the 2DEG density of about $10^{15}\,m^{-2}$, while the mobility was about $0{\cdot}8\,m^2\,V^{-1}\,s^{-1}$. Given the low carrier concentration, the mobility result is comparable to that achieved in other 2DEG structures where the GaAs layer has been grown on the modulation doped layer of AlGaAs.[10] In future designs the precise collector barrier profile will be altered to increase this transfer efficiency. Even allowing for possible parallel conduction in the collector barrier at room temperature in our present structure, the base–base resistance of 800 Ω can be scaled down by improving the aspect ratio of our device. We note that this resistance increases to around 1 kΩ at 77 K and to around 10 kΩ at 4 K, where the parallel conduction is likely to be frozen out. These results are also consistent with the relatively low carrier density and mobility from an inverted heterojunction.

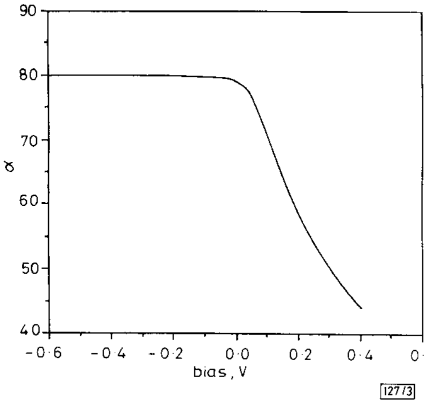

Fig. 3 *Base transfer efficiency ($\alpha = dI_C/dI_E$) as a function of base–collector bias at 300 K*

Experience with microwave high-electron mobility transistors that use a 2DEG suggest that we could achieve a base resistance of less than 300 Ω per square, which is sufficient to achieve F_T and F_{max} in excess of 100 GHz where an identical geometry to the present one, but with the horizontal feature sizes in Fig. 1*c* scaled down by a factor of 100 is used. One might even anticipate some of the advantages seen in the heterojunction bipolar transistor from such scaling down.[11] The precision required to expose the base and achieve a shallow ohmic contact is nontrivial. We have found our large area devices prone to early failure from shorting to the collector layer if we subject them to strong biasing. This problem may also be eased with small area devices. As a first step, the results presented here prove the validity of the 2DEG base hot electron transistor.

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OUTAGE PROBABILITY ANALYSIS FOR MICROCELL MOBILE RADIO SYSTEMS WITH COCHANNEL INTERFERERS IN RICIAN/RAYLEIGH FADING ENVIRONMENT

Indexing terms: Radio links, Interference

A microcell mobile radio system where the desired signal within a cell experiences Rician fading while interfering signals from cochannel cells experience Rayleigh fading is studied. This model is named a Rician/Rayleigh fading environment. Expressions of outage probabilities are presented for the mobile radio system in the Rician/Rayleigh fading environment.

Introduction: In a mobile radio system, adequate signal strength and signal-to-interference ratio (SIR) are essential for successful communications. Outage probability defined as the probability of failing to simultaneously achieve a signal-to-noise ratio (SNR) and a signal-to-interference ratio sufficient to give satisfactory reception is an appropriate measure to evaluate the performance of a mobile radio system. A simpler analysis may need only one of the two, SNR and SIR, requirements for system evaluation.

The outage probabilities based on either SNR or SIR have been reported.[1,2] Studies considering both SNR and SIR have also been reported.[3–6] Although previous studies on outage probabilities deal with a variety of channel models, including Rayleigh fading,[5] log-normal shadowing,[3] and superimposed Rayleigh fading and log-normal shadowing,[4,6] the Rician fading environment has not been considered. In a mobile radio system, a direct line of sight accompanied by a diffused signal component may exist.[7] The microcell mobile communication system is a particular example of such signal environment.

This letter presents expressions for outage probabilities of a microcell mobile radio system in which the transmission from a base station is received at a mobile in the presence of cochannel interference signals and both SNR and SIR requirements are under considerations. The desired signal is assumed to be Rician faded implying that a direct line-of-sight signal component exists in within-cell transmission. The interference signals are assumed to be Rayleigh faded because a direct line of sight between cochannel cells is unlikely to exist. This is called a Rician/Rayleigh fading environment. Future personal communications are likely to operate in microcell systems where the Rician/Rayleigh fading environment becomes important.

Fading model: In the Rician/Rayleigh fading environment, the envelope of the desired signal has Rician probability density function (PDF). The PDF of the corresponding instantaneous signal power, x, is found to be

$$p_x(x) = \frac{1}{X} \exp\left(-\frac{2x + s^2}{2X}\right) I_o\left[\frac{\sqrt{(2x)}s}{X}\right] \tag{1}$$

where $I_o(.)$ is the modified Bessel function of the first kind and order zero. The mean signal power is $X + s^2/2$, where X is contributed by the diffused signal component and $s^2/2$ by the direct line-of-sight signal component.

