

DESIGN AND REALIZATION OF A FLAT-TOP SHAPED-BEAM ANTENNA ARRAY

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Abstract—The design and realization of a ten-element shaped-beam antenna array are presented. A flat-top pattern in the main beam which allows a well-proportioned power distribution in desired zone is achieved by optimizing the amplitudes and phases of array elements using genetic algorithm. Being different from the most optimization in reported literatures, the proposed synthesis has taken the actual element patterns but identical and isotropic ones into account, which can reduce the error between computation and realization. Besides, both the optimized amplitudes and phases are set to be realizable. The array operating at 1.71–1.74 GHz is manufactured and measured. The measured radiation patterns of the proposed array show a flat-top main beam of about 40° and a peak side-lobe level of -20 dB, exhibiting a good agreement with the simulated results.

1. INTRODUCTION

In wireless communication systems, antennas with shaped-beam radiation patterns have been widely used for better power managements [1–3]. The shaped radiation patterns are usually realized by controlling the feeding amplitudes and phases of antenna array elements. This problem has received much attention in recent years [4–6]. However, most reported literatures regarded the element patterns as identical and isotropic in the array pattern synthesis. This will surely make the synthetical results inaccurate. Moreover, both the optimized feeding amplitudes and phases of array elements shouldn't fluctuate acutely for easy realization of the feeding network.

In this paper, a ten-element dipole antenna array with flat-top radiation pattern is presented. Array synthesis has been done using a genetic algorithm (GA) and the actual element factor has been

taken into account in optimization. The antenna array element chosen for the purpose is a cross-dipole which has been used in commercial base stations. The feeding network is designed using Ansoft Designer software and manufactured for realizing the array excitations. The proposed antenna array is finally measured outdoors and the measured patterns show good agreements with simulated results.

2. ARRAY SYNTHESIS AND MEASUREMENTS

2.1. Array Element

The wideband cross-dipole antenna which has been used in commercial base station is chosen as the array element. Figure 1 gives the prototype of the dipole. The VSWR against frequency for the proposed dipole is measured with a Wiltron-37269A network analyzer and depicted in Figure 2. It is seen from the measured results that the proposed antenna exhibits a good impedance match characteristic over 1.71–1.74 GHz.



Figure 1. Prototype of the array element.

Since the element factor has been taken into account in the proposed optimization, the E -plane radiation patterns of the array elements are measured, respectively. Figure 3 shows each element factor of the proposed ten-element shaped-beam antenna array. It can be seen that the measured patterns are different from each other due to the existence of element coupling and the effect of the ground-plane. The difference in the patterns also proves that the introduction of the element factor into optimization is necessary.

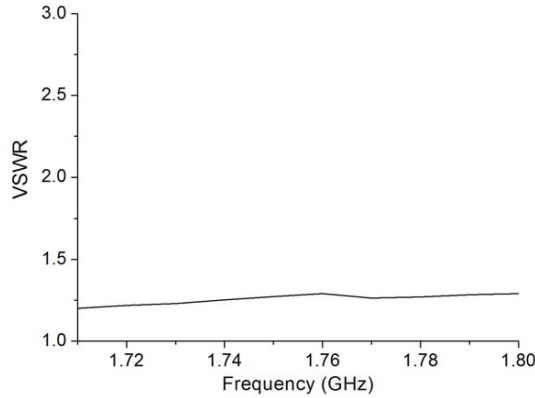


Figure 2. Measured VSWR of the proposed array element.

2.2. Array Synthesis and Optimization

Since the radiation pattern of an equally spaced linear array distributed along the z axis with element spacing $d = 128$ mm will be optimized, we begin with the general expression of the far field of a N -element ($N = 10$) linear antenna array, given by:

$$E(\theta) = \sum_{n=1}^N g_n(\theta) \cdot a_n \exp[j(k(n-1)d \cos \theta + \beta_n)] \quad (1)$$

Here, $k = 2\pi/\lambda$ is the free space wave-number, and d denotes the element spacing of the array. The amplitude and phase weights of the n th element are a_n and β_n , respectively. The expression $g_n(\theta)$ represents the radiation pattern of the n th element.

For synthesizing the desired pattern, element excitation (a_n, β_n) will be optimally determined by genetic algorithm. In this paper, we choose the conventional GA and set the following GA parameters consistently during the optimization: population size = 200, number of the maximum generation = 100, selection type = tournament, crossover type = uniform, crossover probability = 0.85, mutation probability = 0.3. The fitness function for this study is defined in the following manner.

