PHASE DIVERSITY ARRAYS FOR MOBILE COMMUNICATION NETWORKS

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Abstract

Diversity reception is a widely used technique in radio communications to reduce signal fading due to complex propagation environments. Fading is caused by multipath propagation of the radio signal in complex environments, which in practice are either downtown areas in large cities or indoor environments. This presentation is focused on the design problem of an antenna array, which could be used for instance as a base station antenna of a radio communications system to provide antenna diversity. Special attention is given to cases, where the phase properties of the array are used to provide diversity in the same time as the radiation pattern of the array is constantly the same for all cases of the phase pattern. This special case of antenna diversity is called phase diversity. The theory in itself is rather general and it can be applied for either linear, planar or 3-dimensional array geometries. A specific case of a planar array, which consists of two by three antenna elements, is presented as an example of a phase diversity array. The fading reduction performance of the array in a true multipath radio signal propagation environment was simulated with UTD-base raytracing radio channel model made by Nokia Telecommunications.

1 Introduction

There are many techniques, which can be used to reduce signal fading problems due to multipath propagation in mobile communication systems. This presentation is focused on diversity arrays that could be used as base station antennas in mobile communication networks. Since the antenna diversity in case of antenna arrays is more of a property of a group of antenna elements than a single antenna element, the analysis of the diversity can be completely based on array theory and the effect of the single element can be in itself neglected. The parameters allowing the diversity can be therefore listed as: amplitude and phase excitations, antenna element locations and polarizations of the antenna elements. Although polarization diversity is a very important form of antenna diversity, polarization properties of the antenna elements are not taken into account in the following theory. Instead, the emphasis of the analysis is on phase diversity characteristics of diversity antennas [1]. For every conceivable array geometry of two or more antenna elements, there are antenna element excitations which correspond to exactly the same amplitude pattern but variant phase patterns. This condition can be considered as a special subspace of antenna element excitations in the full, arbitrary, multidimensional space of element excitations. The existence and definition of this subspace is the starting point in the following analysis. Phase diversity is an attractive case of antenna diversity, since the radiation pattern is totally independent of the chosen diversity array excitations in that case. The unchanging radiation pattern of a base station antenna assists network and frequency planning of mobile communication networks, since it is often necessary to minimize the interference from the neighboring cells of the base station.

2 Theory

Array theory is based on a group of similar antenna elements, where the neighboring elements can be considered as only straightly displaced from each other without rotation. In this case the effect of the antenna group to the radiation pattern can be separated from the effect of the single elements and the far-field radiation pattern of an array antenna can be presented in the following form

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}_0(\mathbf{r}) f_{\mathrm{AF}}(\theta) \tag{1}$$

where $\mathbf{E}_0(\mathbf{r})$ is the radiated electric field produced by the element located at the origin whereas $f_{\mathrm{AF}}(\theta)$ denotes the array factor of the antenna array. It does not affect on the polarization of the radiated field whereas it may have a great effect on the amplitude and phase properties of the array. If we consider an array of only two antenna elements, the array factor can be presented as a function of three array design parameters, and it can be written as

$$f_{\mathrm{AF}}(\theta) = 1 + I_1 e^{j(kd_1 \cos\theta + \delta_1)} \tag{2}$$

where the first term of the sum corresponds to the element at the origin and the second term is due to the other element, whose excitation is defined by the excitation current ratio I_1 and the phase difference parameter δ_1. The antenna elements are separated by the distance d_1. k denotes the free space wave-number $k = 2\pi/\lambda = \omega\sqrt{\epsilon_0\mu_0}$. By taking the absolute value of this complex valued quantity one obtains the corresponding radiation pattern function

$$|f_{\mathrm{AF}}(\theta)| = \sqrt{1 + 2I_1 \cos(kd_1 \cos\theta + \delta_1) + I_1^2} \tag{3}$$

Studying of the properties of this function reveals the phase diversity possibilities of the array. The phase diversity qualities of the array can be observed, if one substitutes the current ratio parameter I_1 by its inverse

$$I_1 \to \frac{1}{I_1}, \tag{4}$$

when it can be noticed that the shape of the radiation pattern function doesn't change; it will only be scaled by a coefficient I_1.

This basic construction of only two antenna elements can be used as a building block for more general antenna array cases. In the same time the same requirement for phase diversity can be utilized in order to get the antenna element excitations irrespective of the chosen array geometry. If the antenna elements are allowed to reside in 3-dimensional space defined by unit vectors $\mathbf{r}_n$, the array factor of 2^N-antenna element array can be written as

$$f_{\mathrm{AF}}(\mathbf{u}_r) = \prod_{n=1}^{N} \left[1 + I_n e^{j(k\mathbf{u}_r \cdot \mathbf{r}_n + \delta_{1n})}\right], \tag{5}$$

where the true antenna element locations are given by sum combinations of vectors $\mathbf{r}_n$ in arbitrary three-dimensional space. Instead of a single angle as before, the array factor is now a function of unit vector $\mathbf{u}_r$, which points towards the observation point. It can be seen from the array factor how this 2^N-element array has N amplitude ratio parameters I_n, which correspond to up to 2^N possible phase diversity excitations of the array.

