PHASED ARRAY USING RECTANGULAR MICROSTRIP PATCH

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ABSTRACT

The rectangular microstrip patch antenna and its phased arrays are analyzed using the full wave Transverse Transmission Line (TTL) method. For the microstrip patch resonator a set of equations that represents the electromagnetic fields in the *x* and *z* direction as function of the fields in the *y* direction are obtained applying the TTL method. The phased array is analyzed in a planar microstrip antenna. Numerical results, in 2D and 3D, of the radiation pattern for some phase excitation in a phased array are shown.

INTRODUCTION

Different configurations of the microstrip antenna can be used on spacecraft and aircraft applications, as patch antenna reflector array, microstrip patch antenna arrays, square patch, wide band array, in land mobile satellite communications, with various kinds of substrate and in biomedical applications [1]-[13]. In particular the phased arrays are frequently used in radar application and wireless communications.

Basically, the phased antenna array is composed of a group of individual radiators which are distributed and oriented in a linear or two-dimensional spatial configuration. The magnitude and phase excitations of each radiator can be individually controlled to form a field radiation of any desired shape in space. The position of the field in space is controlled electronically by adjusting the phase of the excitation signals at the individual radiators.

Phased antennas array have properties that make the best choice for directivity in modern mobile communication. They are well suited for use in the microwave frequencies. In the transmitter they add the output power of several amplifiers. With digital beam forming, phased antennas array can create beams of virtually any form, varying the bandwidth, gain etc. The beam can be quickly reconfigured, typically in a few nanoseconds.

This work also is devoted for various applications of rectangular microstrip phased antenna array by using the dynamic TTL-Transverse Transmission Line method, including substrate with losses or semiconductor, as GaAs, that can be used in active devices. Graphics in 2-D and 3-D, of the field radiation are shown for several phase excitation in a planar array. In the Fig. 1 an planar microstrip array of 3x3 elements is shown. The microstrip antenna consists of a radiating structure spaced a small fraction of wavelength (0.01 to 0.05 free-space wavelength) above a conducting ground plane. Antenna arrays of this type have found applications where low cost, lightweight, reduced dimensions, and high efficient are necessary requirements for wireless communications and can be used in many applications over the broad range of frequencies.

Recently several works using the TTL method was published, being shown the efficiency of this method in several structures H.C.C. Fernandes et al [3], [14-17].

Usually the radiation pattern of a single element is relatively wide, and each element provides low values of directivity.

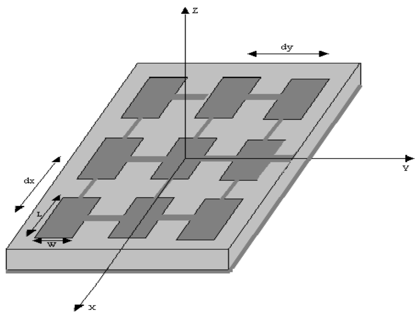

Fig. 1. Planar microstrip phased antenna array of 3x3 elements.

In many applications it is necessary to design antennas with very high directive characteristics to meet demands of long distance communications using antenna array. Results for the phased antenna array are presented, confirming the exactness of the TTL method applied to such devices and showing the influence of the phase.

THEORY

Considering the microstrip antenna resonator of Fig 2, the equations that represent the electromagnetic fields in the **x** and **z** direction as function of the electric and magnetic fields in the **y** direction are obtained applying the TTL method.

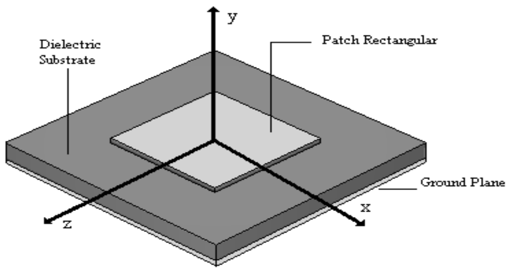

Fig 2. Microstrip patch antenna resonator

Starting from the Maxwell's equations and after various algebraic manipulations the general equations for the structure in the FTD are obtained, for the **x** direction as:

$$\tilde{E}_{xi} = \frac{1}{\gamma^2 + k_i^2}\left[-j\alpha_n \frac{\partial}{\partial y}\tilde{E}_{yi} + \omega\mu\beta_k \tilde{H}_{yi} \right] \quad (1)$$

