



**HAL**  
open science

## Original accurate synthesis model applied to various shape of microstrip antennas

Jean-Marc Ribero, Jean-Pierre Damiano, Robert Staraj

► **To cite this version:**

Jean-Marc Ribero, Jean-Pierre Damiano, Robert Staraj. Original accurate synthesis model applied to various shape of microstrip antennas. Journées Internationales de Nice sur les Antennes (JINA 94), Nov 1994, Nice, France. pp.589-592. hal-00922000

**HAL Id: hal-00922000**

**<https://hal.science/hal-00922000>**

Submitted on 29 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# ACCURATE ORIGINAL SYNTHESIS MODEL APPLIED TO VARIOUS SHAPES OF MICROSTRIP ANTENNAS

J.-M. Ribero, J.-P. Damiano, R. Staraj

Laboratoire d'Electronique - Université de Nice-Sophia Antipolis URA CNRS 1400  
250 rue A. Einstein, 06560 Valbonne, France  
Tel: + 33.92.94.28.00 - Fax: +33 92.94.28.12

**Abstract -** We present an original synthesis model applied to multilayer probe-fed microstrip antennas. We have developed an original modified Wolff cavity model to obtain, with a low computing time, the optimal size and the shape of the antenna, versus the physical and geometrical parameters, necessary to a good approach. Unpublished results for elliptical and annular ring antennas are presented. We show and discuss numerical and experimental results for different synthesis.

**Résumé -** Nous présentons un modèle original pour la synthèse d'antennes imprimées multicouches alimentées par sonde coaxiale. Nous avons développé un modèle de cavité basé sur le concept de Wolff, afin d'obtenir les dimensions optimales et la forme de l'antenne en fonction des paramètres physiques et géométriques. Des résultats inédits sur des antennes en forme d'ellipse et d'anneau sont présentés. Des comparaisons théorie/expérience sont présentées et discutées.

## Introduction

Many theoretical models of probe fed microstrip antennas have aimed at determining the electrical characteristics of printed antennas of various shapes, during the last years. These different models are generally with a good agreement with experiments and other rigorous investigations. They are valid for small values of  $H/\lambda_0$  (the ratio between the substrate thickness and the wavelength). However, at our knowledge, a synthesis model for multilayer probe-fed microstrip antennas with or without an air-gap, taking into account the shape of the element has not been published yet.

On our different studies antennas (rectangle, disc, triangle, ring, ellipse) can be added a dielectric cover to offer protection against environmental hazards (ice, snow) [1 - 3] and an air-gap to obtain exactly the resonant impressed frequency [4 - 5](figure 1). The ring microstrip antenna can be proposed for dual band operation [6 - 9], and the eccentricity of the elliptical antenna allows us to obtain a wider frequency band [10 - 17].

For all these reasons, we propose an original synthesis. The analytical model introduced in the synthesis, takes into account all of these parameters and the advantages and drawback of each shape and proposed the best structure possible for each case. Electrical criteria like bandwidth, quality of polarisation, circular polarisation or efficiency versus the shape of the element are associated concurrently with geometrical and physical parameters. The behaviour of the rectangular, circular and triangular shapes are now wellknown and, in this paper, the original work is axed on the ring and elliptical shapes who shown interesting advantages in synthesis.

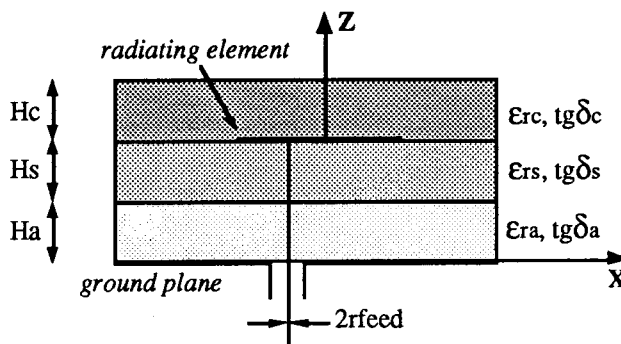


figure 1 : Studied structures

## Methodology

Our theoretical study is achieved from a modified Wolff model [3] which we have adjusted to treatment of various shapes of radiating elements. The boundary conditions are taken into account using dynamic

permittivity including physical and geometrical parameters and fringing field effects. The calculation of the dynamic edge capacitance is required. It consists in considering the radiating element as an open microstrip line for which a variational expression of the characteristic impedance allows us to take into account the multilayer lossy structure. In particular case of the ellipse the theoretical study was carried out with  $\epsilon_{eff}$  (the results with the dynamic permittivity will be presented at the conference).

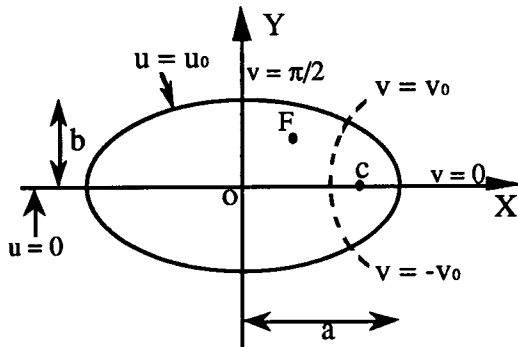


figure 2 : Elliptical coordinates

We show a coordinate system on figure 2 for an elliptical radiating element.

The focal length is  $c = \sqrt{a^2 - b^2}$

The eccentricity is defined as  $e = \frac{c}{a}$

Elliptical coordinates of  $u$  and  $v$  are used in substitution of  $X$  and  $Y$  coordinates.

They are related by the following formulas :

$$X = c \cosh (u) \cos (v)$$

$$Y = c \sinh (u) \sin (v)$$

$$u_0 = \text{Ln} \left( \frac{(a+b)}{c} \right) \text{ and } \cosh (u_0) = 1/e.$$

If  $h \ll \lambda$  dielectric, the Maxwell's equations reduce to the following equation in  $E_z$  :

$$\frac{\delta^2 E_z}{\delta u^2} + \frac{\delta^2 E_z}{\delta v^2} + k^2 c^2 (\cosh^2 (u) - \cos^2 (v)) E_z = 0 \quad \text{where } k^2 = \epsilon_{eff} \epsilon_0 \mu_0 \omega^2 \quad (1)$$

Solutions to the partial differential equation (1) are expressed in terms of Mathieu functions  $S_{om} (kc, \cos v)$  and  $S_{em} (kc, \cos v)$  and related radial functions  $J_{om} (kc, \cosh (u))$  and  $J_{em} (kc, \cosh (u))$  [10].

The even (subscript e) and odd (subscript o)  $TM_{mn}$  modes are considered for the elliptical radiating element.

The first approximation of the resonant frequency is deduced from the zeros  $q_{mn}$  (nth parametric zero of the even or odd modes) of the derivative of the radial Mathieu functions of order  $m$  for  $u = u_0$  [11].

$$2 \sqrt{q_{mn}} = k_{mn} c \quad F_{res} = \frac{c_0 \sqrt{q_{mn}}}{\pi a e \sqrt{\epsilon_{eff}}} \quad (2)$$

$\epsilon_{eff}$  is computed from the dimensions of radiating elements and from the physical characteristics of the substrate (Subscript s for the substrate, a for the air-gap and c for the cover).

The input impedance is determined using the following equivalent electrical circuit.

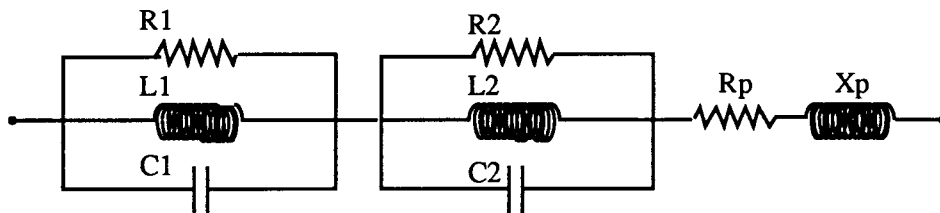


Figure 3 : An equivalent circuit for two resonances and the coaxial feed

$R1$  and  $R2$  correspond to the real part of the input impedance of the even and the odd  $TM_{mn}$  modes of the ellipse. We have considered the ellipse as a circular disk whose radius is equal to  $a$  (for  $R1$ ) or  $b$  (for  $R2$ ) for the calculation of the impedance.

The closed-form expressions for the resonant frequency and the input impedance allow us to work in synthesis. For example, the dielectric substrate being given and a set of physical criteria being known, it is easy to compute the dimensions of the patch and the optimal position of the feed to obtain a real part of the impedance equal to  $50 \Omega$ , for the impressed resonant frequency. The dimension of the patches is another important point [17].

Then, a microstrip antenna destined to be integrated in an array structure with a small distance between radiating source, should be as small as possible to limit the coupling effects. