Design and Optimisation of an Antenna Array for WIMAX Base Stations

W. Mahler, F.M. Landstorfer
ma@ihf.uni-stuttgart.de
University of Stuttgart, Institute of Radio Frequency Technology, Pfaffenwaldring 47, 70550 Stuttgart, Germany
http://www.ihf.uni-stuttgart.de/

Abstract: To increase the capacity and coverage in broadband data communication according to the IEEE 802.16e WiMAX standard, an intelligent base station antenna with beam- and nullsteering over a full circle is developed and optimised.

In this paper a circular antenna array of 8 vertical dipoles with a feeding network is described, which provides m beams simultaneously in m directions for m subscribers with a full coverage of 360° around the basestation. By means of optimisation techniques it is either possible to provide a null without ambiguity in every direction, or to optimize the side lobe attenuation by calculating the amplitudes and phases of every antenna of the array. With this, detection finding or location based services are also possible.

1. Introduction

Conventional base station antennas in existing operational systems are either omnidirectional or sectorized. The greater part of the transmitted signal power is radiated into directions other than toward the specific user. This causes interference, reduces efficiency and the range of coverage. Especially in new broadband services as WiMAX, where the user front-end is very simple, it becomes necessary to provide every user with a specific beam offering enough gain to increase the range. It is also important to reduce interference by other users or services by means of beam forming in a way, that either the side lobe attenuation of the base station antenna array as a whole is optimised or by null steering. In rural areas a whole 360° degrees coverage around the base station is desired. This leads to the solution introduced here of circular antenna arrays, a setup which can also be used for direction finding. The antenna array consists of n vertical dipoles equally spaced on a ring with diameter d (Fig. 1). This building block is vertically stacked many times to achieve enough gain in the horizontal plane.

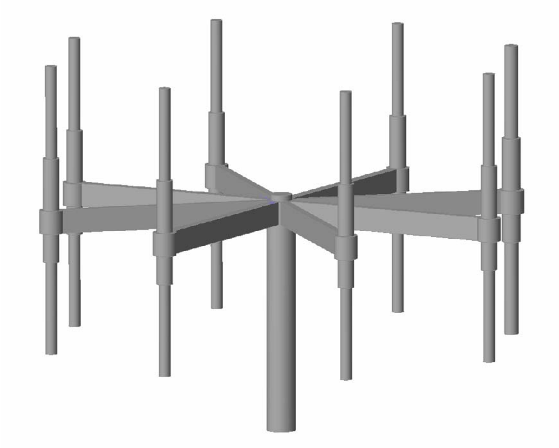

Fig. 1

The number of side lobes and the side lobe attenuation depends on the ratio d/λ whose optimum is given in this paper. In principle by means of a feeding network as in Fig. 2 it is possible to provide m dif-

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ferent and independent beams in m directions concurrently.

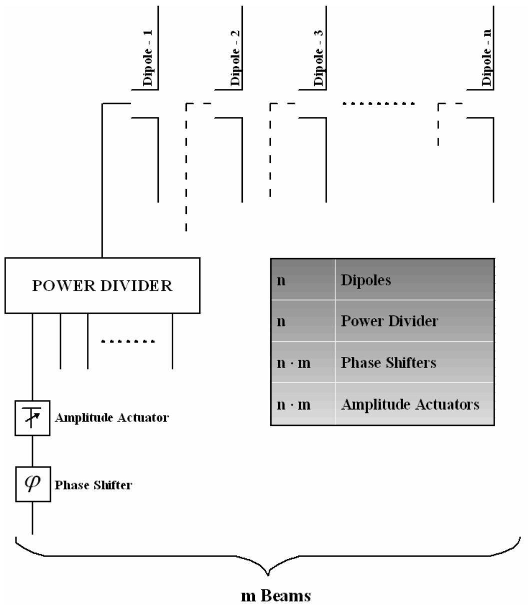

Figure 2 Equivalent Circuit of the antenna array

Each dipole is fed by an amplitude and phase actuator and isolated power dividers. In principle this can also be achieved by means of a digital signal processor.