For each field sample point in shaped-beam regions, the relative error is the difference between the actual power level and that of the desired pattern over M total sample points:

$$e_m = S_{\text{actual}}(\theta_m) - S_{\text{desired}}(\theta_m), \quad m = 1, 2, \dots, M \quad (2)$$

where S denotes the power density pattern of the array. A least mean-square measure is used to represent the overall pattern error as:

$$EMA = \left(\frac{1}{M} \sum_{m=1}^M |e_m|^2 \right)^{\frac{1}{2}} \quad (3)$$

On the other hand, the peak side-lobe level (PSLL) of the array pattern must be considered. The PSLL can easily be searched out in side-lobe regions and the difference between the computational PSLL and the desired can be expressed as:

$$EMB = PSLL_{\text{actual}} - PSLL_{\text{desired}} \quad (4)$$

To control the actual pattern both in the shaping region and in the predetermined side-lobe regions, weighting factor w is included in the fitness function, given as:

$$\begin{aligned} \text{fitness} &= w \times EMA + EMB \\ &= w \times \left(\frac{1}{M} \sum_{m=1}^M |e_m|^2 \right)^{\frac{1}{2}} + (PSLL_{\text{actual}} - PSLL_{\text{desired}}) \end{aligned} \quad (5)$$

An optimized pattern with a flat-top main beam of about 40° and a peak side-lobe level of -20 dB is obtained by GA completed with a MATLAB program. Some parameters are set as follows: weighting factor $w = 2.5$, $PSLL_{\text{desired}} = -20$ dB, total sample points $M = 41$. The optimized excitation distribution is given in Table 1. It can be seen from the table that the current amplitude taper ratio is -9 dB. This will simplify the realization of the feed network without doubt.

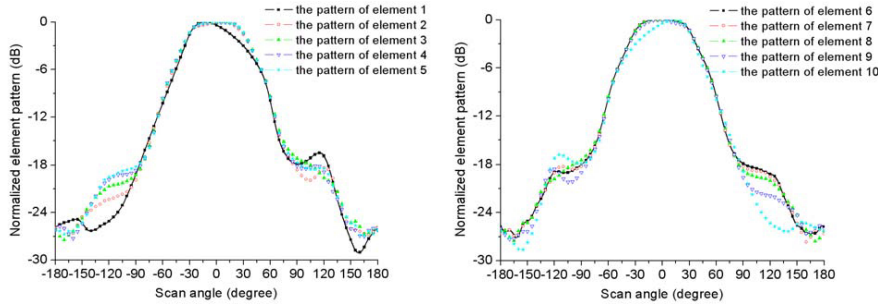


Figure 3. Measured element factor of the proposed ten-element shaped-beam antenna array.

For the easy realization of the feeding network, we have made the amplitude and phase distributions to be symmetric by strong hand in the optimization. The comparison of the optimized radiation patterns obtained by GA and that simulated by Ansoft high-frequency structure simulation (HFSS) is shown in Figure 4. The good agreement between the two results proves the validity of the proposed design.

2.3. Feeding Network

A (1:10) way hybrid feeding network which consists of a microstrip power divider and some $50\ \Omega$ -cables has been designed for realizing the array excitations. The microstrip power divider deals with the amplitude distribution while the cables aim at the phases. The hybrid

