AN ELECTRICAL BEAM TILT ARRAY ANTENNA FOR MOBILE BASE STATIONS

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ABSTRACT

A base station antenna is an RF component capable of critically affecting performance of a cellular system. Down tilting base station antennas is used in mobile communication to prevent co-channel interference. In this paper, we introduce antenna configuration for electrical downtilt. Here a genetically optimized technique is employed. Printed circuit dipoles are employed as radiation elements.

I. INTRODUCTION

Most mobile communication users are located in highly populated urban areas. In such areas traffic is high and coverage radius of base station is one to two kilometers. Frequency reuse is employed to improve frequency spectrum usage, therefore more voice channels is available for end-users. In such cellular systems co-channel interference effects must be considered. One of the best techniques is the use of downtilt antenna technology to control the radius of coverage and reduce co-channel interference. Antenna downtilt can effectively improve CIR ratio in the coverage area of the base station. An approximate equation for tilt angle is [1]:

$$\theta_t = \tan^{-1}\left(\frac{h}{D}\right) + \left(\frac{HPBW}{2}\right) \quad (1)$$

where h and D are effective antenna height and coverage radius of the base station respectively.

To implement such systems, one has to use antennas with low side lobes and tilted beam [2]. In this article we present methods to fulfill these requirements. A novel method is introduced for synthesis of patterns with low side lobes. Finally, design and simulation of antenna element of this base station will be presented.

II. DESIGN OBJECTIVES

Characteristics of a base station antenna are shown in Table.1. System bandwidth is 70 MHz. Side lobe level is set at -20dB. Electrical downtilt range is considered between angles $3^0 - 15^0$. Electrical downtilt increases side lobe level while decrease antenna gain. The H-plane beamwidth for a tri-sector cell is 120^o.

Table1: Antenna specifications.

Parameter	Specifications
S.L.L	< -20 dB
F/B	> 20 dB
Beam tilt	3°-15° adj. 1°
VSWR	< 1.5
HPBW	120° (H-plane) 15° (E-Plane)
Polarization	Vertical
Antenna Length	1.3 m

III. CONFIGURATION OF THE ELECTRICAL DOWNTILT ANTENNA

The antenna structure under consideration is shown in Fig.1. Printed dipoles are used as radiating elements. N elements are distributed in the vertical line, spaced at d distances. All antenna elements such as radiators, transmission lines, and power dividers are implemented on a dielectric substrate. A corner reflector is mounted behind the array elements to achieve 120^o beamwidth in horizontal plane. Beam tilt box is isolated from antenna body, and located at antenna base. Array elements are fed through the feed network including transmission lines and power dividers. The excitation coefficient (amplitude and phase) of array elements is achieved with designing feed network. Amplitudes are determined by setting power ratios of power dividers. Phases are also determined by choosing appropriate transmission line lengths. Another important feature is electrical downtilt. This is implemented by applying definite phase differences to sub-arrays (consisting of M elements). Proper phases are given to sub-arrays by the bean tilt box.

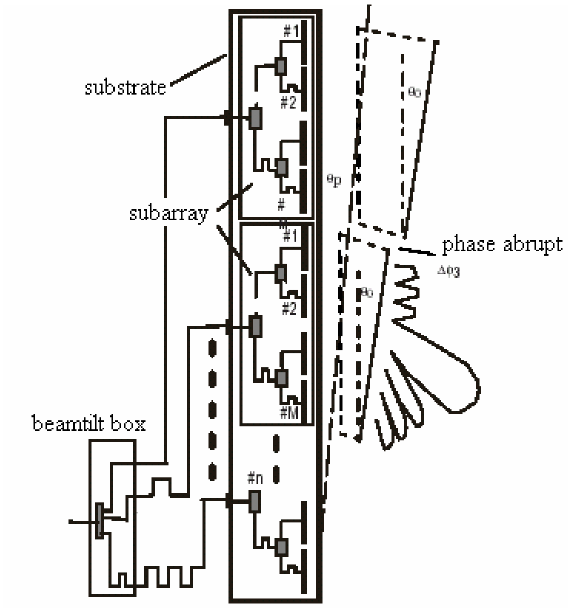

Fig.1: Antenna Configuration [2]

IV. EXITATION COEFFICIENTS FOR DESIGN OF LOW SLL

The side lobe level is designed in vertical plane of the base station antenna as shown in Fig.2. The side lobe level in the region of interfering cell is decreased as low as SLL=-20dB.

