Particle Swarm Optimization for Pattern Synthesis of Superconducting Antenna Array

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Abstract— **In this work, particle swarm optimization (PSO) is used to optimize the radiation pattern of non-uniform linear arrays of High superconducting tunable triangular microstrip antennas. Using super-conductors can reduce the insertion loss, and obtain a rather high gain. The full-wave method is used to study the scattering properties of superconducting tunable triangular antennas. Galerkin method is used in the resolution of the electric field integral equation. The far zone radiation fields are derived using Huygens principle and pattern multiplication approach. Also we have presented an optimization technique based on PSO algorithm, which is successfully used to determine the element excitations and/or positions of non-uniform linear antenna arrays, for simultaneous reduction of the side lobe level.**

Keywords— tunable triangular; antenna arrays; full-wave method; PSO

I. INTRODUCTION

In recent years, microstrip antennas play an increasingly significant role because of the advantages of their low profile, minimal weight, and cheap printed circuit construction. These antennas have been widely considered in investigating the structures as; millimetre wave integrated circuits, and monolithic microwave integrated circuits. In order to further improve the performance of patch antennas, it has been proposed to replace the conventional patch structures by superconductors [1]. The recent successful results of High temperature superconducting thin film technology have been encouraged, in realization of microwave circuits and antennas. Major property of superconductor is very low surface resistance compared with normal metals, such as copper, silver, and gold. Using this low surface resistance Z_s, superconductors can reduce the insertion loss, and obtain a rather high gain, but suffers from a very narrow bandwidth, which severely limits its application [2]. The superconducting microstrip antenna can take any shapes. It may regular or regular.

The radiation characteristics provided by a single element were gradually found to be inadequate. To solve this problem, an arrangement of several radiating elements called an array was developed. Large numbers of papers are devoted to the important problem of array synthesis. Recently, several microwave design optimization problems, are using, a stochastic technique of global optimization appeared based on genetic algorithms (GAs) and particle swarm optimization (PSO), and particularly, for design optimization of array antennas [3-4]. In this paper a very efficient technique to derive the dyadic Green's function in the Fourier transform domain. The complex resonant frequency of a tunable triangular patch on uniaxial substrate is calculated by using Galerkin method in solving the integral the integral equation. The sinusoidal functions are selected as the basis functions, which show fast numerical convergence. The radiation pattern of non uniform linear arrays is presented by using the method of neural network which will be applied to the synthesis of linear arrays.

II. FORMULATION OF PROBLEM

As shown in Fig. 1, the geometry of non periodic array with a non uniform for even number of identical elements (2N). The phase Ω_i, spacing Y_i and current I_i, have symmetry with respect to the centre of the linear array.

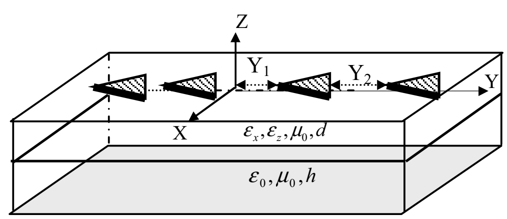

Fig. 1. Geometry of 2N element non periodic Linear array with non-equidistant elements

Each one element of the array antennas is an high Tc superconducting triangular patch as illustrated in fig.2, of thickness t, and and sidelength W, is printed on a grounded uniaxial dielectric of thickness d. An adjustable air gap layer of thickness h is inserted between the substrate and perfectly conducting ground plane.

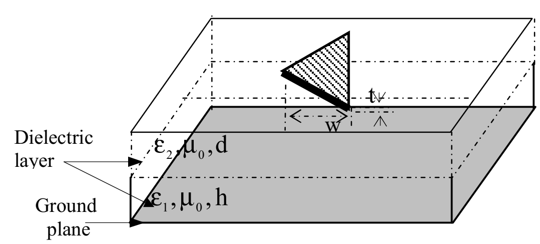

Fig. 2. Geometry of High superconducting tunable triangular microstrip patch on uniaxial substrate

The transverse field components in the *j*th layer can be obtained using the Fourier transform formulation .

