TWO-BRANCH SPACE DIVERSITY AT THE MOBILE UNIT IN THE UHF BAND: SIGNAL MEASUREMENTS AND SIMULATION RESULTS FOR RICIAN FADING

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1. Introduction

The characteristics of the received signal level for selection, and for switch and stay diversity schemes at the mobile unit have been studied from measurements of received signal level for CW transmission at 910 MHz, and for simulated signals corresponding to different Rician fading conditions.

The data for this study consisted of 121 files of signal recordings in a mixture of medium density urban, low density urban, suburban and open areas as received by a single monopole antenna. Using odometer recording at the mobile unit, the received data in function of time was converted to be in function of position, with a space resolution of $\lambda/20$, thus permitting it to be used for the study of space diversity, and of signal correlation in function of antenna separation: the physical configuration is then the one of two horizontally separated vertical monopoles located along the direction of displacement of the mobile unit.

2. Correlation vs distance in Rician fading

In order to study space diversity in Rician fading and to estimate the minimum or optimal spacing required between two antennas, one can calculate the correlation function $\rho(t)$, defined as below, between two received signals $r_1(t)$ and $r_2(t)$

$$\rho(t) = \frac{\overline{r_1(t)\, r_2(t)} - \overline{r_1(t)}\;\overline{r_2(t)}}{[(\overline{r_1^2(t)} - \overline{r_1(t)}^2) \bullet (\overline{r_2^2(t)} - \overline{r_2(t)}^2)]^{1/2}} \tag{1}$$

Under the hypothesis of a constant speed of the mobile unit, a correlation function versus distance can be obtained. For Rayleigh fading and for a uniform angular distribution of the angle of arrival, this correlation function can be expressed by:

$$\rho(d) = J_0^2(\beta d) \tag{2}$$

where $\beta = 2\pi/\lambda$ and d is the horizontal spacing. The first minimum of this correlation function corresponds to an horizontal separation of about 0.4λ between antennas.

The correlation coefficients in function of distance for antenna separations up to 2λ were calculated, with the length of each recording standardized at 20 meters for adequate statistical reliability. Most of the 121 data files, namely 89, corresponded to open areas, with 21, 7 and 4 data files corresponding to suburban, medium density urban, and urban areas respectively. Statistical analysis for those files, and mainly for those in open areas, shows strong evidence of a Rician behaviour and namely a Direct Ray to Multipath Component Ratio (DMR) which had a mean of 9 dB for the files taken in open areas [1].

The average cross-correlation function obtained for each type of area (open, suburban, low-density urban, urban) is shown on figure 1. The figure indicates that the width of the main lobe is quite narrow, less than 0.4λ, that it would seem to have a tendency to decrease as one moves from an open to an increasingly urban area.

In order to have a statistical basis for comparison, five files corresponding to different Rician statistical characteristics were created for simulation purposes. As shown on table 1, these files cover the whole spectrum from a nearly Rayleigh characteristic with a very small direct component to a strongly Rician channel. Attention should be given to the fact, shown on table 1, that the mean fading length (MFL) increases from 0.54 at one extreme (nearly Rayleigh) to 0.74 for a strongly Rician signal. (Let us recall that the standard deviation for a Rayleigh distributed signal is 0.523).

Figure 2 shows the cross correlation functions corresponding to three of these simulated files (A, C and E). This figure confirms that space diversity, even with small antenna separation of the order of 0.4λ, is indeed very effective even in Rician channels with a strong direct component. It is worth noting that, here also, the width of the first lobe of the cross-correlation function tends to decrease somewhat as one moves from a more Rician to a more Rayleigh situation, the position of the first minimum corresponding closely enough to one half of the mean fading length.

File	(dB)	Standard	Mean Fading Length
A	-40.0	0.523	0.54
B	0.1	0.480	0.66
C	4.9	0.381	0.68
D	8.9	0.268	0.70
E	15.0	0.140	0.74

Table 1

For the sake of completeness, let us specify that, in the above discussion, the following relations apply for the Mean Fading Length (MFL) in Rician fading. The MFL under a level Ψ of a function ψ is defined as

$$MFL(\Psi) = P\{\psi \leq \Psi\}/LCR\{\psi = \Psi\} \tag{3}$$

where LCR is the Level Crossing Rate. When the rapid fading variations are expressed on a linear scale, their mean is unity and one obtains for the MFL under the mean:

$$MFL(1) = \frac{\int_0^1 f_{r_0}(r_0)\,d_{r_0}}{\frac{f}{c}\frac{\sqrt{\pi}}{\alpha} I_o\left(\frac{b}{\alpha^2}\right)\exp\left(\frac{(1+b^2)}{2\alpha^2}\right)} \tag{4}$$

where the numerator term is an integral of a Rice probability density, f and c are the frequency and the light velocity, b and α are the parameters of the Rice distribution, whose standard deviation is given by:

$$\sigma = \sqrt{b^2 + 2\,\alpha^2 - 1} \tag{5}$$

As for the Direct Ray to Multipath Component Ratio (DMR), it is defined as the ratio between the direct ray b and the mean of the multipath (Rayleigh) component

$$DMR = b/a\,\sqrt{\pi/2} \tag{6}$$

3. Signal level distributions with two-branch switching diversity

It is well known that switching diversity offers a convenient means to approach the characteristics offered by ideal selection diversity. The available data has been processed in order to obtain the signal cumulative probability density with ideal two-branch selection diversity and with a two-branch switching diversity system using switch and stay strategy with a -5 dB switching threshold.

