Smart Antennas with Patch Elements. Modeling with Matlab

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Abstract – **This paper focuses on the antenna array modeling and adaptive estimation principle for antenna pattern creation of smart antenna composed of a number of uniformly distributed identical microstrip antenna elements. The utilities of adaptive beamforming and coupling compensation techniques in adaptive antenna modeling are depicted and accompanied by suitable simulation results. Numerical results are presented for the dependence of the radiation patterns of smart antennas on the properties of the estimation methods.**

Keywords – **adaptive beamforming algorithm, antenna radiation pattern, patch element, smart antenna, uniform rectangular array.**

I. INTRODUCTION

In wireless communications larger capacity of the channel in the frequency-reused radio-communication system and better quality of the channel are the main conditions for the existing wireless system improving [1]. To meet these requirements, smart antennas with microstrip (patch) elements can be used.

A suitable adaptive array is a planar smart antenna because possesses the ability to scan the main beam in any direction of elevation and azimuth in 3-D space. In antenna array modeling, where size, cost, and performance are the main constraints, a number of uniformly distributed identical patch antennas may be required. These patch elements are low profile, low cost and simple to manufacture, mechanically robust, with a variety of impedance, polarization, and pattern characteristics [2].

In this paper, the least mean square (LMS) method and mutual coupling compensation technique are applied to antenna array modeling. The model descriptions are attended by simulation results obtained for a specific uniform rectangular array (URA).

II. THE RECTANGULAR MICROSTRIP ANTENNA ELEMENT MODELING. THE SMART ANTENNA PATTERN FORMATION

A. The rectangular microstrip antenna

The rectangular microstrip antenna is very easy to mathematical description and analysis. The patch element with a length L ($0.33\lambda_0 \le L \le 0.5\lambda_0$), illustrated in Fig. 1, consist of a very thin metallic patch with a thickness t ($t << \lambda_0$, λ_0 is the wavelength in the free space) placed on a dielectric substrate with a thickness h ($0.003\lambda_0 \le h \le 0.05\lambda_0$) above a perfectly conducting ground plane [3].

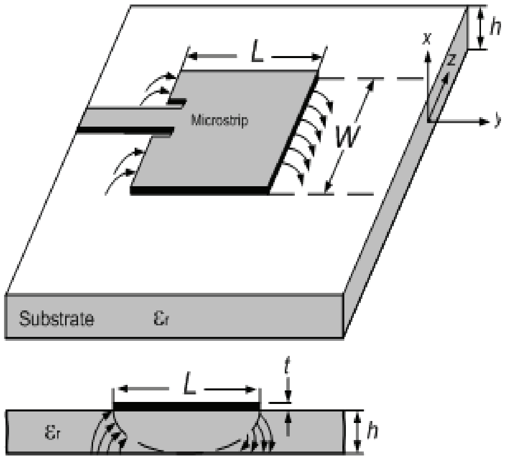

Fig. 1. Geometry of the rectangular microstrip element.

For the rectangular patch antenna design the most popular methods are: are used the transmission line model (TLM) and the cavity model. Here the TLM model is applied which gives accurate enough results avoiding complicated computations (like in the full-wave model). For the element modeling, the microstrip antenna is described as a configuration of two radiating slots with width *W*, height *h*, separated by a transmission line with length *L* into a dielectric with an effective dielectric constant ε_{reff} [3]. It is assumed that only the principal mode TM_{010}^{x} propagates in this line. For the design procedure is necessary to specify the substrate (ε_r- relative dielectric constant, *h*-height) and the resonant (operating) frequency f_r. The procedure has the following steps:

- width calculation:

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

- effective dielectric constant:

$$\varepsilon_{r\,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\, h/W}} \qquad (2)$$

- length extension ΔL (Fig.2):

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$$\Delta L = 0.412\, h \frac{\left(\varepsilon_{r\,eff} + 0.3\right)\left(W/h + 0.264\right)}{\left(\varepsilon_{r\,eff} - 0.258\right)\left(W/h + 0.8\right)} \quad (3)$$

- effective microstrip length:

$$L = 1 \Big/ 2 f_r \sqrt{\mu_0 \varepsilon_0 \varepsilon_{reff}} \qquad L_{eff} = L + 2\Delta L \quad (4)$$

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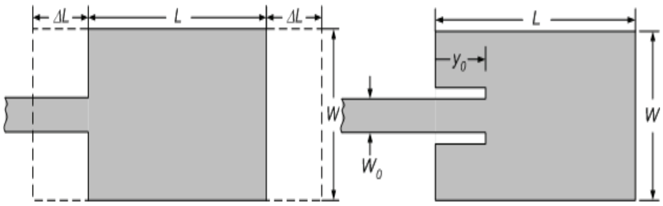

Fig. 2. The rectangular patch element modeling parameters.

