Microstrip Antennas Array with patch superconductor at High Temperature

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Abstract — **New results and the analysis of the resonance frequency and pattern fields of microstrip antennas array, with superconductor patch for different very high critical temperatures, are presented. The linear superconducting rectangular microstrip antennas array uses the new materials $Sn_5InBa_4Ca_2Cu_{10}O_y$ at temperature of 212 K, conductivity of 1.88×10^5 S/m and $Tl_5Ba_4Ca_2Cu_{10}O_y$ at temperature of 233 K with conductivity equal 2.0×10^5 S/m. The concise full wave Transverse Transmission Line (TTL) method, is used in the analysis. New results as functions of the temperature, and resonant frequency as functions of the various antenna parameters, for different superconductor are presented.**

Keywords -Ttemperature; antenna; microstrip; superconductor; patch; antenna array; linear.

I. INTRODUCTION

H. R. Onnes, in 1908,discovered that basic metals had null resistance, when the temperature was below of the critical temperature, Tc. In 1933, W. H. Meissner and R. Ochsenfeld reported that in type I superconductors, when they were caught a cold below the critical temperature, the magnetic flow was expelled of the interior of the superconductor [1] and [2]. This phenomenon is known as the Meissner effect, and it is illustrated in Figure 1.

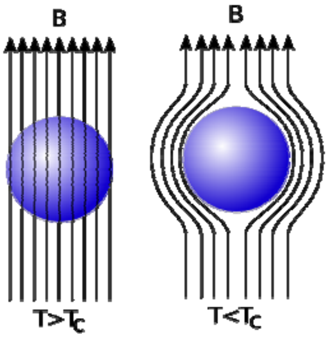

Figure 1. Behavior of superconductor in the presence of an magnetic field **B,** the Meissner effect.

A theory widely used for superconductor it is the BCS theory, developed by Bardeen, Cooper and Schrieffer. The macroscopic theory uses the two fluids model and the London equations.

In this work are used microstrip antennas with news very high superconductor patch. The structure is shown in Figure 2.

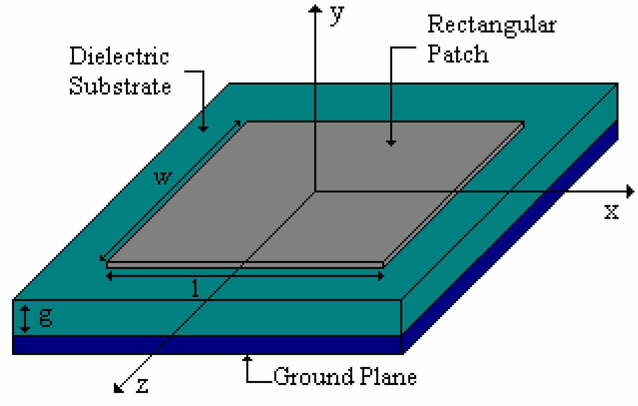

Figure 2. Superconducting microstrip antenna with patch of width, w, and length, *l*.

Considering the microstrip antenna resonator of Figure 2, the equations that represent the electromagnetic fields in the **x** and **z** directions as function of the electric and magnetic fields in the **y** direction are obtained, applying the TTL method [4]-[10].

II. THEORY

Starting from the Maxwell's equations, after various algebraic manipulations, the general equations for the antenna in the FTD - Fourier Transformed Domain are obtained, for the x and z directions as [8]-[10]:

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

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

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

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

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where i = 1, 2 are the dielectric regions 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 the wave number of the dielectric region, and $\varepsilon_{ri}^* = \varepsilon_{ri} - j\frac{\sigma_i}{\omega\varepsilon_0}$ is the relative dielectric permittivity of the complex material.

After the application of the boundary conditions, the dyadic Z matrix is obtained, and adequate basis functions are used to substitute the current densities. The electric fields are zero in the patch.

$$\begin{bmatrix} Z_{xx} - Z_S & | & Z_{xz} \\ ---- & | & ---- \\ Z_{zx} & | & Z_{zz} - Z_S \end{bmatrix} \cdot \begin{bmatrix} \tilde{J}_x \\ -- \\ \tilde{J}_z \end{bmatrix} = \begin{bmatrix} \tilde{E}_x^{out} \\ -- \\ \tilde{E}_z^{out} \end{bmatrix} \qquad (5)$$

Where, $Z_S = \frac{1}{\sigma_S t}$ (6)

Zs is the superconductor impedance, σ_s is the conductivity and "*t*" is the thickness of the superconductor patch.

