Variable Beamwidth Array for Wireless Communications

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Abstract

This paper presents a new concept of a variable beamwidth array, which allows continuously variable beamwidth in the azimuth plane for adaptive sectorization in wireless communications. The variable beamwidth array (VBA) is based on the proposed principle of two-ring array. The concept is implemented using three independent linear arrays arranged on two cylindrical surfaces. The position of the center column can be linearly displaced in the direction away from or toward the antenna phase center by using a remote controlled mechanism. This relative spatial displacement between the center column and the edge columns produces phase offset between the antenna elements and results in varying beamwdith in the azimuth beam pattern. The azimuth HPBW can be broaden as the center column is moved away from the phase center of the array in relative to the two edge columns. Continuous variation of HPBW from 33 deg and to over 100 deg is feasible with a total relative displacement of less than 3 cm for the operating frequencies between 1.7GHz and 2.2 GHz.

Background

A wireless communication network is generally composed of cells of various shapes and sizes. And the optimum traffic distribution and loading patterns in a wireless network may not be uniform across each sector. In a high-capacity wireless network, the number of users in one sector may exceed the capacity, while the number of users in another sector may have excess capacity. This loading pattern may also be varying as a function of time. As a result, use of conventional fixed-beamwidth antennas for fixed size sectors may be undesirable and resulting in inefficient utilization of base station radio resources. To overcome the problems associated with fixed size sectors, adaptive or variable sectorization has been considered.

Adaptive sectorization requires flexible control of service coverage in a cell, which allows for sector sizes to be adjusted by varying the associated beam coverage. This leads to the concept of a 3-way beam control antenna which has adjustable functions of downtilt, steering and beamwidth. By using a variable beamwidth (azimuth) antenna, cell coverage of a network can be adjusted to the environment with on-tower or remotely controlled adjustment of sector pattern. A typical wireless base station antenna today is already equipped with remote electrical tilt (RET) function for the downtilt control. This article describes an antenna array which also allows remote adjustment of the azimuth beamwdith.

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Proposed Concept of Two-Ring Array

The proposed VBA (patent pending) can be viewed as a superposition of two partially-filled cylindrical sector arrays. The azimuth pattern of a partially filled two-ring array can be broadened or narrowed by adjusting the relative dimension of the radius of the rings. Fig. 1 depicts the theoretical model of a general two-ring array.

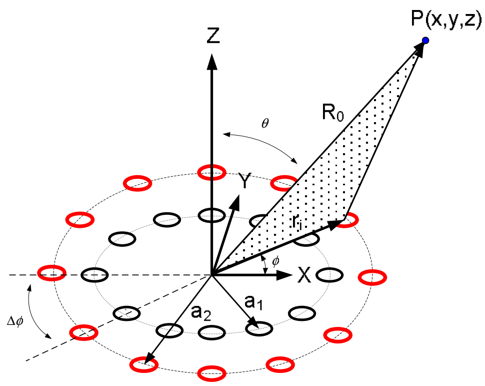

Fig. 1 Concept of Two-Ring Array

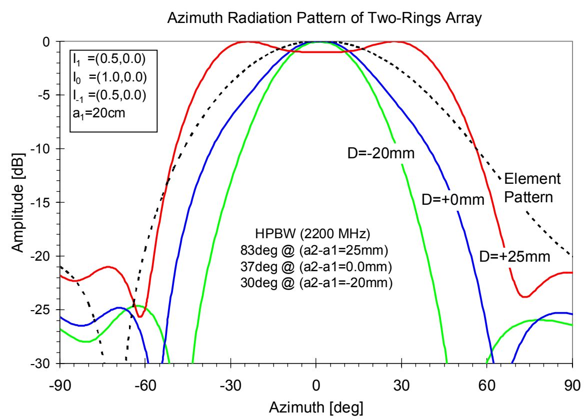

Fig. 2 Predicted Azimuth Pattern

Evidently, norms of the position vectors between the radiator ***n*** and ***m*** and an observation point P(x,y,z) are

$$\left|\hat{R}_o - \hat{r}_n\right| = a_1 \sin\theta \cos(\phi - n\Delta\phi)$$

$$\left|\hat{R}_o - \hat{r}_m\right| = a_2 \sin\theta \cos(\phi - m\Delta\phi)$$

Therefore, the total array pattern at any angular position (θ, ϕ) can be expressed as the total sum of field components from all radiating elements on the two circular ring arrays

$$\hat{F}(\theta,\phi) = \sum_{n=0}^{N-1} I_n * \hat{E}_n(\theta,\phi) * \exp[jka_1 \sin\theta\cos(\phi - n\Delta\phi)] + \sum_{m=0}^{M-1} I_m * \hat{E}_m(\theta,\phi) * \exp[jka_2 \sin\theta\cos(\phi - m\Delta\phi)]$$

Where, $\hat{E}_n(\theta,\phi)$ and $\hat{E}_m(\theta,\phi)$ represent the element patterns of ***n*** and ***m*** radiators. I_n and I_m are complex excitation coefficients for radiator n and m. N and M, and a_1 and a_2, are the total number of radiators and radius of ring 1 and 2, respectively. k is the wave number. $\Delta\phi$ is the angular spacing between radiating elements, assuming equal angular distribution of radiating elements for both rings.