$$\tilde{\tilde{E}}(k_s,z)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\overline{E}(x,y,z).e^{-j(k_x.x+k_y.y)}dx.dy \quad (1)$$

$$\tilde{\tilde{H}}(k_s,z)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\overline{H}(x,y,z).e^{-j(k_x.x+k_y.y)}dx.dy \quad (2)$$

Starting from Maxwell's equations in the Fourier transform domain, the relationship between the patch current and the electric field on the patch is given by:

$$\tilde{\tilde{E}}(\mathbf{k}_s)=\overline{Q}(\mathbf{k}_s)\cdot\tilde{\tilde{J}}(\mathbf{k}_s) \quad (3)$$

Where $\overline{Q}$ is the spectral dyadic Green's function and $\tilde{\tilde{J}}(\mathbf{k}_s)$ is the current on the patch.

To include the effect of the superconductivity of the microstrip antenna in full-wave analysis, surface complex impedance for a plane electromagnetic wave incident normally to its surface is defined as the ratio of $|E|$ to $|H|$ on the surface of the sample it is given by:

$$Z_S=R_S+X_S \quad (4)$$

Where R_s and X_s are the surface resistance and the surface reactance.

When the thickness t of the superconducting patch is less than three times the penetration depth λ_0 at a

temperature $T=0K$ the surface impedance can be approximated as follows:

$$Z_S=\frac{1}{t\sigma} \quad (5)$$

Where the conductivity $\sigma=\sigma_c$ is real for conventional conductors. These approximations have been verified for practical metallization thicknesses by comparison with rigorous mode matching result. For superconductors, a complex conductivity of the form $\sigma=\sigma_n(T/T_c)^4-i(1-(T/T_c)^4)/\omega\mu_0\lambda_0^2$, where σ_n is often associated with the normal state conductivity at T_c and λ_0 is the effective field penetration depth [2].

Now, we have the necessary Green's function, it is relatively straightforward to formulate the moment method solution for the antenna characteristics. The boundary condition at the surface of the rectangular microstrip is given by $\overline{\mathbf{E}}_{scat}+\overline{\mathbf{E}}_{inc}-\overline{Z}_{\mathbf{s}}\cdot\overline{J}=0$

Here $\overline{\mathrm{E}}_{\mathrm{inc}}$ and $\overline{\mathrm{E}}_{\mathrm{scat}}$ are tangential components of incident and scattered electrics fields.

The transverse electric fields out of the patch can be expressed via the inverse Fourier transform as follows:

$$E_x(x,y)=\frac{1}{4.\pi^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}[(G_{xx}-Z_S).\tilde{J}_x+G_{xy}.\tilde{J}_y]e^{j(k_x.x+k_y.y)}.dk_x.dk_y \quad (6)$$

$$E_y(x,y)=\frac{1}{4.\pi^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}[G_{yx}.\tilde{J}_x+(G_{yy}-Z_S).\tilde{J}_y].e^{j(k_x.x+k_y.y)}.dk_x.dk_y \quad (7)$$

The far zone radiation fields are derived using Huygens principle. The basic equations of far zone fields of superconducting tunable triangular patch antennas are given as:

$$E_\phi(\theta,\phi)=-E_x\sin\phi+E_y\cos\phi \quad (8)$$

$$E_\theta(\theta,\phi)=E_x\cos\theta\cos\phi+E_y\cos\theta\sin\phi \quad (9)$$

In many array structures, triangular microstrip antennas find more applications than any other geometry of microstrip antenna. For simplicity in analysis, the overall radiation pattern of an antenna array can be obtained by multiplying the array factor of the array and the element pattern of the superconducting tunable triangular antenna. Hence, in an array of identical antennas, the radiation pattern of the array is given by:

$$AF(\theta,\phi)=\left(\left|\frac{E_{\theta,\Phi}}{E_{\max}}\right|\right).F(\theta,\phi) \quad (10)$$

Where

$$F(\theta,\phi)=\sum_{i=1}^{2N}I_i\exp[j(k_0Y_i\sin\theta\cos\phi+\Omega_I)] \quad (11)$$