The Moment method is used to eliminate the electric fields in (5), and to obtain the homogeneous matrix equation (7) for the calculation of the complex resonant frequency.

$$\begin{bmatrix} K_{xx} & K_{xz} \\ K_{zx} & K_{zz} \end{bmatrix} \cdot \begin{bmatrix} a_x \\ a_z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (7)$$

The determinant of this K matrix, witch is the inner product of the Z matrix and the basis functions, provides the real and imaginary resonant frequencies, which are numerically calculated using computational programs developed in this by the authors, in Fortran Power Station Language.

A. BCS Theory

The quantum theory of the superconductivity was launched in 1957 by the work of Bardeen, Cooper and Schrieffer. This theory include:

a) An attractive interaction between electrons can be conduced to a ground state, separated from an excited states by an energy gap, that separates the superconducting electrons below of the gap of the normal electrons. The critical field, the thermal and electromagnetic properties are many other consequences of this energy gap.

b) The penetration depth λ, appear as natural consequences of the BCS theory [3]. The London equation is obtained at the magnetic fields, that vary slowly in space. Thus the Meissner effect is obtained naturally.

c) The BCS theory predicts the critical temperature of an element or alloy. There is a paradox: the greater resistivity at room temperature, is the likelihood that this metal is a superconductor when cooled.

The London equations are used [7],

$$e\vec{E} = m\frac{d\vec{v}}{dt} \qquad (8)$$

$$\Lambda\frac{\partial\vec{j}}{\partial t} = \vec{E} \qquad (9)$$

(3.1)

III. ANTENNA ARRAYS

The antenna array [4] consists of a finite number of identical irradiants elements, which combines the induced signals in these antennas, to form the array. The maximum beam direction is controlled, adjusting the phase of the sign in elements of different spaces. The phase induced in the several adjustments in the elements, so that the sign obtain maximum directivity and gain.

(3.2)

The antenna array can be classified as linear and planar. Figure 3 shows the linear array of microstrip antenna with four elements. The linear array factor is,

$$FA_n = \left[\frac{\operatorname{sen}\left(\frac{N}{2}\psi\right)}{\left(\frac{N}{2}\right)}\right] \qquad (10)$$

Where $\psi = kd\cos\theta + \beta$ (11)

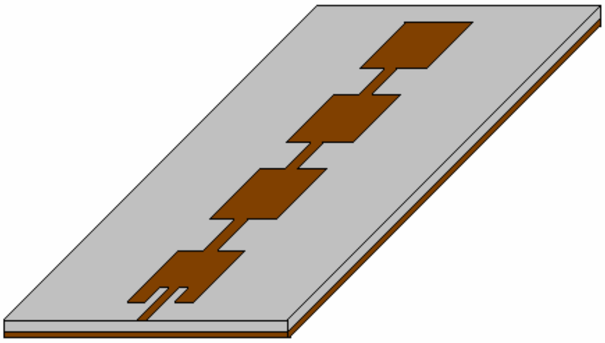


Figure 3. Linear antenna array with four superconducting patch.

IV. RESULTS

In this work the Transverse Transmission Line (TTL) method was applied, using double Fourier Transform [10].

Computational algorithms were developed in Matlab and Fortran PowerStation languages.

Fig.4 shows the frequency resonance as function of the patch length for different critical temperatures. The parameters are w = 25 mm, *l* = 30 mm, ε_{r1} = 10.233 (RT DUROID 6010), ε_{r2} = 1; and the (Sn$_5$In) Ba$_4$Ca$_2$Cu$_{10}$Oy [8] at the superconducting temperature of 212 K.

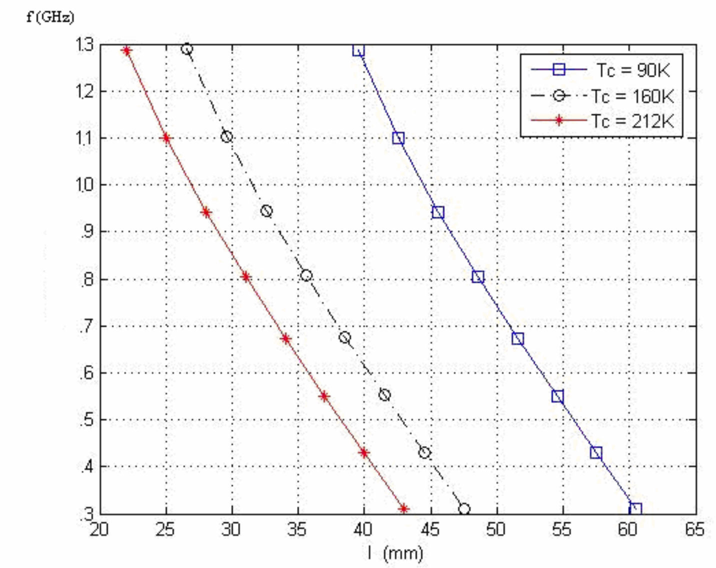


Figure 4. Resonance frequency in GHz as functions of the patch length, at critical temperature of 90 K, 160 K and 212 K.