The cochannel interferer is Rayleigh faded and its power is exponentially distributed. For the ith interferer, the PDF of the interference power, y_i, can be expressed as

$$p_{y_i}(y_i) = \frac{1}{Y_i} \exp\left(-\frac{y_i}{Y_i}\right) \tag{2}$$

where Y_i is the mean power of the ith interferer.

Single interferer: In the case of single interferer, considering both the SNR requirement (assuming that the minimum required desired signal power is $R_N X$) and the SIR requirement (assuming that the signal-to-interference protection ratio is R_I), the outage probability is

$$\begin{aligned} P_{out} &= 1 - \text{prob}\,(x > R_N X, x/y_1 > R_I) \\ &= 1 - \int_{R_N X}^{\infty} \left[\int_0^{x/R_I} p_{y_1}(y_1)\, dy_1\right] p_x(x)\, dx \end{aligned} \tag{3}$$

Detailed derivation gives

$$\begin{aligned} P_{out} = {} & 1 - Q[\sqrt{(2a)}, \sqrt{(2R_N)}] \\ & + \frac{R_I}{R_I + b_1} \exp\left(-\frac{ab_1}{R_I + b_1}\right) \\ & \times Q\left\{\sqrt{\left(\frac{2aR_I}{R_I + b_1}\right)}, \sqrt{\left[2\left(1 + \frac{b_1}{R_I}\right)R_N\right]}\right\} \end{aligned} \tag{4}$$

where

$$a = \frac{s^2}{2X} \tag{5}$$

$$b_1 = \frac{X}{Y_1} \tag{6}$$

and $Q(.,.)$ is the Q-function.

If noise is negligible and interference is the major concern (e.g., interference-limited systems), eqn. 4 can be simplified by assuming $R_N = 0$ and we have

$$P_{out} = \frac{R_I}{R_I + b_1} \exp\left(-\frac{ab_1}{R_I + b_1}\right) \tag{7}$$

Fig. 1 shows the numerical results of eqn. 7. The curve with $a = 0$ shows the outage probability when the desired signal is assumed to be Rayleigh faded. It is indicated that, in a microcell system where a direct line-of-sight component exists, the assumption that the desired signal is Rayleigh faded gives a pessimistic result.

Multiple interferers: Assume that there are I mutually independent Rayleigh faded interferers, each with mean power Y_i ($i = 1, 2, \ldots, I$). The instantaneous power of each interferer is an exponentially distributed random variable with PDF given in eqn. 2. The resulting total interference power, y, is a sum of the I instantaneous powers. The PDF of y is found to be

$$\begin{aligned} p_y(y) = {} & \sum_{i=1}^{I} Y_i^{I-2} \exp\left(-\frac{y}{Y_i}\right) \\ & \times \prod_{j=1, j\neq i}^{I} \frac{1}{Y_i - Y_j} \end{aligned} \tag{8}$$

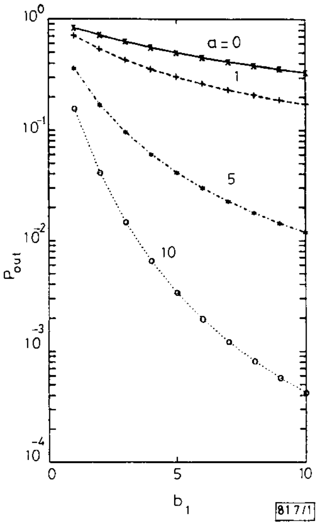

Fig. 1 *Outage probability, single interferer case*
$R_N = 0$; $R_T = 5$

The outage probability in presence of I interferers is given by

$$\begin{aligned} P_{out} &= 1 - \text{prob}\,(x > R_N X, x/y > R_I) \\ &= 1 - \sum_{i=1}^{I} Y_i^{I-2} \\ &\quad \times \left\{\int_{R_N X}^{\infty} \left[1 - \exp\left(-\frac{x}{R_I Y_i}\right)\right] p_x(x)\, dx\right\} \\ &\quad \times \prod_{j=1, j\neq i}^{I} \frac{1}{Y_i - Y_j} \end{aligned} \tag{9}$$

The above equation can be numerically evaluated. For the special case with $R_N = 0$, eqn. 9 can be simplified to a closed form

$$\begin{aligned} P_{out} = {} & 1 - \sum_{i=1}^{I} \left[1 - \frac{R_I}{R_I + b_i} \exp\left(-\frac{ab_i}{R_I + b_i}\right)\right] \\ & \times \prod_{j=1, j\neq i}^{I} \frac{b_j}{b_j - b_i} \end{aligned} \tag{10}$$

where

$$b_i = \frac{X}{Y_i} \tag{11}$$

Eqns. 9 and 10 are valid only for $Y_i \neq Y_j$ when $i \neq j$, i.e., different interferers have different mean power. For the cases where some interferers have the same mean power, different expression for the outage probability is needed. For the special case where all the interferers have the same mean power, the expression may be derived as follows.