The mathematical model can be further simplified for a simple three-column array model. In such case, the model consists of single radiator residing on the outside ring flanked by two radiators located on the inside ring. The total field expression is therefore simplified to

$$\begin{aligned}\hat{F}(\theta,\phi) = I_1 * \hat{E}_1(\theta,\phi) * \exp[jka_1 \sin\theta\cos(\phi-\Delta\phi)] \\ + I_0 * \hat{E}_0(\theta,\phi) * \exp[jka_2 \sin\theta\cos(\phi)] \\ + I_{-1} * \hat{E}_{-1}(\theta,\phi) * \exp[jka_1 \sin\theta\cos(\phi+\Delta\phi)]\end{aligned}$$

Fig. 2 shows the predicted azimuth field pattern of the 3-element, two-ring model at operating frequency of 2200 MHz. The radiating elements are aperture-coupled stacked patches. In this particular example, the radius of the inside ring is fixed at 20cm, while the radius of the outside ring is varied to change the azimuth beamwidth. Excitation coefficients are set at I_1=I_{-1}=(0.5,0.0) and I_0=(1.0,0.0) and a fixed 25 deg of angular element spacing ($\Delta\phi$) is assumed.

The Azimuth HPBW is broadened as the radius of the outside ring (a_2) is increased. When the radius a_2 is reduced, the phase of center radiator on the outside ring is operating more and more in-phase with the two edge radiators on the inside rings. As a result, the azimuth HPBW is approaching that of a three-column planar array. A relatively wide range of azimuth HPBW can be obtained using this method. In this particular example, the HPBW is approximately 30deg when the radius of the outside ring is 20mm smaller than that of the inside ring, and is widen up to 83deg when the outside radius is 25mm larger than a_1. Note that the total azimuth HPBW performance depends on the radiation pattern of the radiators used.

Three-Column Variable Beamwidth Array

Fig. 3(a) and 3(b) show the isometric and cross-sectional views of a three-column, 30-element cylindrical array based on the two-ring array principle. The array is designed to operate in a typical wireless communication band, 1700 MHz to 2200 MHz. The radiating elements are aperture-coupled patches. Each of the three columns of linear arrays is mounted on a separate reflector. Radius of the inside ring, a_1, is determined by the subtend angle of the two edge reflectors, **α**. Radius of the outside ring, $\boldsymbol{a_2}$, is set and adjusted by the vertical displacement, D. The positions of the two edge columns are fixed, while the center column can be moved up and down by a mechanical mechanism. HPBW from 33 deg to over 100deg is achievable with linear displacement distance between -5mm to +25mm. The maximum directivity of the 3x10 array varies between 18dBi and 23 dBi, depending on the frequency and displacement distance D.

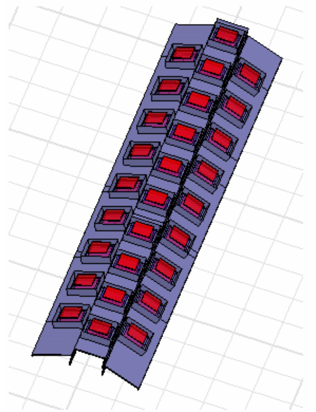

Fig. 3(a) 30-Element Array

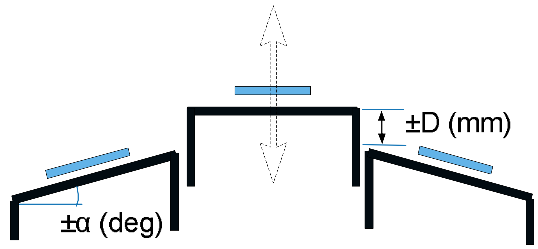

Fig. 3(b) VBA Cross-Sectional View

A 4-element sub-array model of the three-column array is simulated using the Ansoft 3D full-wave Finite Element Method (FEM) HFSS. For these analyses, the subtend angle is set to 20deg. Fig. 4 shows the simulated azimuth patterns (2200 MHz) at displacement distance (D) of +25mm and -20mm. These results are in agreement with the predicted results using the proposed two-ring array equation. The HPBW varies between 33 deg to 100deg depends on the displacement D. Fig. 5 plots the HPBW as a function of displacement D. These results show that the HPBW varies linearly as a function of the displacement distance for the value of D between -2mm and +25mm. For D between -2mm and -20mm, the HPBW slowly converges to constant as all three columns operate toward in-phase condition.

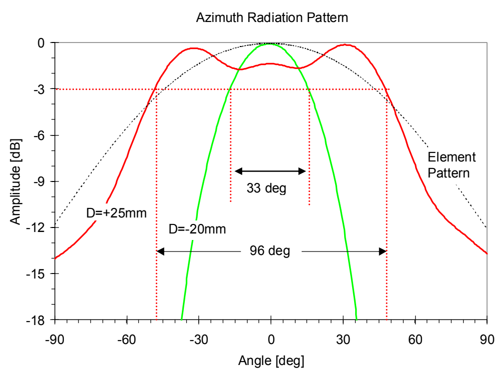

Fig. 4 Az Pattern of 3-Column Array

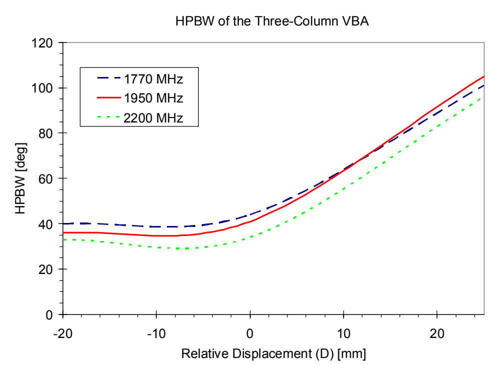

Fig. 5 HPBW of 3-Column Array

Conclusion

A proposed concept of variable beamwidth array (patent pending) is presented. The array is based on the concept of a sector two-ring array. This antenna concept allows adaptive sectorization and flexible control of service coverage in a wireless network. The azimuth HPBW can be varied by a changing the relative radius of the two ring arrays. In a three-column array implementation, the HPBW is varied by simply producing a linear displacement of the center column with respect to the two edge columns.