Fig. 5 shows the frequency resonant in function to the patch length for different critical temperature. The parameters are w = 25 mm, *l* = 30 mm, ε_{r1} = 10.233, ε_{r2} = 1; and the Tl$_5$Ba$_4$Ca$_2$Cu$_{10}$O$_y$ [8] at the superconducting temperature of 233 K.

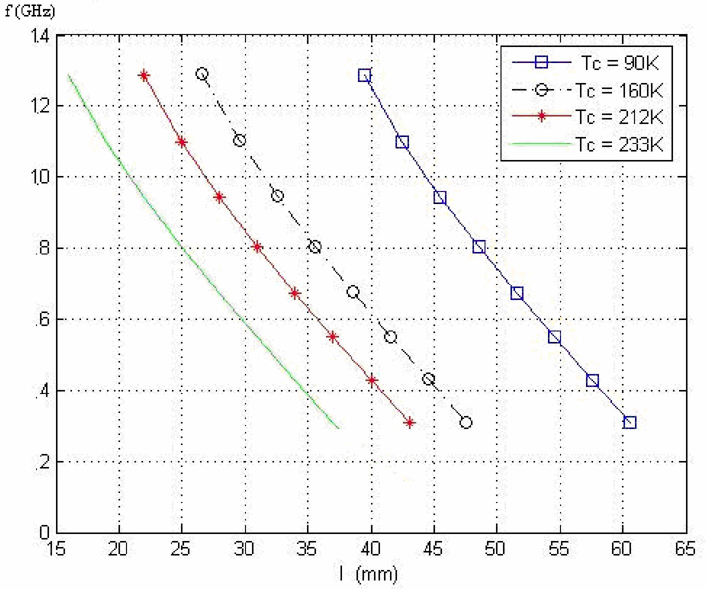
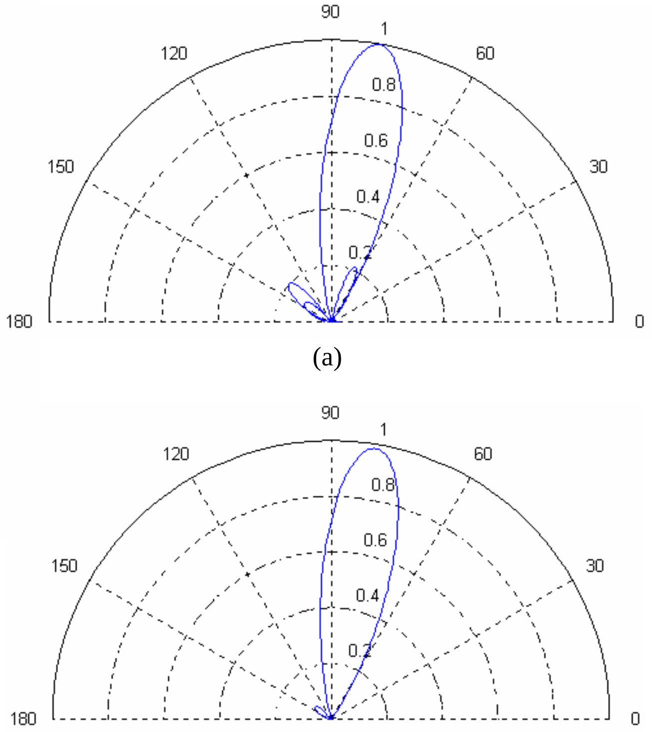


Figure 5. Resonant frequency in GHz as functions of the patch length, at critic temperature of 90 K, 160 K, 212 K and 233 K.