Figure 3 shows the results for all available files processed for the condition of a 0.81λ separation between the two receiving antennas (three times the minimum separation), the average correlation coefficient for the whole set of files being 0.15. The three curves of figure 3 correspond to the case without diversity at the left, to ideal selection diversity towards the right and switching diversity in the center. The conclusion is that, even in open areas, with a strong direct component, diversity reception will permit to gain an advantage of 4 to 5 dB.

It is worth noticing that to use a wider separation between antennas of 0.81λ as has been done here instead of a minimum separation of 0.27λ, does not improve results. Measurements, in fact, show the opposite, although the difference does not amount to more the 1 or 2 dB.

Reference

[1] W.C.Y. Lee, Mobile Communications Engineering, McGraw-Hill, New York, 1982.

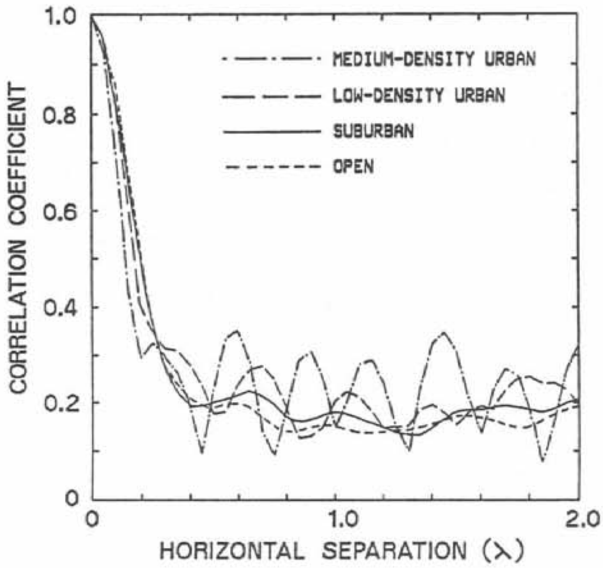

Figure 1

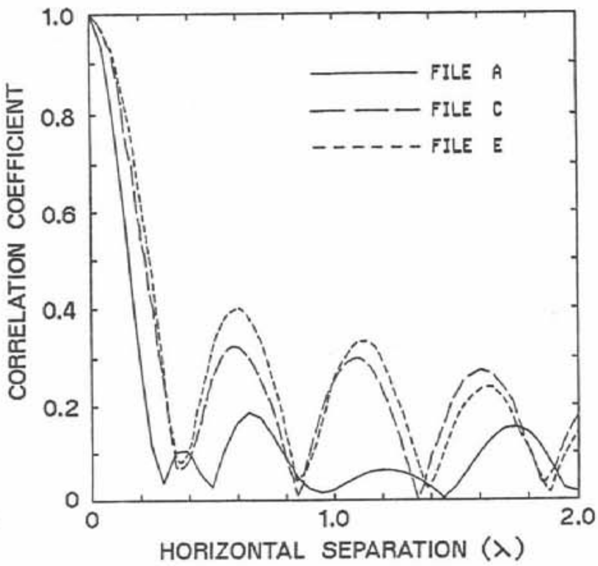

Figure 2

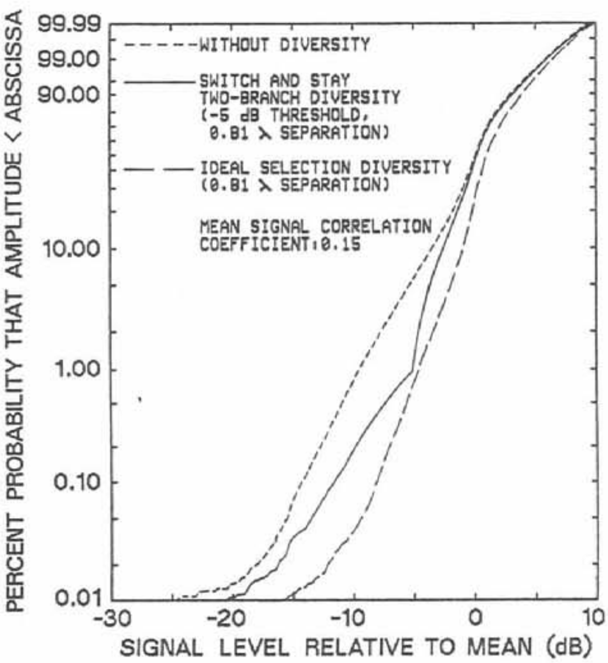

Figure 3