3 Planar phase diversity array

As an example of this general theory of phase diversity arrays let us define a planar antenna array, which consists of two times three antenna elements. Let us also choose the array geometry to be an equally spaced, rectangular grid. Furthermore, if one limits the observation point to reside only in the same plane as the array elements are located, the radiation properties of the array are then defined by an array factor, which can be written as

$$f_{\mathrm{AF}}(\theta) = \left(1 + I_{11} e^{jkd\cos\theta + \delta_{11}}\right)\left(1 + I_{12} e^{jkd\cos\theta + \delta_{12}}\right)\left(1 + I_{21} e^{jkd\sin\theta + \delta_{21}}\right), \tag{6}$$

where d is the spacing between the grid of array elements, I_{11}, I_{12} and I_{21} are the excitation amplitude ratio parameters and δ_{11}, δ_{12} and δ_{21} are the phase difference parameters. If one expands the products of binomial terms to see what the true element excitations are, the following array of antenna array excitations is obtained

$$\begin{matrix} I_{21} e^{j\delta_{21}} & I_{11} I_{21} e^{j(\delta_{11} + \delta_{21})} + I_{12} I_{21} e^{j(\delta_{12} + \delta_{21})} & I_{11} I_{12} I_{21} e^{j(\delta_{11} + \delta_{12} + \delta_{21})} \\ 1 & I_{11} e^{j\delta_{11}} + I_{12} e^{j\delta_{12}} & I_{11} I_{12} e^{\delta_{11} + \delta_{12}} \end{matrix} \tag{7}$$

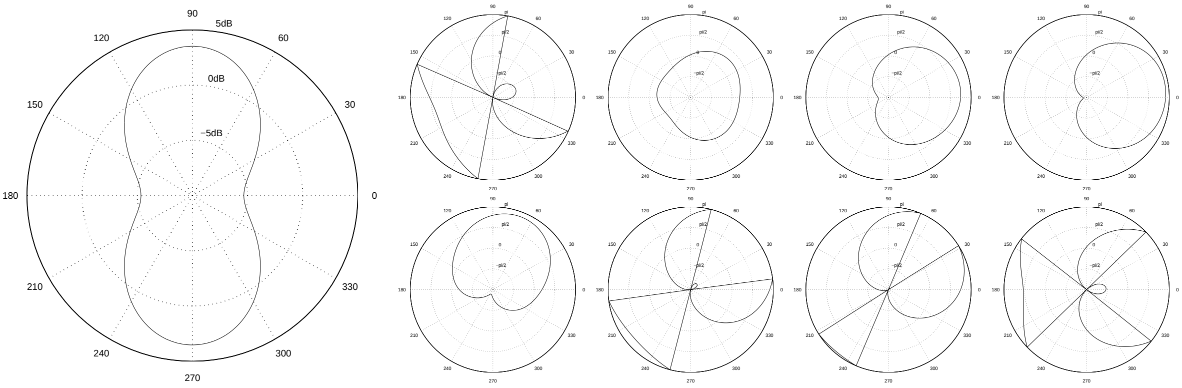

Figure 1: Directivity pattern and the eight phase patterns of the diversity array.

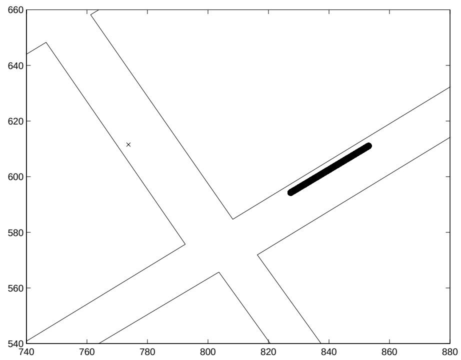

Figure 2: Base station location, simulated route and surrounding street geometry.

The array has three amplitude ratio parameters and three phase difference parameters, which in principle can be chosen arbitrarily and which then in turn define the true array excitations as was presented by Eq. 7. The three amplitude ratio parameters I_{11}, I_{12} and I_{21} each offer two possibilities for phase diversity excitations, because every one of them can be changed to the inverse of the original value, so the total number of diversity excitations obtained is eight. Without limiting generality let us choose some values for both element excitation parameters and for array spacing, so that one has a practical case, whose performance can be simulated in multipath propagation environment as follows. The values chosen for the simulation were $d = 1.3\lambda$, $I_{11} = 2$, $I_{12} = 4$, $I_{21} = 6$, $\delta_{11} = \delta_{12} = \delta_{21} = 0$. The directivity pattern and the eight obtained phase patterns are shown in Figure 1.