Right side of the pattern is shaped as uniform array and the left side is designed a by Chebychev or Taylor pattern with SLL=-20dB [3].

To achieve an asymmetrical pattern, one should find excitation coefficients of the array elements using schelkunoff method along with genetic algorithm.

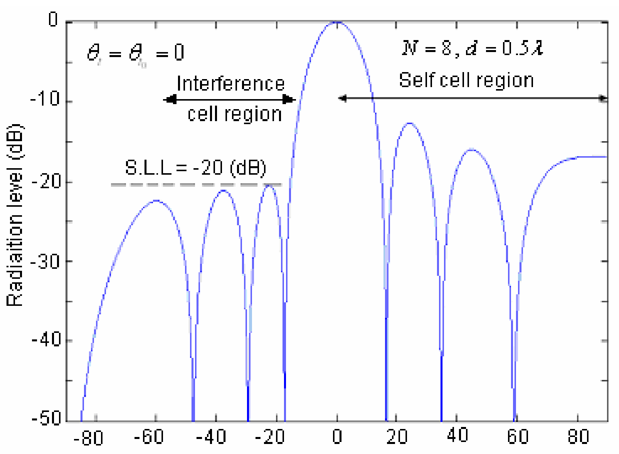

Fig.2: Desired radiation pattern in vertical plane

V. GENERIC ALGORITHM AND SCHELKUNOFF METHOD

The array factor for a linear array consisting of N elements, with equal separation, d, is well known [4]:

$$AF = \sum_{n=0}^{N} I_n \exp\left(jnk_0 d\cos(\theta)\right) \qquad (2)$$

where, I_n is excitation of the n'th element and θ is measured with respect to the array axis. Substituting $\psi = k_0 d\cos(\theta)$ and $w = e^{j\psi}$, the array factor is obtained as

$$AF = I_N \sum_{n=0}^{N}\left(\frac{I_n}{I_N}\right)\cdot w^n = I_N \prod_{n=1}^{N}\left(w - w_n\right) \qquad (3)$$

where $w_1, w_2, \ldots, w_N$ are zeros of the above polynomial. In the Schelkunoff's technique, nulls of pattern are displaced with changing the location of the w_n's. Only those roots which are located on unit circle will affect on nulls of the pattern. Therefore, one can obtain a desired pattern by selecting location of the roots. If M roots of Eq.3 are not selected on the unit circle (w'_m); then,

$$\left|w_m'\right| \neq 1 \quad , \quad m \leq M$$

And therefore Eq.3 can be written as

$$AF = \prod_{m=1}^{M}\left(w - w_m'\right)\cdot \prod_{m=M+1}^{N}\left(w - w_m\right) \qquad (4)$$

where, $w_m' = (1 + b_m) w_m e^{j\xi_m}$, and b_m is a non-zero real number. Pattern control can be achieved by controlling b_m and ξ_m using genetic algorithm [4]. The results are shown in Fig.3. Excitation amplitudes are: $I_1 = I_8$=0.544, $I_2 = I_7$=0.794, $I_3 = I_6$=0.916, $I_4 = I_5$=1. Amplitude distribution is symmetric and relatively flat. As a result the mutual coupling between array elements will be low.