$$\tilde{H}_{xi} = \frac{1}{\gamma^2 + k_i^2}\left[-j\alpha_n \frac{\partial}{\partial y}\tilde{H}_{yi} - \omega\varepsilon\beta_k \tilde{E}_{yi} \right] \quad (2)$$

and for **z** direction as:

$$\tilde{E}_{zi} = \frac{1}{\gamma^2 + k_i^2}\left[-j\beta_k \frac{\partial}{\partial y}\tilde{E}_{yi} - \omega\mu\alpha_n \tilde{H}_{yi} \right] \quad (3)$$

$$\tilde{H}_{zi} = \frac{1}{\gamma^2 + k_i^2}\left[-j\beta_k \frac{\partial}{\partial y}\tilde{H}_{yi} + \omega\varepsilon\alpha_n \tilde{E}_{yi} \right] \quad (4)$$

where i = 1, 2 are the regions dielectric of structure, $\gamma_i^2 = \alpha_n^2 + \beta_k^2 - k_i^2$ is the propagation constant in **y** direction, α_n is spectral variable in **x** direction, β_k is spectral variable in **z** direction, $k_i^2 = \omega^2\mu\varepsilon = k_0^2\varepsilon_{ri}^*$ is number of wave of i*th* dielectric region and $\varepsilon_{ri}^* = \varepsilon_{ri} - j\frac{\sigma_i}{\omega\varepsilon_0}$ is the relative electric permissive of material, α_n is the spectral variable, k is the wave number , $\Gamma=\alpha+j\beta$ is the complex propagation constant, α is the attenuation constant, β is the phase constant and γ is the propagation in the y direction in the FTD-Fourier Transform Domain.

After the application of the boundary conditions, the Moment method is used to eliminate the electric fields and to obtain the homogeneous matrix equation for the calculation of the complex resonant frequency. The roots of this matrix are the real and imaginary resonant frequencies.

To provide radiation in two angular dimensions, a planar array of radiating elements is used. The complete field of the array is the field of one element positioned at the origin multiplied by the factor array. This is function of the geometry of the array and of the phase excitation. Changing the distance and the phase of the elements, the characteristics of the factor array and of the complete field can be controlled [2]. A planar array of *M x N* uniformly spaced identical microstrip antenna elements localized along the any axis of the coordinate system is considered. The pattern field of the planar array, is given by :

$$E(\theta,\phi) = F(\theta,\phi)\cdot T_x T_y \quad (3)$$

where $F(\theta,\phi)$ is the element pattern, T_x and T_y are the factors array in the x and y directions, respectively.
The element pattern is:

$$F(\theta,\phi) = \frac{sin\left(\frac{k_0 h}{2} sin\theta cos\phi\right)}{\frac{k_0 h}{2} sin\theta cos\phi} \frac{sin\left(\frac{k_0 W}{2} cos\theta\right)}{\frac{k_0 W}{2} cos\theta} sin\theta \quad (4)$$

In these equations *h* is the dielectric substrate thickness and *W* is the width of the antenna element.

The factor array is calculated, considering the excitation, phase and the relative displacement between the elements as well as the dimensions and number of elements. The factor array of a rectangular planar array of *M* x *N* elements is then given by

$$T_x = \sum_{m=-N_x}^{N_x} I_{m0}\, exp\left[j\left(mk_0 d_x sin\theta cos\phi + \beta_x\right)\right] \quad (5)$$

$$T_y = \sum_{m=-N_y}^{N_y} I_{n0}\, exp\left[j\left(nk_0 d_y sin\theta sin\phi + \beta_y\right)\right] \quad (6)$$

where β_x is the phase excitation and I_{m0}, is the *real* current gain, in this x direction, β_y is the phase excitation and I_{n0}, is the *real* current gain in the y direction, and, the current in the surface is [5]

$$I_{mn} = I_{mo} \,.\, I_{no} \quad (7)$$

Considering the phase excitation uniform, the total excitation can be defined by Imn=Io, then the array factor will be expressed as:

$$T = I_o \sum_{m=1}^{M} e^{j(m-1)(kd_x sin\theta\cos\phi + \beta_x)} \sum_{n=1}^{N} e^{j(n-1)(kd_y sin\theta\cos\phi + \beta_y)} \quad (8)$$