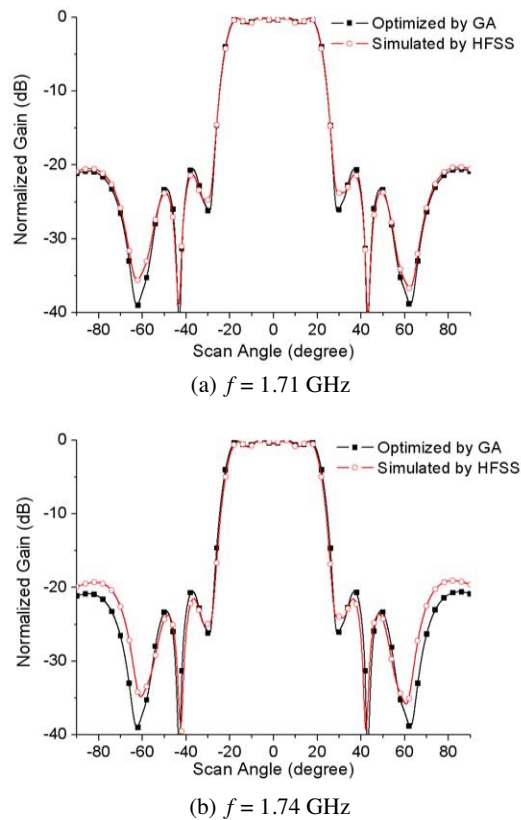


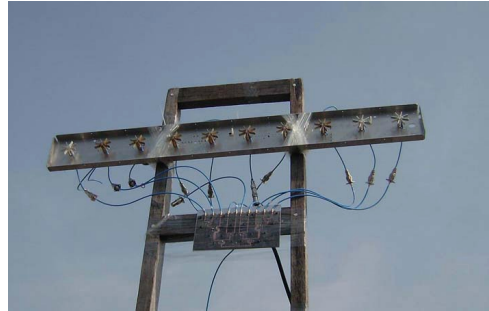
Figure 4. Comparison of the optimized radiation patterns obtained by GA and that simulated by Ansoft HFSS.

Table 1. Optimized excitation distribution of the array elements.

<i>Element Number</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
Optimized Amplitude(dB)	-9.0	-9.0	-1.25	0.0	0.0	0.0	0.0	-1.25	-9.0	-9.0
Optimized Phase (°)	70	148	212	245	316	316	245	212	148	70

Table 2. Measured excitation distribution of the proposed feeding network.

<i>Port Number</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
Power distribution in simulation (dB) (Normalized)	-9.0	-9.0	-1.25	0.0	0.0	0.0	0.0	-1.25	-9.0	-9.0
Measured Power Distribution (dB) (Normalized)	-8.9	-9.0	-1.4	0	-0.2	-0.3	-0.3	-1.3	-9.1	-9.2
Measured phase Distribution (°)	64.8	139.4	208	240	312.5	318	248.2	212.4	149.8	77

**Figure 5.** Photograph of site measurement of the proposed array assembled with feeding network.

feeding network has been manufactured and tested with the amplitude and phase accuracies 0.3 dB and 4.6° as shown in Table 2. Figure 5 depicts the proposed ten-element shaped array assembled with the feeding network.

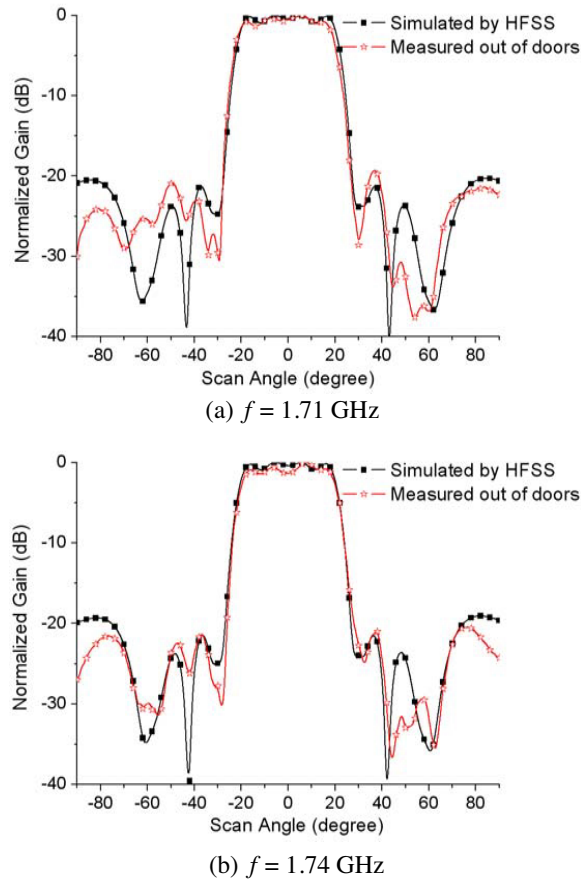


Figure 6. Comparison of simulated and measured radiation patterns.

2.4. Measured Results and Discussion

The radiation pattern of the proposed shaped antenna array is measured in the open air as shown in Figure 5. The comparison of the simulated and measured results is plotted in Figure 6, where we can see the maximal ripple in the measured shaped-beam region covering $-20^\circ \sim 20^\circ$ is about 1.07 dB and the PSL is -20 dB. Good agreement in the shaped-beam region between the simulated and measured results can also be observed.

3. CONCLUSIONS

In this paper, a ten-element shaped-beam linear antenna array is designed and realized, which is used to give a well-proportioned power distribution in desired zone. The proposed antenna array is optimized by GA with actual element factor taken into account and measured after being manufactured. The measured radiation patterns show a flat-top shaped-beam region covering $-20^\circ \sim 20^\circ$ and the PSL is -20 dB. Besides, good agreement between the computed and measured results proves the validity of the proposed design.

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