The PDF of the total interference power is given by the I-fold convolution of independent and identical exponential PDF. This results in a gamma PDF of the form

$$p_Y(y) = \frac{y^{I-1}}{Y_1^I (I-1)!} \exp\left(-\frac{Y}{Y_1}\right) \tag{12}$$

The outage probability can be found to be

$$P_{out} = \frac{R_I}{R_I + b_1} \exp\left(-\frac{ab_1}{R_I + b_1}\right) \times \sum_{k=0}^{I-1} \frac{b_1^k}{(R_I + b_1)^k} \times \sum_{m=0}^{k} C_k^{k-m} \frac{1}{m!} \left(\frac{aR_I}{R_I + b_1}\right)^m \tag{13}$$

R_N has been assumed to be zero in the derivation of eqn. 13.

Fig. 2 shows the outage probability when there are two interferers. The mean total interference power is assumed to be Y and $b = X/Y$. The case with one dominant interferer ($Y_1 = Y$, $Y_2 = 0$) and the equal interference case ($Y_1 = Y_2 = 0{\cdot}5Y$) are included in the Figure. They give approximately the same result. This also applies to the system with more interferers (see Fig. 3).

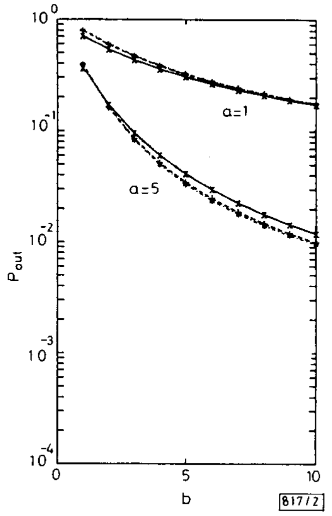

Fig. 2 *Outage probability, two interferer case*
$R_N = 0$; $R_I = 5$

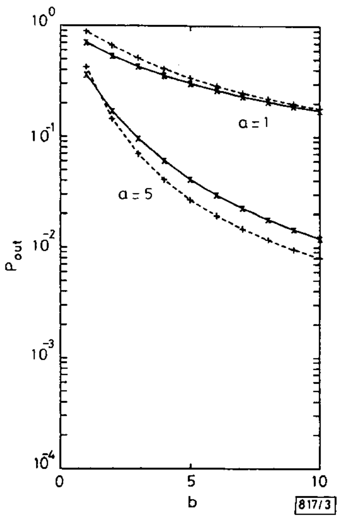

Fig. 3 *Outage probability, multiple interferer case*
$R_N = 0$; $R_I = 5$

Conclusions: A microcell mobile radio environment, in which the desired signal is Rician distributed while the cochannel interference signals are Rayleigh distributed, was studied. The expressions for the outage probability are derived and numerical results are presented. Several observations are made. First, the outage probability in a microcell system with Rician/Rayleigh fading environment is lower than that in the case of medium to large cell mobile radio systems where both the desired and interfering signals are assumed to be Rayleigh faded. Second, the single interferer and multiple interferers are found to have approximately the same effect on outage probabilities provided that the mean total interference power is fixed.

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EFFECT OF *n*-TYPE DOPANT SPECIES ON THE COMPENSATING EFFECTS OF OXYGEN IMPLANTATION IN GaAs

Indexing terms: Semiconductor devices and materials, Gallium arsenide, Ion implantation, Doping

The effect of *n*-type dopant species on the compensating behaviour of oxygen implants has been studied using Hall effect and C/V profiling techniques. Stronger compensation is retained if silicon rather than selenium is used to form the *n*-type layer. The compensation has been separated into damage related and oxygen atom related mechanisms, both of which are shown to be *n*-type dopant sensitive. The dopant sensitivity of the damage related compensation is tentatively described by assuming that localised regions of stoichiometric imbalance are introduced by the oxygen implantation, which promotes activation on the arsenic site. However, the reason for the dopant sensitivity of the oxygen atom related mechanism remains unclear.

Introduction: The use of nondopant ion implantation to produce highly resistive layers in GaAs has proved to be a useful technique by which to electrically isolate devices. Favennec[1] has shown that oxygen implantation can be used to form semi-insulating layers if the dose is above a certain