2. Design and Structure

The antenna array under consideration consists of 8 vertical dipoles, equally spaced on a circle with diameter d, according to Fig. 1. A power-combiner/divider network is connected to the feed point of every dipole with m inputs/outputs according to the number of wanted coinstantaneous beams or null directions. For each independent beam direction the weights of the amplitudes and phases have to be calculated and optimised. The adjustment can be performed directly by phase shifters and attenuators in the RF-region or after linear down-conversion and analog to digital conversion by a DSP.
The analysis of the structure is done by FEKO, a field simulation programme using the Method of Moments and additional hybrid methods [2].

The numerical calculations and the optimisation process can be vastly accelerated using impressed currents similar to a Hertzian dipole, but omitting its infinitesimal length. With impressed currents (infinite generator impedance) there is no mutual coupling and the analysis is very fast.
To consider mutual coupling an simple procedure has been found that uses a coupling impedance matrix $\|Z\|$ [3].
From given currents (magnitude and phase) for each beam direction the generator voltages (magnitude and phase) can be calculated using $\|Z\|$ and equation (1).

$$\vec{U}_0 = \begin{pmatrix} U_{01} \\ U_{02} \\ \cdots \\ U_{0N} \end{pmatrix} = \|Y\|^{-1} \cdot \vec{I} = \|Z\| \cdot \begin{pmatrix} I_1 \\ I_2 \\ \cdots \\ I_N \end{pmatrix} \qquad (1)$$

$\|Z\|$ remains the same for all scanning directions and thus has to be determined only once.

3. Optimal Geometry

The ratio of the array-parameter and the wavelength d/λ is crucial for optimal results. For d « λ the antenna characteristic of the whole array is not different from the pattern of a single dipole. The horizontal pattern is a circle; with an increasing ratio d/λ the gain of the array increases also. For d/λ > 1 the side lobe level is growing at the cost of the main lobe. With increasing d/λ the number of side lobes (and nulls) and the energy radiating into unwanted directions are increasing. The optimum region for obtaining maximum gain, high side lobe attenuation and/or an unambiguous null is

$$\frac{1}{2} \le \frac{d}{\lambda} \le \frac{3}{2} \qquad (2)$$

Within this region it is possible to adjust every azimuth angle of the beam with a side lobe attenuation better than 22 dB and/or to provide an unambiguous null by using the optimizer OPTFFEKO [2].

4. Rotation of the beam in azimuth and elevation

For any wanted beam direction around the base station we derived a formula for the phase of the feed current of every dipole. To achieve a planar wave front in the direction of the user the relationships in Figure 3 are valid.

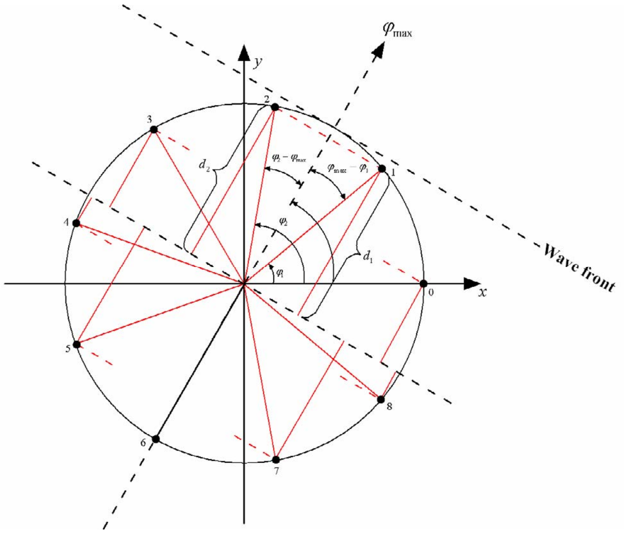

Figure 3: Planar wave front

To maintain a main lobe in the direction φ_{max} with $0 < \varphi_{max} < 360°$, the phase Ψ of every dipole has to be adjusted according to:

$$\Psi_\nu = -\frac{2\pi}{\lambda} R \cdot \cos\left(\varphi_\nu - \varphi_{max}\right) \quad (3).$$