Techniques for maximize the output power in adaptive antenna have been developer [18].
Normalizing (8), it is obtained the factor array [5]:

$$T(\theta,\phi) = \left\{ \frac{1}{M} \frac{sin\left(\frac{M}{2}\psi_x\right)}{sin\left(\frac{\psi_x}{2}\right)} \right\} \left\{ \frac{1}{N} \frac{sin\left(\frac{N}{2}\psi_y\right)}{sin\left(\frac{\psi_y}{2}\right)} \right\} \quad (9)$$

where

$$\psi_x = kd_x sin\theta\cos\phi + \beta_x \quad (10)$$

$$\psi_y = kd_y sin\theta\cos\phi + \beta_y \quad (11)$$

In the planar array, the element spacing and lattice must be chosen so that the total number necessary of elements in the planar array is minimized.

For a rectangular lattice, the principal maximal and grating lobes can be located by

$$sin\theta\cos\phi - sin\theta_0\cos\phi_0 = \pm\frac{m\lambda}{d_x},\ m = 0,1,2,... \quad (12)$$

$$sin\theta\cos\phi - sin\theta_0\cos\phi_0 = \pm\frac{n\lambda}{d_y},\ \ n = 0,1,2,... \qquad (13)$$

and the element spacing must be chosen so that

$$\frac{\lambda}{d_x} = \frac{\lambda}{d_y} = 1 + sin\theta_m \qquad (14)$$

where θ_m is the maximal scan angle.

NUMERICAL RESULTS

The computational program used to calculate the factor array and the complete radiation field for the planar phased antenna array was developed in FORTRAN PowerStation and MATLAB 5.0, using a 500 MHz PC microcomputer. In all the graphics it will be considered the values of the frequency (f=2.5 GHz), dielectric effective and relative constants (ε_{ef} = 8,3, ε_r = 12), height of the substrate (h = 2.5mm). Different values may be used obviously. The total field will be given as function of phases β_x and β_y, distance between the elements radiators (d_x=d_y for square lattice) and number of elements radiators.

The Fig. 3 and 4 shows the radiation pattern to the E-plane and the H-plane, respectively, the phased array is constitute of 4x4 elements with phase shift equal to π/8, the maximal scan angle is π/3 resulting in a spacing equal at 0,536λ.

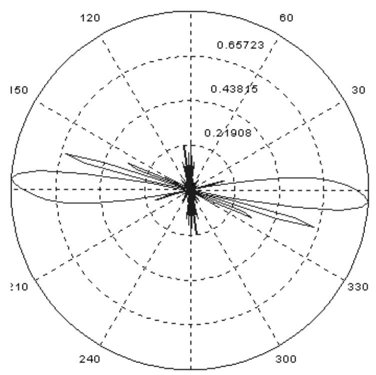

Fig. 3. Plane E for the microstrip antenna array with β_x=β_y=π /8 and d_x=d_y=0,536λ

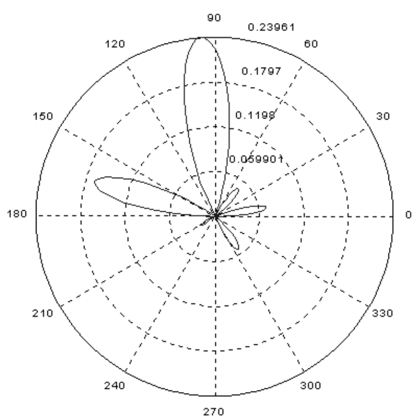

Fig. 4. Plane H for the microstrip antenna array with β_x=β_y=π /8 and d_x=d_y=0,536λ

In Fig. 5 and 6 the same array is considered however the shift phase is equal to maxim possible for this array. This is the maximal angle scan, larger angles would result in high power losses. The solution is to adjust the spacing between the elements as shown in (14).