In order to determine the input impedance we apply the following formula [3] (Fig.2):

$$R_{in} = \frac{1}{2\left(G_1 + G_{12}\right)} \;, R_{in}\left(y = y_0\right) = R_{in} \cos^2\left(\frac{\pi}{L} y_0\right) \quad (5)$$

where

$$G_1 = \frac{-2 + \cos\left(k_0 W\right) + \left(k_0 W\right) S_i\left(k_0 W\right) + \frac{\sin\left(k_0 W\right)}{k_0 W}}{120\pi^2} \quad (6)$$

is the conductance of a single radiating slot, k_0 is the free space phase constant, S_i (X) is an integral sine function, while G_{12} is the mutual conductance between the two radiating slots (often neglected in first approximation).

The next parameter of interest is the directivity of the patch antenna that can be calculated by the following expression [3]

$$D_{patch} = D_0 \frac{2G_1}{G_1 + G_{12}} \quad (7)$$

where

$$D_0 = \frac{2\pi W / \lambda_0}{-2 + \cos\left(k_0 W\right) + \left(k_0 W\right) S_i\left(k_0 W\right) + \frac{\sin\left(k_0 W\right)}{k_0 W}} \quad (8)$$

is the directivity of a single slot. If we neglect the mutual coupling (in first approximation) the directivity of the antenna is $D_{patch} \approx 2D_0$.

B. The antenna array pattern creation

In the previous subsection, the singe patch element modeling procedure was represented. Because the single element radiation pattern is relatively wide and the directivity values is relatively low it is necessary to use a uniform rectangular array (URA) smart antenna to synthesize a required antenna pattern, to scan array beam in order to increase the directivity in the direction of SOI (signal of interest) and to decrease the directivity in the direction of SNOIs (signals not of interest).

The URA consists of N x M equally distributed identical microstrip antenna elements, is analyzed on the base of adaptive beamforming (ABF) estimation technique. The array element is modeled using the design procedure described above.

To achieve the desired array radiation pattern the LMS algorithm is used. It is applicable to estimate optimal weights of an antenna array. Briefly description of the method is presented below.

The expression of optimal weights is given by [4]

$$\mathbf{w}(n+1) = \mathbf{w}(n) - \mu \mathbf{g}(\mathbf{w}(n)) \quad (9)$$

where $\mathbf{w}(n+1)$ denotes a new computed weights vector at the (n+1)th iteration, μ is a gradient stepsize, and the array output is given by

$$y(\mathbf{w}(n)) = \mathbf{w}^H(n)\mathbf{x}(n+1) \quad (10)$$

where $\mathbf{x}(n+1)$ is an array signal vector computed at the (n+1)th iteration, and $y(\mathbf{w}(n))$ is an output signal.

In its standard form it uses an estimate of the gradient by replacing array correlation matrix **R** and correlation between array signals and reference signal *r* by their noisy estimates at the (n+1)th iteration [6]

$$\mathbf{g}\left(\mathbf{w}(n)\right) = 2\mathbf{x}(n+1)\mathbf{x}^H(n+1)\mathbf{w}(n) - 2\mathbf{x}(n+1)r^*(n+1) \quad (11)$$

where **g** is the gradient vector.

The error between the array output and the reference signal is given by [4]

$$\varepsilon(\mathbf{w}(n)) = r(n+1) - \mathbf{w}^H(n)\mathbf{x}(n+1) \quad (12)$$

and

$$\mathbf{g}(\mathbf{w}(n)) = -2\mathbf{x}(n+1)\varepsilon^*(\mathbf{w}(n)) \quad (13)$$

is the estimated gradient as a product of the error between the reference signal and the output of the array and the signals after the nth iteration.

In array configuration is important to take into account mutual coupling effect. It can be significant for the microstrip elements and the neglecting of this effect in the beamforming algorithm may produce inaccurate results. Here is applied a simple mutual coupling compensation technique [5], [6]. The new weights are chosen based on the matrix equation

$$\mathbf{w}_{\mathrm{comp}} = \mathbf{C}^{-1}\mathbf{w} \quad (14)$$

where **C** is the coupling matrix determined by

$$\mathbf{C} = \mathbf{I} + \mathbf{Z}\mathrm{Z}_{\mathrm{L}}^{-1} \quad (15)$$

where Z_L is the load impedance of each element, **I** is the unit matrix, **Z** is a matrix with diagonal elements self-impedances, and off-diagonal elements – mutual impedances. In the analysis these elements can be easily computed by Matlab implementation [7].