4 Simulations of the array in multipath propagation environment

The effect of the multipath radio wave propagation environment and the performance of the phase diversity technique implemented with the suggested diversity array was simulated by using a ray-tracing radio-wave propagation model. The receiving base station antenna was placed to the middle of the street block while the transmitter was assumed to be moving behind the corner of the corresponding street intersection. The base station location, simulated mobile station route and the street geometry are shown in Figure 2. The response of the received signal field strength level was recorded as a function of the moving mobile station antenna and the simulation was repeated with all phase diversity antenna configurations. The transmitting antenna was assumed to be ideally omnidirectional during the all simulations. The operating frequency was set to be 1GHz.

Figure 3 shows all the eight diversity responses during a short strip taken from the simulated path. It can be clearly seen, how the fast-fading phenomenon is present regardless of the choice of the diversity array excitation. Nevertheless, the fading nulls doesn't exist in the same locations of the responses, and therefore it is possible to temporarily select the best excitation of the array and thus reduce the effect of signal fading by selection combining. The assessment of the actual fading reduction performance was obtained by calculating

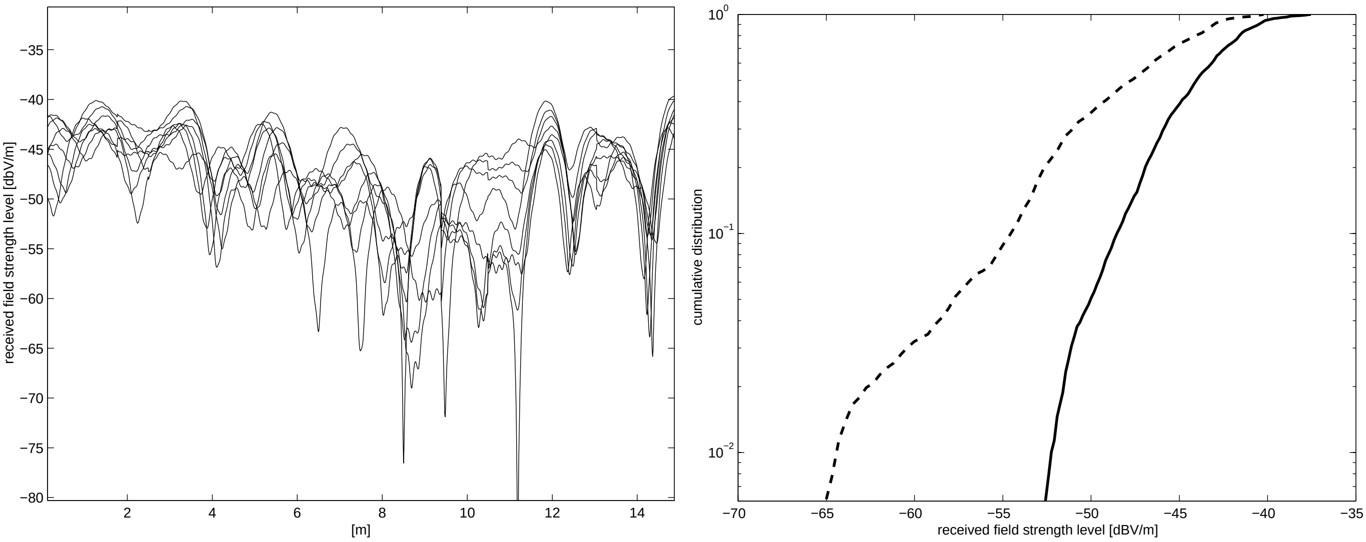

Figure 3: Received field strength levels as a function of transmitter location and received signal statistics for the simulated array.

the statistical probabilities of the simulated responses. Figure 3 also shows the probability of the received signal to not exceed a threshold value of the received signal strength in field strength units dBV/m. The first dashed plot represents the statistics calculated from the simulated response of an ideally omnidirectional receiver antenna while the other plot is obtained by calculating the statistics from the simulations of the suggested diversity antenna, when all the eight different phase patterns are used in selection combining. For both cases the radiation patterns of the antennas have been normalized to the same radiation power.

5 Conclusions

A design method for implementing phase diversity arrays, which can be used to obtain either linear, planar or 3-dimensional arrays, was presented. The method was used to plan a planar two by three element diversity array as a demonstration of the design technique. Furthermore, this suggested phase diversity array was simulated by using a multipath radio channel model to get an estimate of the fading reduction performance of the presented antenna.

Statistics calculated from the simulated received field strength level of the moving transmitter antenna show that if the probability of the received radio signal to be below a certain threshold value is chosen to be eg. 0.05, a diversity gain of 8dBV/m in field strength level can be expected if all the designed diversity excitations are used in the optimization of the received signal.

6 Acknowledgements

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References

[1] J.J.A. Lempiäinen, K.I. Nikoskinen, J.O. Juntunen, *Multistate phase diversity microcell antenna*, Electronic Letters, vol. 33, no. 6, March 1997, pp. 438-440.