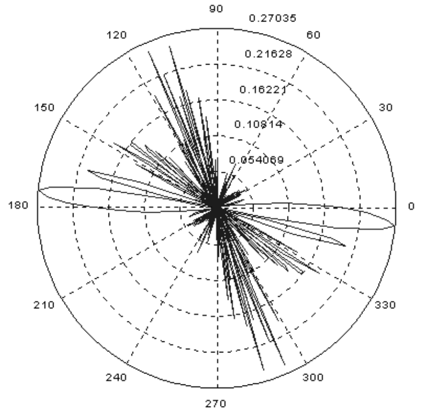

Fig. 5. Plane E for the microstrip antenna array with β_x=β_y=π /3 and d_x=d_y=0,536λ

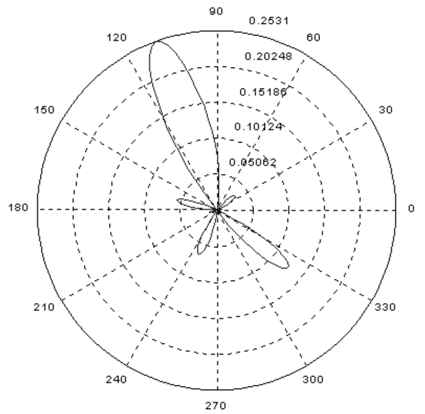

Fig. 6. Plane H for the microstrip antenna array with β_x=β_y=π /3 and d_x=d_y=0,536λ

The Fig. 7 and 8 shows the pattern radiation field. The microstrip antenna is form for a phased array of 4x4 elements and phase shift in **x** and **y** directions (β_x, β_y) equal to π/4 and maximal scan angle of 60^o , in Fig. 7. In the Fig. 8 have 7x7 elements, β_x=β_y=π/7 and maximal scan angle of 45^o . The modification in phase excitation has the objective of adjusting the antenna for new transmission or reception conditions, not being necessary mechanical fittings. The other parameters that constitute the microstrip planar stay the same ones.

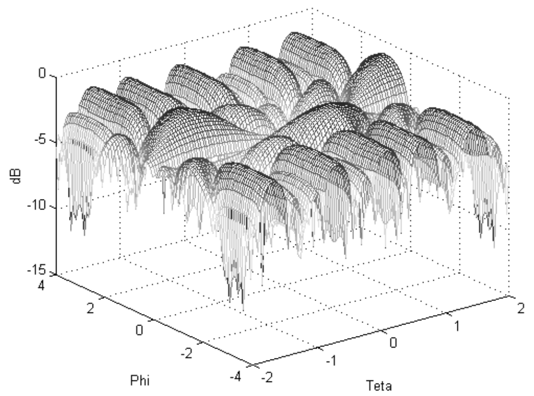

Fig. 7. Radiation Pattern for the microstrip antenna array with $\beta_x = \beta_y = \pi/4$.

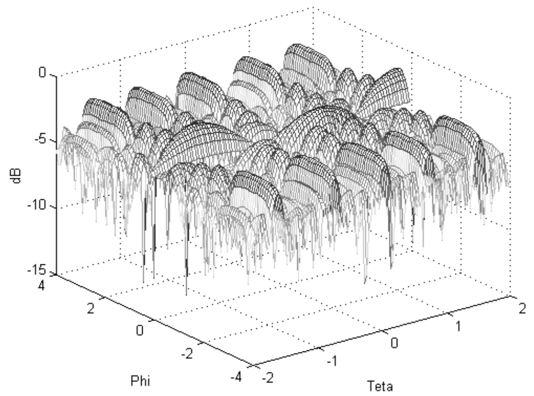

Fig. 8. Radiation Pattern for the microstrip antenna array with $\beta_x = \beta_y = \pi/7$.

CONCLUSIONS

The Transverse Transmission Line (TTL) method was used for analysis of the microstrip phased antenna array. The TTL is an efficient and accurate method applied to the analysis and design of rectangular microstrip antenna arrays. This is a very versatile method that can be used with a losses less and a losses or semiconductor substrate in various planar structures. The antenna phased array has been shown very efficient and used in several applications. Radiation diagrams were presented in 2D and 3D for the array of microstrip antenna. It was observed that the variation of the phase excitation has a great influence on the array, including modifications in the radiation pattern. The computational programs was developed in FORTRAN PowerStation and in MATLAB 5.0 using a 500 MHz PC microcomputer.

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