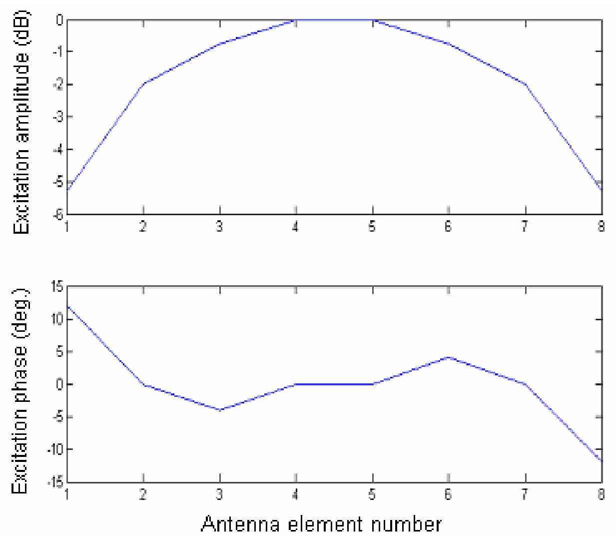

Fig.3: Amplitude and phase distribution of the array elements

VI. DESIGN OF HORIZONTAL PLANE RADIATION PATTERN

To achieve a sectored pattern in the horizontal plane, a corner reflector should be used. Fig.4 depicts dependency of horizontal plane beamwidth with reflector width, w. The angle between the reflector faces (γ) is an important parameter. To obtain HPBW of 120^o in horizontal plane, w=0.1m and γ $=180^o$ is selected.

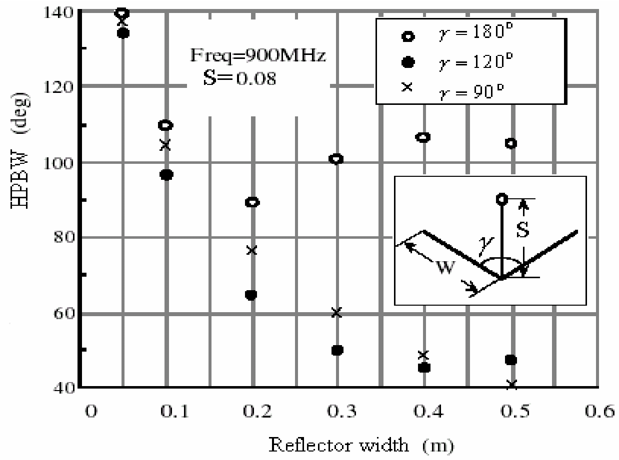

Fig.4: Dependency of horizontal plane beamwidth with reflector face width

VII. DESIGN AND SIMULATION OF BASE STATION ANTENNA

In base station antennas, printed dipole antennas are often used as radiating elements [7]. The structure of a printed dipole antenna is illustrated in Fig.5.

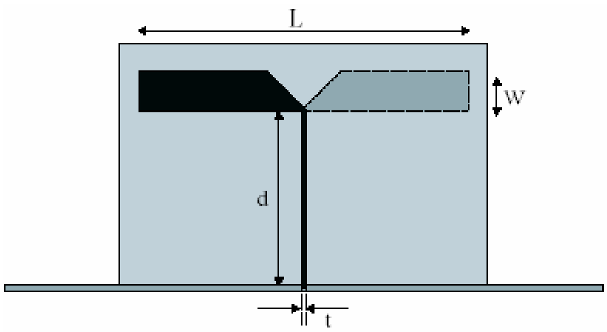

Fig.5 Printed dipole antenna structure [5]

In this figure, strips are printed on both sides of a dielectric slab, and the antenna is fed via parallel strip lines. Prior to determining the characteristics of the dipole strip antenna, a suitable substrate has to be selected. Substrate thickness should be as small as possible, since the same thickness will be used for antenna feeding network. For our purpose, we selected a low price epoxy substrate (FR-4) with a dielectric constant of $\varepsilon_r = 4.15$, $\tan\delta = 0.013$ at 1GHz. Substrate thickness is also selected to be 1mm. The primary parameter in designing dipole antenna is the required length for resonance. To calculate the length L, the dipole antenna is modeled as a rectangular microstrip antenna. In this way, the resonant length can be obtained as [6].

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{re}}} - 2\Delta l_{oc} \qquad (5)$$

where, ε_{re} is the effective dielectric constant of the dipole antenna and Δl_{oc} represents effects of the open end line. Assuming H>>h, the ε_{re} of strip dipole can be obtained from ε_{re} of suspended microstrip line (Fig.6).