Recently, Through, to determine the values of parameters (Ω_i, Y_i and I_i), we used particle swarm optimization (PSO) to approximate the radiation pattern function, for getting better the radiation pattern of array. Particle swarm optimization (PSO) was developed in 1995 is by James Kennedy and Russell Eberhart. This technique is an optimizer that models the behaviour and intelligence of a swarm of bees, school or fish or flock of birds in searching for food. In technique particle swarm optimization (PSO), the swarm is typically modelled by particles. These particles fly through hyperspace and have two essential reasoning capabilities: their memory of their own best position and knowledge of the global best. Each particle will move from its current position using the velocity and the distance from current best local and global solution reached. The basic pseudo code for the PSO algorithm, given by reference [3] was used to optimize the radiation pattern of linear array of superconducting triangular antennas: In antenna array problems, there are many parameters that can be used to evaluate the fitness function such as; gain, side lobe level, and radiation pattern. Here, we are interested in designing a linear array with minimum side lobes levels. Thus, the following fitness function is defined by:

$$\text{fitness} = \min\left(\sum_{\varphi_i=\varphi_0}^{\varphi_i=\varphi_R} (\max \ \text{NLS}(\theta, \varphi_i)) / R\right) \quad (12)$$

Where

$\text{Max NLS}(\theta, \varphi)$ is the maximum sidelobe level obtained by using PSO, respectively, and R is the total sample points.

III. RESULTS

The aim in this section is to valid our results, the proposed antenna patch was carried out by using the Galerkin method in the spectral domain. The change in the resonance frequency of a triangular microstrip antenna with perfect conductor patch, caused by the variation in the air gap thickness was theoretically studies in [5], [6]. The results of these studies are compared with our theory in table 1 (W=15.5mm, d=0.508mm, ε_{r2}=2.2, ε_{r1}=1). The comparison among the theories and measurements shows good agreement.

TABLE I. COMPARISON OF CALCULATED RESONANT FREQUENCIES OF EQUILATERAL TRIANGULAR MICROSTRIP PATCH

h(mm)	Fr (GHz)			
	Measured [6]	**Guha [6]**	**Nasimuddin [5]**	**Present model**
0.35	9.512	9.547	9.518	9.678
0.28	9.433	9.447	9.437	9.485
0.00	8.324	8.325	8.325	8.516

The tunability has been theoretically studied in Figs 12-13. The design data are presented for two different substrates having widely varying dielectric constant. The superconducting patch is fabricated with an YBCO thin film. The resonant frequency normalized with respect to that with d = 0 is plotted against (h/d) with d = 0.508 mm. In Figure 3, the resonant frequency versus the air separation (h/d) for various substrate materials is shown. It is observed that when the air separation grows, the resonant frequency increases rapidly until achieving a maximum operating frequency at a definite air separation d_{max}. Note that the effect of the air gap is more pronounced for small values of d_1. This air gap tuning effect increases when the substrate relative permittivity value is increased. Graphical representation of the bandwidth is shown in Figure 4. Note that it increases monotonically with increasing air separation.

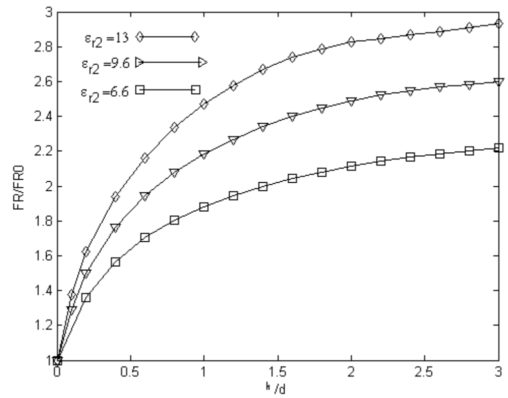

Fig. 3. The Resonant Frequency normalized of HTSTMA structure with respect to that for h=0 versus d_1/d_2 ($\sigma_n=10^6$ S/m, λ_0=140 nm and T_c=89K, T=50K, d= 0.508 mm, t=350nm, and W=1.0cm). (ε_{r2}= 13, FR0= 5.097GHz); (ε_{r2}= 9.6, FR0=5.82GHz); (ε_{r2}= 6.6, FR0= 6.87GHz).