Where ν is indicating dipole ν, φ_ν his angle position on the circle and φ_{max} the direction of the user. By adding a sin(ϑ)-term it is also possible to adjust the elevation angle of the main lobe within certain limits due to the characteristics of the single dipole.

$$\Psi_\nu = -\frac{2\pi}{\lambda} R \cdot \sin\left(\vartheta_{max}\right) \cdot \cos\left(\varphi_\nu - \varphi_{max}\right) \quad (4)$$

where φ_{max} and ϑ_{max} points in the direction of the desired direction.

With this analytical formula every azimuth angle of the main lobe is tuneable, the side lobe attenuation reaches values up to 12 dB. In Figure 4 the antenna pattern is shown for 3 different user directions.

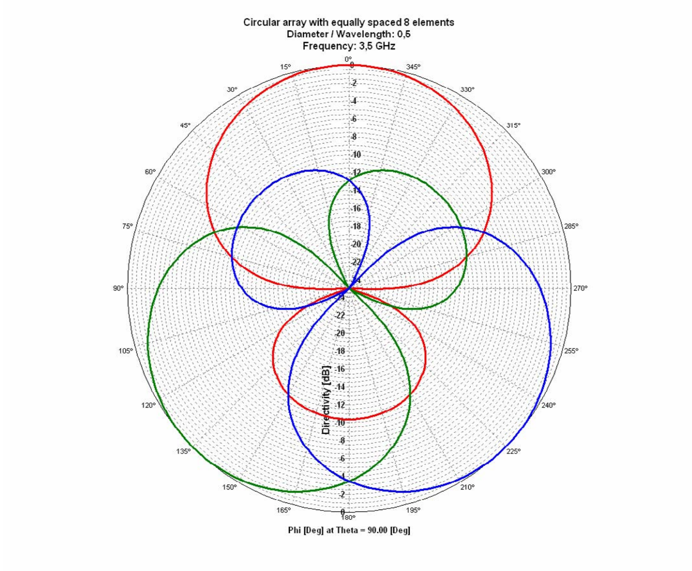

Figure 4: 3 examples of beam steering

The form of the antenna characteristic remains nearly the same with a gain of 7.5 dB and a side lobe attenuation of 12 dB.

5. Results of the optimisation

To obtain better side lobe suppression or even unambiguous nulls in any user direction, it is necessary to adjust the phase and the amplitude of each dipole in the array. The optimal values of the phase are no longer identical to the values delivered by the analytical formula. Both values can be achieved by an optimisation process. Due to the high speed and high efficiency of OPTFEKO the resulting data are available for every user direction in a broad frequency band. In Figure 5 typical results are shown for high side lobe attenuation and in Figure 6 for a Cardiode suitable for detection finding with a deep null of better than 30 dB.

