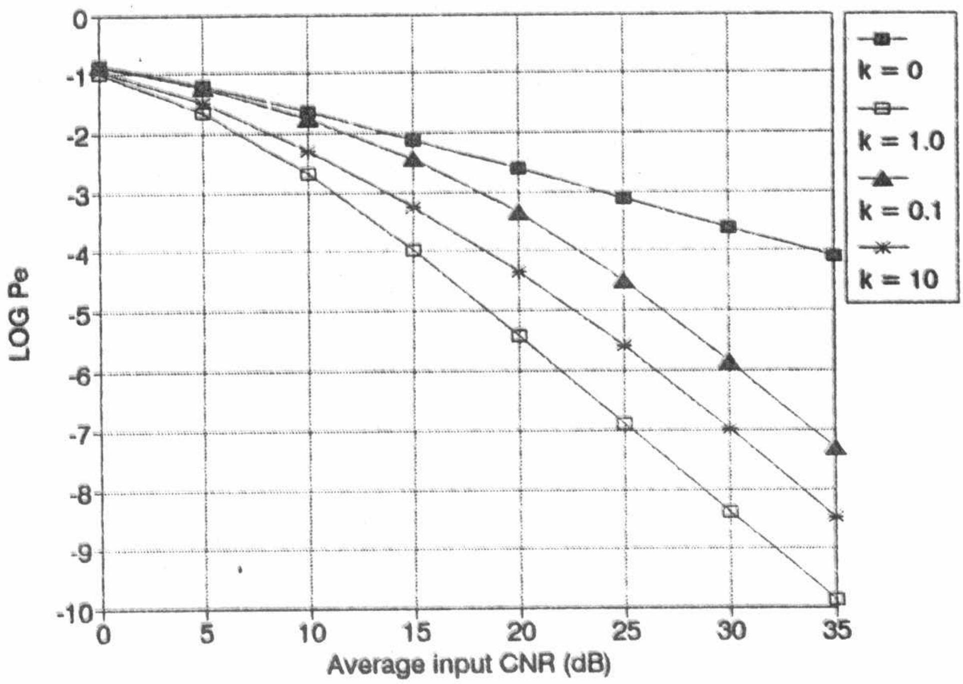

Fig. 2 BER Performance