III. SIMULATION RESULTS

In this section simulation results are based on the theory described in Section 2.

Modeling results (mathematical calculations and Matlab simulations) are presented in Table I and Fig. 3. The design

TABLE I

Microstrip parameters	Mathematical calculation	Matlab simulation results
Physical width	4.9411 cm	4.9411 cm
Physical length	4.1373 cm	4.1356 cm
Effective length	4.3047 cm	4.3030 cm
Resonant input resistance	244.5795 omhs	244.7745 omhs
Feed point position	1.4504 cm	1.4504 cm
Directivity	5.0295	5.2118
Directivity [dB]	7.0152	7.1699

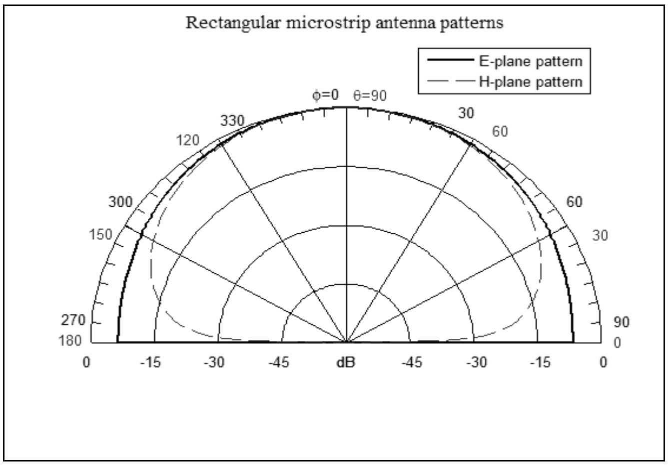

Fig. 3. The rectangular microstrip element radiation pattern.

procedure was realized for rectangular patch antenna operating at 2.4 GHz and using substrate with parameters $\varepsilon_r = 2.2$, $h = 0.1588$.

Simulation results, utilizing the LMS algorithm give precise data when adapt the beamforming pattern. To illustrate the ABF algorithm applicability for URA, we consider two cases where LMS algorithm is used: a) the URA with N=8 and M=8 elements and interelement spacing (the center-to-center separation between elements) $s_x = s_y = 0.45\lambda$ (Figs. 4 and 5); b) URA with N=8 and M=8 elements and interelement spacing $s_x = s_y = 0.45\lambda$ when using coupling compensation (Figs. 6 and 7). These figures present the Matlab simulation results. The URA is examined about following scenario: the SOI impinges from direction $(\theta = 135^\circ, \phi = 70^\circ)$ in the presence of one SNOI from direction $(\theta = 105^\circ, \phi = 95^\circ)$, that is an Additive White Gaussian Noise (AWGN) with a zero mean, and a variance 0.1. All simulation results are based on 100 times Monte Carlo runs. A stepsize is $\mu = 0.001$ and a signal with uncoded BPSK modulation are used in the numerical examples to simplify the simulations. These figures illustrate the resulting beamforming pattern with respect to $\theta_0 = 0^\circ$. The results demonstrate its good performance, characterized by accurate estimation ability, and it is evident that after compensation the radiation pattern (Fig. 7) has better ability to distinguish the SOI from the SNOI.

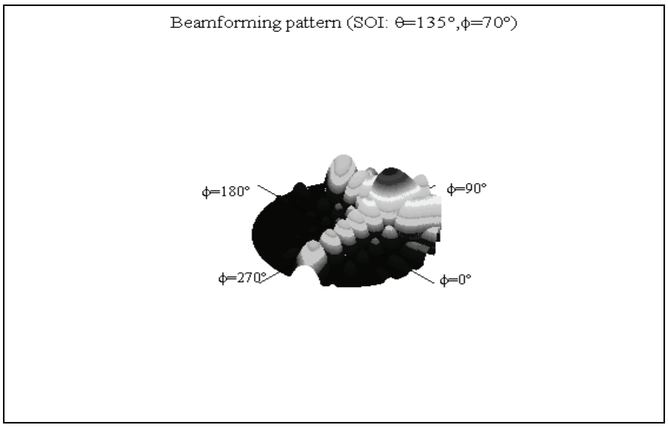

Fig. 4. Beamforming pattern 3D plot.