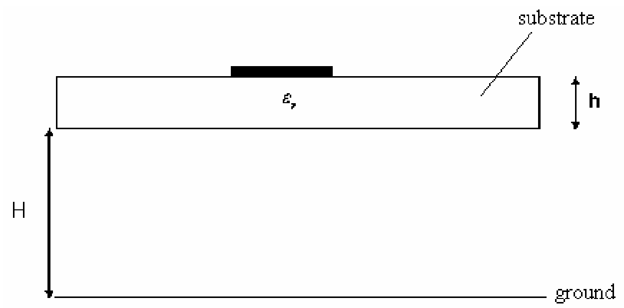

Fig.6: Suspended microstrip line

At f = 925MHz, ε_{re} and Δl_{oc} will be 1.91 and 0.69mm for h =1mm, ε_r = 4.15 respectively. Therefore, the resonance length of the antenna will be L=114mm. Input impedance of dipole antenna is very low (about several ohms). Hence we have to use an impedance transformer (balun) for the 50 ohm standard.

The printed dipole antenna is shown in Fig.7 along with its matching balun. Printed dipole antenna resonance depends on the length of parallel strip lines. Optimizing feature of HFSS package (Empip 3D) was used to find the optimum length of parallel strip lines (d_{opt}). Optimization goal was to achieve VSWR<1.5 (RL<-14dB) in frequency range of 890-960 MHz. The width of strip lines was selected as t= 1mm. The optimum line length was found to be d_{opt} =75mm.

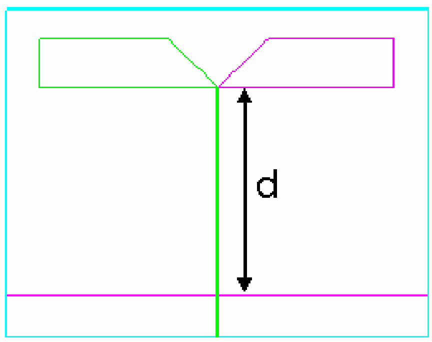

Fig.7: Printed dipole antenna and its feed line

Fig.8 illustrates return loss curves with d as a parameter. It is observed that resonance takes place at f = 924 MHz for d_{opt} and the return loss is less than -15dB over the entire frequency range 890-960 MHz.

In directional antenna, a ground plane is placed at a distance of $\lambda/4$ from radiating elements to obtain a directional pattern. A reflecting plane perpendicular to substrate with w = 162mm and $d = \lambda/4 (\approx 75mm)$ from the radiating elements is used to have a beamwidth of 120^o in the horizontal plane (Fig.9). The length of the reflecting plane was selected as $H = 3\lambda/2 (= 486mm)$ to achieve a front-to-back ratio of FB>20dB. Fig.10 shows horizontal radiation pattern of the antenna. As is observed from this figure, FB is 21dB.

VIII. CONCLUSION

In this paper, a base station antenna is presented which has a low SLL and variable downtilt pattern. The implemented array is composed of dipole strip elements printed on both sides of a thin substrate. The main feature of these elements is their small size and simple manufacturing. The proposed antenna of such a design can also reduce the co-channel interference in cellular land mobile communication system. The front back ratio is also found to be of excellent value. The amplitude distribution is symmetric and relatively flat. As a result the mutual coupling between array elements becomes low.

ACKNOWLEDGMENT

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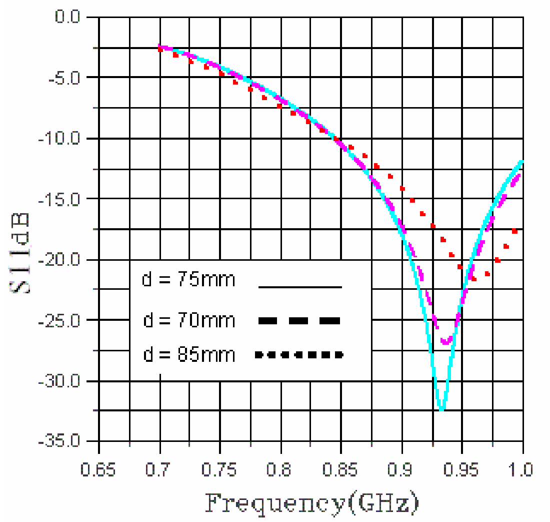
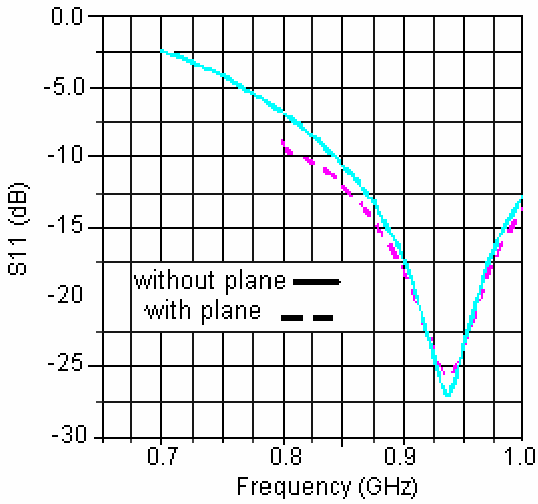