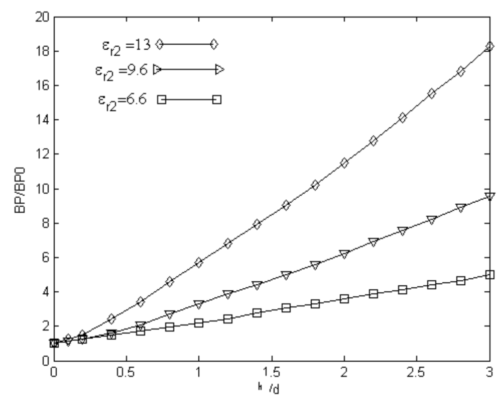

Fig. 4. The Bandwidth normalized of HTSTMA structure with respect to that for h=0 versus d_1/d_2 ($\sigma_n=10^6$ S/m, λ_0=140 nm and T_c=89K, T=50K, d= 0.508 mm, t=350nm, and W=1.0cm). (ε_{r2}= 13, FR0= 5.097GHz); (ε_{r2}= 9.6, FR0= 5.82GHz); (ε_{r2}= 6.6, FR0= 6.87GHz).

In order to illustrate the capabilities of the particle swarm optimization (PSO) to find acceptable side lobe level (SLL), equal or less than the desired value. The PSO program has been written in Matlab language. using 400 iterations. The number of particles taken is 200, the values of C1 and C2 are 2 respectively, and we have set (W1 = 0.9, W2 = 0.4). In fig. 5, we consider a linear array of the 8 and 16 elements, which non-uniform spacing and excitations of elements. The fitness value reached to it minimum, this number is found to be sufficient to obtain satisfactory patterns with a desired performance. The optimum parameters of amplitudes of excitation and positions obtained by our formulation using PSO are utilized to plot the variation of radiation patterns, which shown in Fig. 5. Clearly, our results are generally better in terms of the sidelobe level and directivity of radiation pattern.

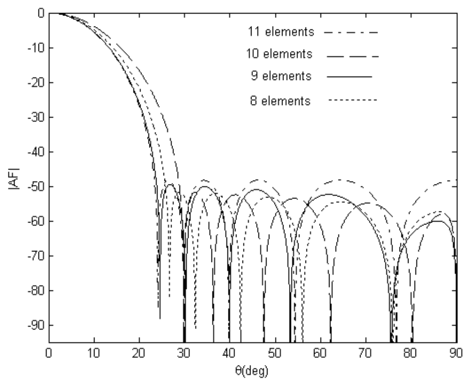

Fig. 5. Radiation pattern of linear array of (8-11) superconducting equilateral triangular microstrip antennas versus angle θ ($\sigma_n=10^6$ S/m, λ_0=140 nm and T_c=89K, d= 254µm, t=350nm, $\varepsilon_x=\varepsilon_z$= 23.81, and W=1.4mm).

IV. CONCLUSION

Our studies investigated the performance of superconducting microstrip rectangular mounted on linear array. Method utilised in our studies is based on spectral method, which the integral equation formulation is developed by using the basis functions. To include the effect of the superconductor microstrip antenna in full-wave analysis, the surface complex impedance has been considered. The effects of the superconductor patch thickness on resonant frequency and bandwidth are presented. Also we have developed the radiation pattern of array of 8-11 microstrip triangular antennas, on uniaxial anisotropic substrate.

Also we have presented an optimization technique based on PSO algorithm, which is successfully used to determine the element excitations and positions of non-uniform linear antenna arrays, for simultaneous reduction of the side lobe level. The study utilised in this work is just valid for a linear array of superconducting triangular antennas by using pattern multiplication approach, and results are reasonably and therefore this approach can be used for circular array of superconducting triangular antennas.

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