# Study on Superconducting Microstrip Antenna Array Using TTL Analysis

**Rogério T. Carvalho Filho, Eritonio F. Silva and Humberto C. Chaves Fernandes**

*Abstract* — **For the microstrip patch resonator, as a planar antenna of a microstrip, a set of equations that represents the electromagnetic fields in the *x* and *z* direction as function of the electric field in the *y* direction are obtained applying the transverse transmission line method. This method is very suitable at microwave and antenna applications, and gives accurate complex resonant frequency which contributes definitively to obtain higher precision antenna parameters. For each type of array is calculated the array factor, considering the excitation, phase and the relative displacement between the elements as well as the dimensions and number of elements.**

*Index Terms* - **Microstrip, antenna array, TTL method, Wireless.**

## I. INTRODUCTION

The rectangular microstrip antenna arrays is analyzed using the concise full wave Transverse Transmission Line (TTL) method. The microstrip antenna can be used on spacecraft and aircraft applications in different configurations, 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]-[14].

Graphics that show the variation of the complex resonant frequency for the radiation patterns in the E and H-plane for arrays with superconducting resonator are presented in 2-D and 3-D. This work also is expanded for various applications of rectangular microstrip patch antenna by using the TTL method including substrate with losses or semiconductor, as GaAs, that can be used in active devices. 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.

The radiating patch can assume virtually any shape, but simple geometry are generally used in order to simplify the analysis and the performance prediction. In this work, was used rectangular patch. **A**pplications using the TTL method has been presented in [3].

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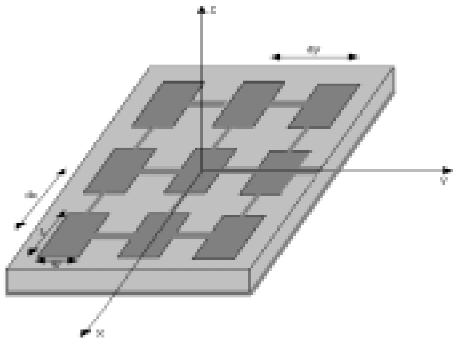


Fig. 1. Microstrip antenna array of 3x3 elements.

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.

Usually the radiation pattern of a single element is relatively wide, and one element provides low values of directivity. In many applications it's necessary to design antennas with very high directive characteristics to meet demands of long distance communications, using antenna array. Results for the rectangular-patch antenna array, efficiency, bandwidth and quality factor are presented, confirming the exactness of the TTL method and showing the influence of the complex resonant frequency on those parameters. Different phase localization of the elements array are also considered.

## II. THEORY

Considering the microstrip patch antenna resonator, 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. Starting from the Maxwell's equations and after various algebraic manipulations the general equations for the structure in the FTD are obtained, for example at the z direction as:

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

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

where $\gamma^2 + k^2 = \alpha_n^2 - \Gamma^2$ , $\alpha_n$ is the spectral variable, k is the wave number , $\Gamma=\alpha+j\beta$ is the complex propagation constant, $\alpha$ is the attenuation constant, $\beta$ is the phase constant and $\gamma$ 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.

The complete field of the array is given by the field of a single element multiplied by the factor array, that is a 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 of the array can be controlled [2]. A linear array of *n* uniformly spaced identical microstrip antenna elements localized along the any axis of the coordinate system is considered. The pattern field of the linear array, is given by :

$$\mathrm{E}(\theta,\phi) = \mathrm{F}(\theta,\phi).T \qquad (3)$$

$$T = \sum_{i=1}^{n} V_i \, exp\left(jk_0 d_i cos\theta\right) \qquad (4)$$

where $F(\theta,\phi)$ is the element pattern and T is the factor array. In these equations, $V_i$ the voltage across the ith slot, $d_i$, the distance between them [2]. The pattern field in the E and H-plane for the microstrip radiator element may be treated as a resonator. The radiator of length *L* and width W of each element, has in the H-plane and E-Plane [2],

$$F(\theta) = \frac{sin\left(\frac{k_o W}{2}\cos\theta\right) sin\theta}{\frac{k_o W}{2}\cos\theta} \qquad (5)$$

$$F(\phi) = \frac{sin\left(\frac{k_o h}{2}\cos\phi\right)}{\frac{k_o h}{2}\cos\phi} \cos\left(\frac{k_o L}{2}\cos\phi\right) \qquad (6)$$

where *h* is the dielectric substrate thickness.