(a)



(b)

Fig.8: Return loss; (a) effect of d without reflector plane, (b) effect of reflector plane

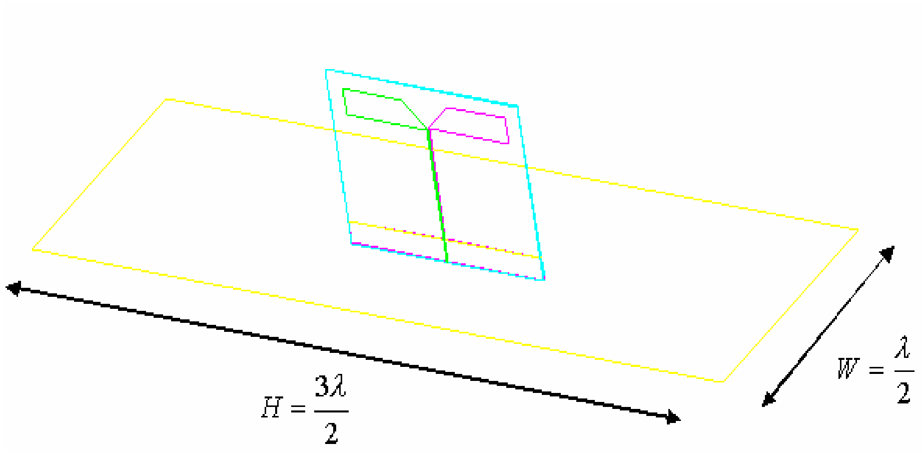


Fig.9: Printed dipole antenna in front of the reflector plane

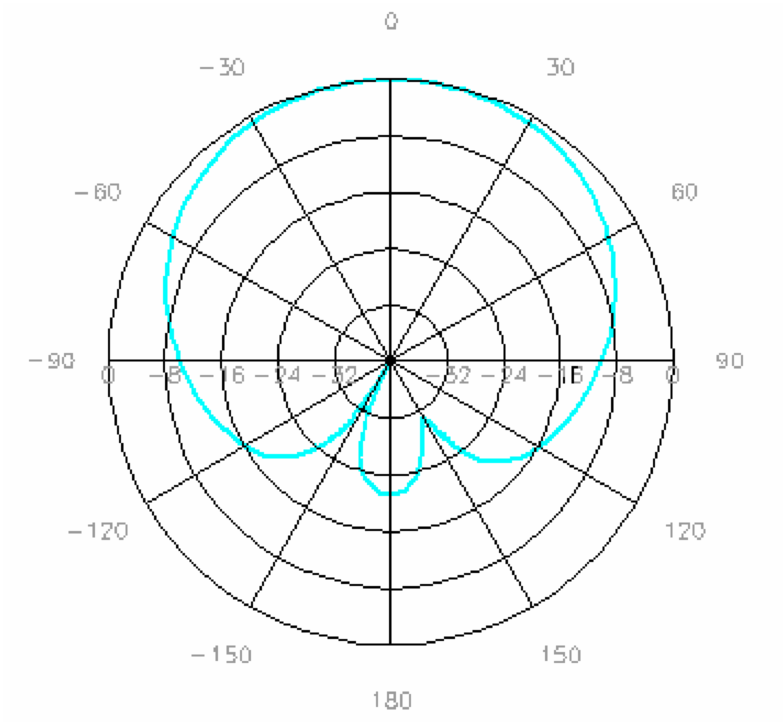


Fig.10: Radiation pattern in the horizontal plane