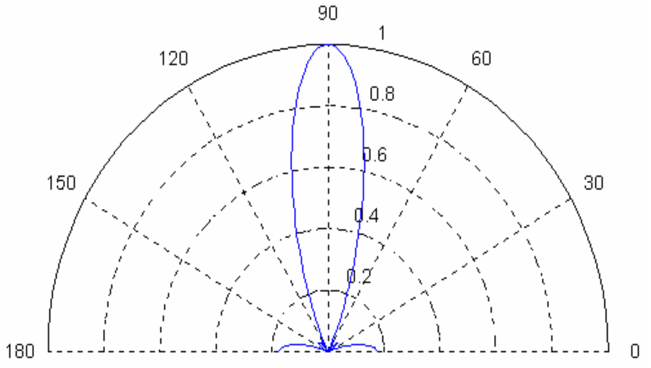
The results in the Figure 6.a and 6.b shows the pattern fields in E-Plane to a linear array with 4 elements with λ/2 for an angle of irradiation of 80^o , resulting in a phase of β = 31,25^o.

Finally the results in Figure 7.a and 7.b shows the pattern fields in H-Plane for a linear array with 4 elements with λ/2 for an angle of irradiation of the 90^o .

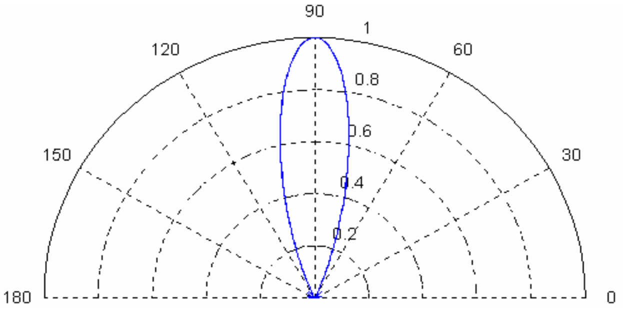


(b)

Figure 6. Irradiation Diagram for a linear array with superconductor patch at Tc = 233 K and θ = 80^o , for plane-E (a) and plane-H (b).



(a)



(b)

Figure 7. Irradiation diagram for a linear array with superconductor patch at Tc = 233 K and θ = 80º , for plane-E (a) and plane-H (b).

V. CONCLUSIONS

The main theories used to explain the phenomenon of superconductivity has been presented at new superconductor materials. The inclusion of superconducting patch was made using the resistive complex boundary condition, and the of two fluids model. Numerial results of the resonance frequency, as functions of the antenna array parameters including irradiation diagrams of the E-plane and H-plane, for linear and planar antennas arrangements, were presented. The results is good and show that, when Tc increase, the dimension of the antenna reduce. New very high critical temperature material was been presented in this sew application.

REFERENCES

[1] A. C. Rose-Innes and E. H. Roderik, "*Introduction to Superconductivity*", 2^a Edition, Pergamon Press, 1978.

[2] E. A. Linton, "*Superconductivity*", London: Mathuen & Co. LTDA, Ney York: John Wiley & Sons Inc. 1964..

[3] E. B. Eckholm and S. W. Mcknight, "Attenuation and Dispersion for High-Tc Superconducting Microstrip Lines", IEEE-MTT, Vol. 38, pp. 387-395, 1990.

[4] D. Nghiem, J. T. Williams and D. R. Jackson, "A General Analysis of Propagation Along Multiple-layer Superconducting Stripline and Microstrip Transmission Lines", IEEE-MTT, Vol. 39, No 9, pp. 1553-1565, Set.1991.

[5] J. M. Pond, C. M. Krowne and W. L. Carter, "On Application of Complex Resistive Boundary Conditions to Model Transmission Lines Consisting of Very Thin Superconductors", IEEE-MTT, Vol. 37, No 1, pp. 181-189, Jan. 1989.

[6] Z. Cai and J. Bornemann, "Generalized Spectral-Domain Analysis for Multilayered Complex Media and High-Tc Superconductor Application", IEEE-MTT, Vol. 40, No 12, pp. 2251-2257, Dez. 1992.

[7] Zhi-Yuan Shen, "High-Temperature Superconducting Microwave Circuits", Artech House, Inc. 1994

[8] H. C. C. Fernandes and L. P. Rodrigues, "Double Application of Superconductor and Photonic Material on Antenna Array", Trans. on Communications, Athens, Greece, pp. 425-432, Jul. 2004.

[9] H.C.C. Fernandes, J.R.S. Oliveira and A.J. Giarola, "Dispersion in Finlines on Semiconductor and the S-Parameters of a Step Discontinuity", International Journal of Infrared and Millimeter Waves, Vol. 12, Nº 5, pp. 505-519, Plenum Press, USA, May, 1991.

[10] H. C. C. Fernandes and H. M. C. A. Maia, "New Antenna with Superconductor at Critical Temperature of 212". IMOC2009-SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference, Belém – PA, Brazil, paper 59111. pp. 197-199, Nov. 2009.