Synthesis of Nonuniformly Spaced Linear Array for GSM/DCS/WCDMA Base Station Application Using Genetic Algorithm

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1. Abstract

The design of nonuniformly spaced linear array suitable for GSM/DCS/WCDMA base station application is presented. In the design, both the interspacing between array elements and the feeding Wilkinson power divider for tri-band antenna array are facilitated using genetic algorithm. The simulation results show the nonuniformly spaced linear array fed by an 8-way Wilkinson power divider is suitable for a tri-band antenna array design. And the performances of radiation patterns and impedance bandwidth meet the specifications of base station antennas.

2. Introduction

Cellular communication systems have become very popular with a corresponding increase in the number of base stations. A dual-band antennas operating at 0.9/1.8 GHz band for base station application had been investigated in literature [1]. However, double main beams of the radiation patterns for an equispaced linear array will occur when the interelement spacing exceeds one wavelength. And the approach is unsuitable for a wideband antenna array design.

The nonuniformly spaced linear arrays [2] are usually used to reduce the number of array elements required to meets the given array pattern requirements at a given frequency. Due to the computational complexity of optimization problem for radiation patterns, a nonuniformly spaced linear array for wideband application is rarely discussed in literatures. In order to avoid the double main beams problem, a synthesis approach for nonuniformly spaced linear array using genetic algorithm is proposed in this paper.

This paper demonstrates the simulated radiation patterns of a nonuniformly spaced linear array realized on a double-sided printed dipole pairs [3] for GSM/DCS/WCDMA base station application. In addition, a new approach to design Wilkinson power divider for a tri-band antenna array using genetic algorithm is proposed.

3. Synthesis of nonuniformly spaced linear array using genetic algorithm

For the conception of nonuniformly spaced linear antenna arrays, some theoretical tools have been developed over years. Most of them are focused on the uniform excitation of each element under the assumption of neglecting the mutual coupling effects. The purpose of this paper is to show the possibility of nonuniformly spaced linear array for wideband antenna array design.

From the simulation results by IE3D, the relation of the interspacing of elements and the mutual coupling effect can be investigated. By choosing a suitable range of interspacing in the solution space of simple genetic algorithm (SGA) [4], the mutual coupling effect can be ignored. And then, the optimal interspacings of a nonuniformly spaced array are searched by SGA. In the study, the solution space of interspacing d_i ranges from 17 cm to 42.5 cm with resolution 0.1 cm. And the radiation patterns are simulated by the product of element factor and array factor at frequency of interest. In order to achieve minimum side lobe level (SLL) at GSM/DCS/WCDMA frequency band, measure of the fitness is given by

$$Objective\ \ Function = \sum_i W_i \times \max(SLL(f_i)) \tag{1}$$

where f_i = 0.9, 1.8, and 2.05 GHz. The genetic algorithm searches for the minimal objective function value in the solution space.

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4. Design of Wilkinson power divider using genetic algorithm

Fig. 1 shows the topology of an 8-way Wilkinson power divider [5] for equally power distribution, whose input and outputs are $50\,\Omega$. The power divider consists of transmission line sections with width W_i, length ℓ_i, and resistor R_i. And the characteristic impedance for transmission line $Z_{0,i}$ is given by [6]

$$Z_{0,i} = \frac{120\pi}{\sqrt{\varepsilon_e}\left[W/d + 1.393 + 0.667\ell n(W/d + 1.444)\right]} \quad (2)$$

where $\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12d/W_i}}$

The problem is to choose suitable dimensions for W_i, ℓ_i and R_i so as to achieve the desired performance. The optimal parameters of the Wilkinson power divider are searched by genetic algorithm. In the study, the substrate thickness d is set to be 1.6 mm and relative dielectric constant ε_r is 4.3.

In order to achieve minimum return loss and good isolations between each port at GSM/DCS/WCDMA frequency band, measure of the fitness is given by

$$\textit{Objective function} = \max(|S_{11}(f_i)|) + \max(|S_{23}(f_i)|) + \max(|S_{24}(f_i)|) + \max(|S_{26}(f_i)|) \quad (3)$$

where f_i = 0.8, 0.82, ..., 1.0 GHz and 1.66, 1.68, ..., 3.0 GHz. The genetic algorithm searches for the minimal objective function value in the solution space.

5. Results

The radiation pattern of one printed-strip dipole antenna array, which operates at 0.9/1.8/2.05 GHz band, had been simulated and leads to a satisfactory performance. Fig. 2 plots the measured mutual coupling at 0.89 GHz and Fig. 3 plots the relation between interspacing of elements and mutual coupling. As shown in the results, the worst case of mutual coupling effect is -16.86 dB at the frequency band of interest when the interspacing is 17 cm.

The simulated radiation patterns in E-plane for the proposed nonuniformly spaced linear array at 0.9, 1.8, and 2.05 GHz are shown in Figs. 4, 5, and 6, respectively. The modified radiation patterns owing to the mutual coupling effects are calculated by introducing S parameters into the formulation [7]. Table II lists the comparisons between radiation patterns with and without mutual coupling effects under the condition of the uniform excitation for each element. The results show mutual coupling effect does not deteriorate the radiation patterns significantly. It validates the proposed design approach of tri-band antenna array.

After a 100-generation run by GA, one set of parameters of Wilkinson power divider is sufficient to meet the specifications for base station antenna array. Fig. 7 shows the simulated results of return loss, power distribution, and isolations between each port for the power divider of the fittest solution versus frequency bands of interest. The bandwidths meet the specifications if the threshold of return loss is −10 dB. And the optimum parameters of the Wilkinson power divider are listed in Table III.

6. Conclusions

A synthesis approach of nonuniformly spaced linear array for tri-band base station application is presented. In addition, the feasibility of Wilkinson power divider application for tri-band antenna array without compensating the output port mismatch due to the mutual coupling effects is demonstrated in this study. The present approach is suitable for the design for tri-band base station antenna array. It also benefits the reduction of base station antenna space if three systems GSM/DCS/WCDMA are co-located.

7. References

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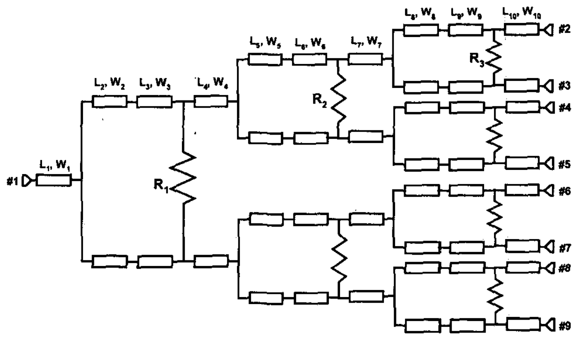

Fig. 1. The topology of an 8-way Wilkinson power divider.

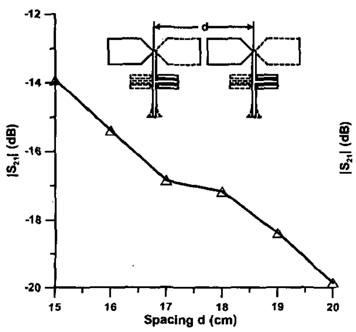

Fig. 2. The relation between interspacing of elements and mutual coupling at 0.89 GHz.

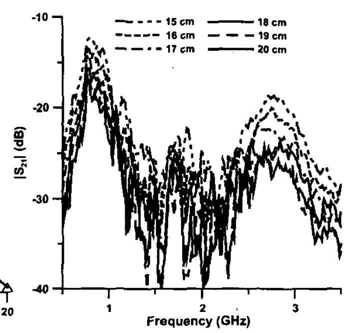

Fig. 3. The measured mutual coupling.

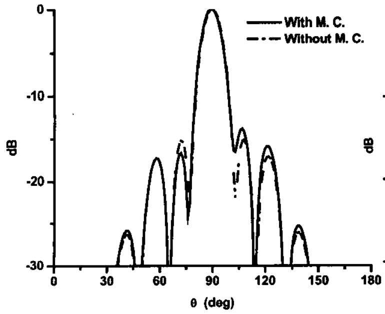

Fig. 4. The simulation of radiation patterns at 0.9 GHz.

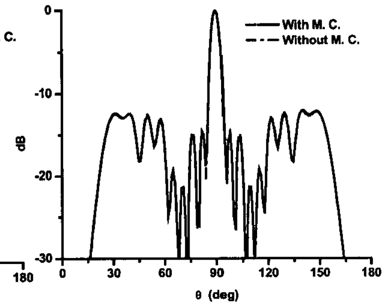

Fig. 5. The simulation of radiation patterns at 1.8 GHz.

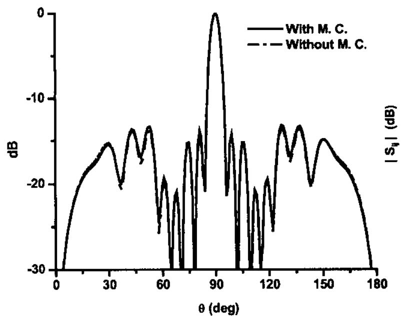

Fig. 6. The simulation of radiation patterns at 2.05 GHz.

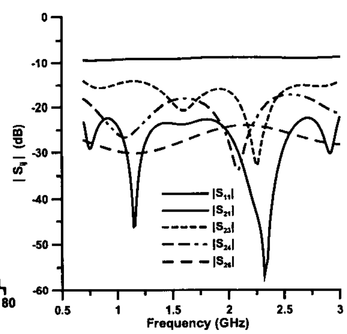

Fig. 7. The performance of Wilkinson power divider.

TABLE I
SPACING OF A DESIGNED LINEAR ARRAY

d_1	d_2	d_3	d_4	d_5	d_6	d_7
23.6	24.6	17.0	17.0	17.9	17.0	17.0

Unit: cm

TABLE II
PARAMETERS FOR A DESIGNED LINEAR ARRAY

Freq. (GHz)	SLL(dB)	
	with M. C.	without M. C.
0.9	-13.9	-15.3
1.8	-13.5	-14.0
2.05	-12.6	-12.4

TABLE III
DIMENSIONS OF A DESIGNED FEED NETWORK

Section *I*	*length,* L_i*(mm)*	*Width,* W_i*(mm)*	*Impedance*(Ω)
1	20.8	3.8	44.378
2	20.6	1.9	65.897
3	18.8	3.9	43.643
4	15.8	7.1	28.707
5	8.4	3.3	48.481
6	15.4	4.2	41.582
7	5	6	32.493
8	16.4	1.8	67.671
9	9.4	2.9	52.389
10	5.8	2.1	62.63

R_1= 220 (Ω) R_2= 27 (Ω) R_3= 100 (Ω)