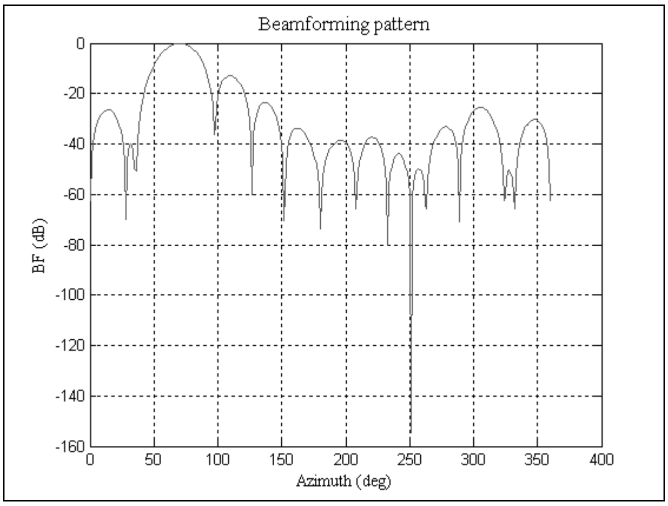

Fig. 5. Beamforming pattern 2D plot.

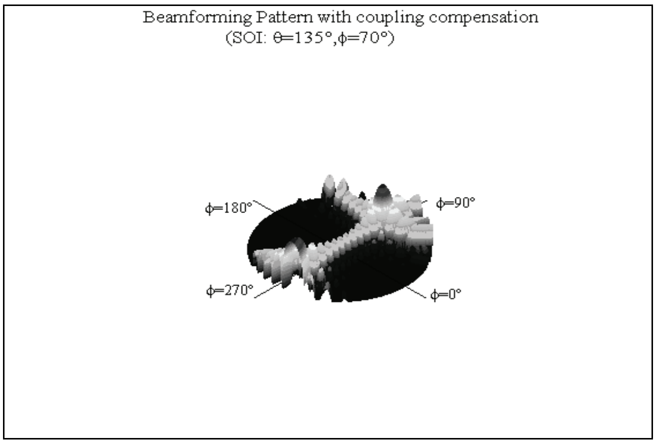

Fig. 6. Beamforming pattern after coupling compensation 3D plot.

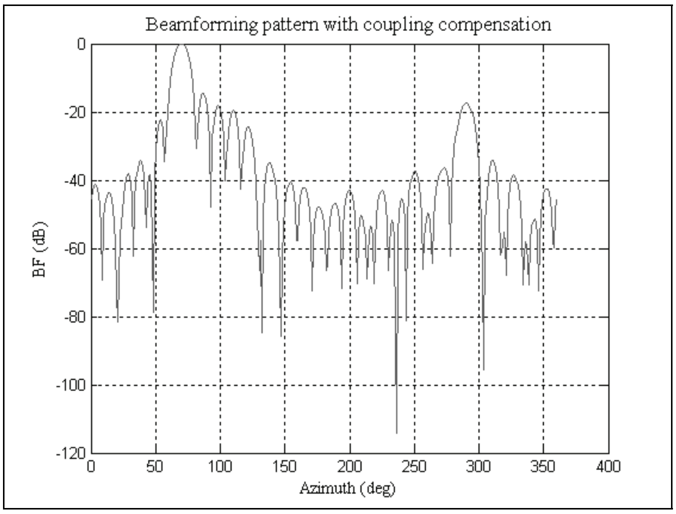

Fig. 7. Beamforming pattern after coupling compensation 2D plot.

IV. CONCLUSION

This paper investigates the issues for a single rectangular microstrip element and a uniform rectangular smart antenna array with patch elements modeling. The adaptive beamforming (ABF) and mutual coupling compensation were examined. The LMS algorithm is used after the ABF technique. As concerns to beamforming the examination array has an accurate and stable enough radiation pattern regarding both: desired signal - the beamforming pattern maximum to the SOI and interfering signals – deep nulls towards the SNOI.

Numerical simulation results are illustrated that the patch element design gives accurate results, and that the antenna geometry configuration with M=N=8 microstrip elements is an optimal scenario, because the ABF estimations are proved to be accurate and stable enough, and the ability of the smart antenna to reject undesired signals is affected by the type of elements, size and geometry of the antenna array. Consequently, it is observed that the array element choice and the smart antenna design impact on the overall wireless communication network efficiency.

The performance of the smart antenna (beamforming pattern) is examined in two cases: a) without a mutual coupling; b) with a mutual coupling compensation. Matlab programs are used for simulations. The numerical results presented here clearly display the importance of the coupling compensation.

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