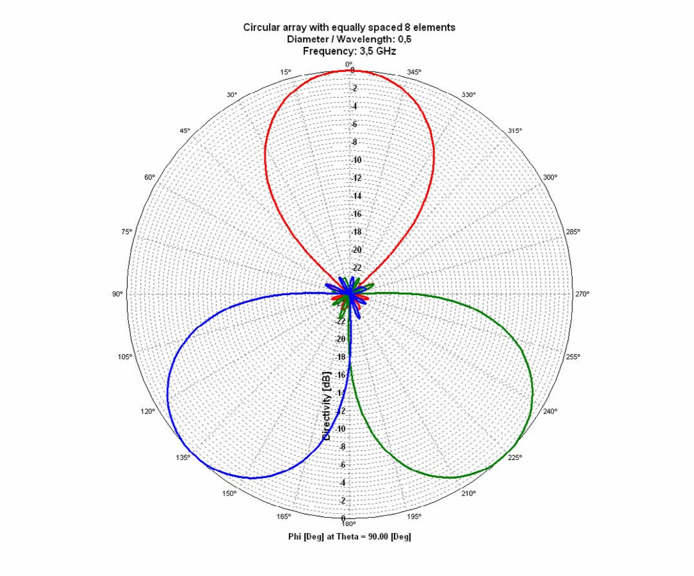

Figure 5: Results of the optimisation

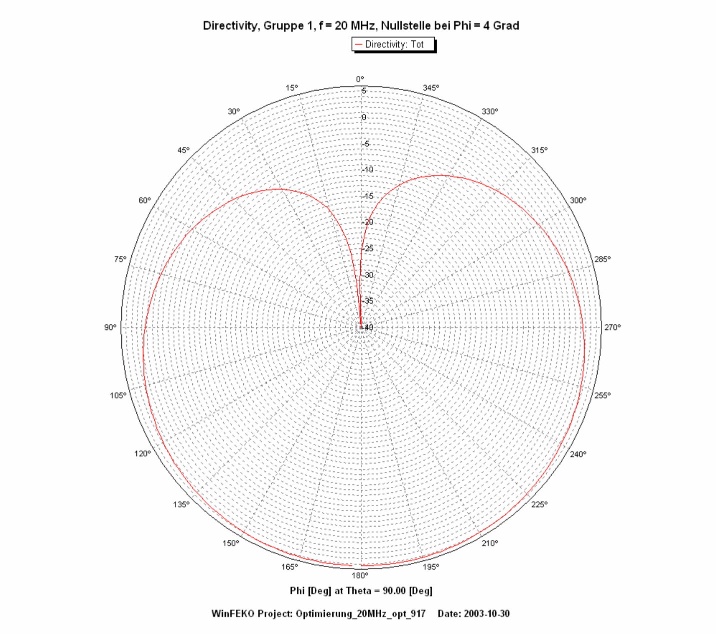

Figure 6: Null steering with a Cardiode

In Figure 7 one can see the result of the optimisation. An increase of more than 10 dB of the side lobe level has been achieved. For an optimal d/λ of 0.5 the side lobe attenuation is 23 dB and the gain is 10.7 dB.

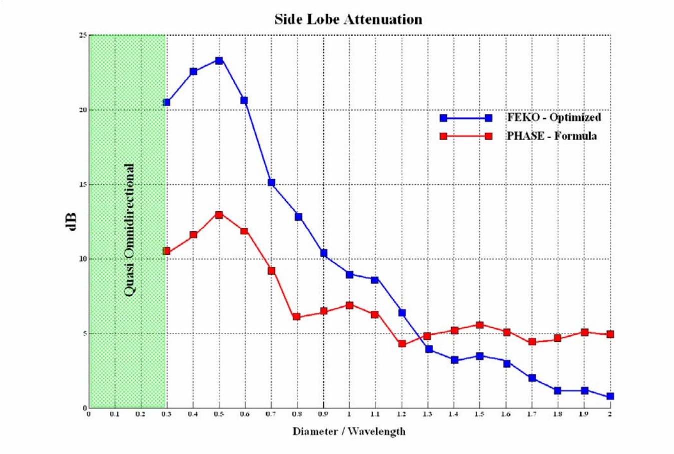

Figure 7: Side lobe attenuation

6. Results

With a circular array of vertical dipoles it is possible to steer the beam in the direction of any user and to provide an optimal side lobe attenuation for m different directions simultaneously. The number of coexistent beams is only limited in practice by the capabilities of the power dividers.

It is also possible to provide a full nullsteering in every direction around the base station. This can be done by phase shifters and attenuators in the RF-region or by DSP after linear down conversion. The results are achieved by the numerical EM-solver FEKO.

With the presented antenna array it is possible to enhance either the coverage in rural areas or to enhance the capacity of the network.

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