The length, *L*, and the width, W, are input data to obtain the complex resonant frequency using the TTL method. The method of analysis for the linear arrays is extended to planar arrays, which may comprise rectangular, circular or elliptical distribution of elements. Some results for the rectangular configuration are considered. The pattern field for the planar array is given by:

$$E(\theta,\phi) = F(\theta,\phi)\cdot T_x T_y \qquad (7)$$

where the pattern element is:

$$F(\theta,\phi) = \frac{sin\left(\frac{k_0 h}{2} sin\theta cos\phi\right)}{\frac{k_0 h}{2} sin\theta cos\phi} \frac{sin\left(\frac{k_0 W}{2} cos\theta\right)}{\frac{k_0 W}{2} cos\theta} sin\theta \qquad (8)$$

and the factor array in the x and y axis are,

$$T_x = \sum_{m=-N_x}^{N_x} I_{m0} \, exp\left[j\left(mk_0 d_x sin\theta cos\phi + \beta_x\right)\right] \qquad (9)$$

$$T_y = \sum_{m=-N_y}^{N_y} I_{n0} \, exp\left[j\left(nk_0 d_y sin\theta sin\phi + \beta_y\right)\right] \qquad (10)$$

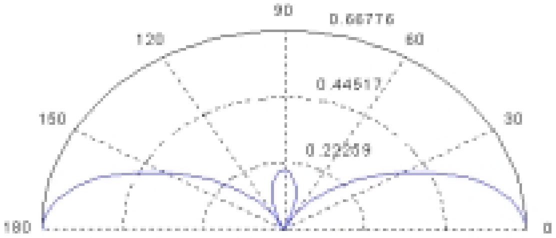
where $\beta_x$ is the phase excitation and $I_{m0}$, is the excitation coefficient of each element, in this x direction, $\beta_y$ is the phase excitation and $I_{n0}$ , is the excitation coefficient of each element in the y direction, if the amplitude excitation coefficients of the elements of the array in the y-direction are proportional to those along the x, the amplitude of the (m,n)th element can be written as [5]:

$$I_{mn} = I_{mo} \cdot I_{no} \qquad (11)$$

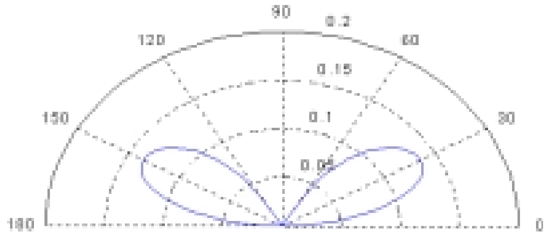
## III. Numerical Results

The computational programs used to calculate the complex resonant frequency was developed in FORTRAN Power Station and MATLAB 5.0. The radiation pattern field for the arrays is calculated using the TTL method. In all figures are used the YBCO superconductor, with the London coefficient depth $\lambda_{eff}$=150.0 nm, the thickness $t_s$= 10.0 nm , the temperature Ta= 88 K, the critical temperature Tc= 90 K, the normal conductivity $\sigma_n$=2.0 $10^5$ S/m. Another materials can be used obviously.

The Fig. 2.a and 2.b show the radiation pattern to the E-plane and the H-plane respectively, presented for the rectangular patch with W=2.5 cm, L=1.0 cm, the substrate thickness h = 1.27 mm, $\varepsilon_r$ = 2.22 , *f*=7.99 GHz and the distance between the antenna elements is d=$\lambda$/4. These plots shown in Fig. 2 were compared with results from [2] and [16]-[18] and are in accordance, and give the representation of the radiation properties of the antenna array as a function of the space coordinates for far-field region.



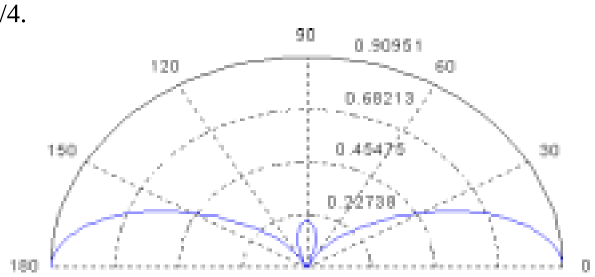

(a)



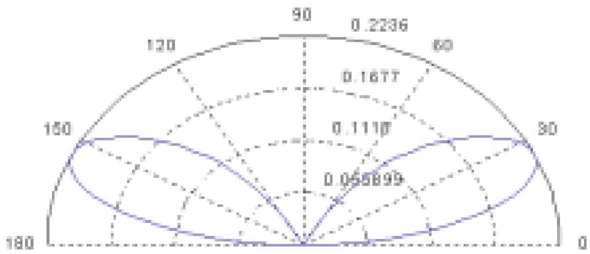

(b)

Fig. 2. Radiation Pattern field for the microstrip antenna of five elements, (a) to the E-plane and (b) to the H-plane.

The Fig. 3.a and 3.b illustrate the radiation pattern field to the E-plane and the H-plane respectively, presented for a linear array build up from five elements. Each element has these parameters: W=25.0 mm, L=10.0 mm, h=1.27 mm, $\varepsilon_r$ = 12.0, $f$ =4.08 GHz and the distance between antennas is d=$\lambda$/4.



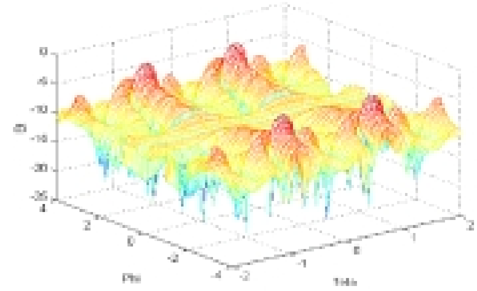

(a)



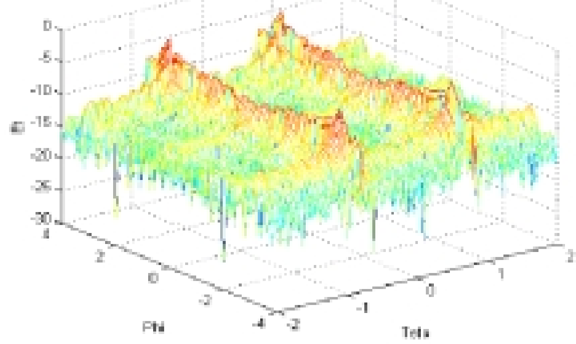

(b)

Fig. 3. Radiation Pattern field for the microstrip antenna array of five elements, (a) to the E-plane and (b) to the H-plane.

In the Fig. 4, 3D results for the radiation pattern field microstrip antenna array are presented. Are used the resonant frequency equal to 6.0 GHz, $\varepsilon_r$=2.22, $d_x$= $d_y$=$\lambda$/4 and $\beta_x$=$\beta_y$=0 of 8x8 elements for the fig.4.a and 4.0 GHz, $\varepsilon_r$=2.22 (GaAs), $d_x$= $d_y$=$\lambda$/4 and $\beta_x$=$\beta_y$=$\pi$ of 80x80 elements for the fig.4.b. The currents in the terminals of the each antenna is normalized.



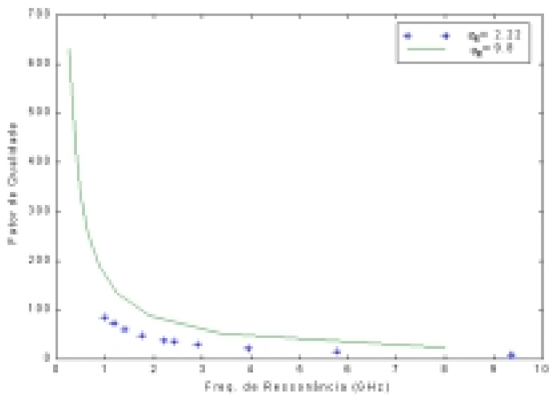
(a)



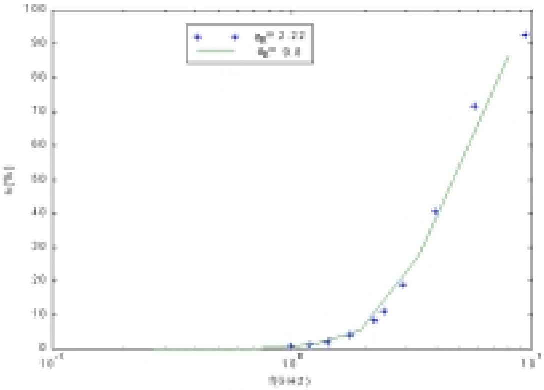

(b)

Fig. 4. Radiation Pattern for the microstrip planar antenna array, (a) (8x8) elements for $\varepsilon_r$=2.22 and (b) (15x15) elements for $\varepsilon_r$=12.0 (GaAs).

In the Fig. 5 are shown curves of the different parameters of a antenna, as so, efficiency, bandwidth and quality factor, Each element has these parameters: W=3.0 mm, L=6.0 mm, h=1.27 mm. Fig. 5a, show the graphic of the quality factor versus resonator frequency, in the Fig. 5b, show the relation between efficiency and resonant frequency and the Fig. 5c, show the graphic of bandwidth.




(a)



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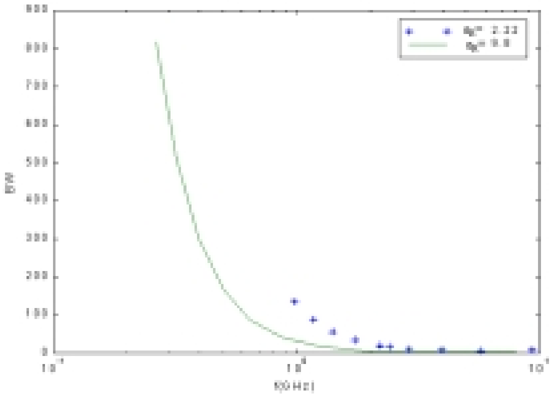

(c)

Fig. 5 - Curves of the quality factor, y bandwidth and efficiency parameters

## IV. Conclusions

The rectangular patch antenna array was analyzed using the TTL Method. Results for the complex resonant frequency and radiation pattern were presented, confirming the exactness of the TTL method applied to such devices. An accurate value of the complex resonant frequency gives a better value for the element which contributes definitively to all others parameters. Graphics that show the variation of the complex resonant frequency, radiation patterns in the E-plane and H-plane for the arrays, efficiency, bandwidth and quality factor are presented in 2-D and 3-D. In conclusion, The Transverse Transmission Line - 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 lossless or semiconductor substrate in various planar structures. The computational programs was developed in FORTRAN POWER STATION and in MATLAB 5.0. This work received financial support of the CNPq.

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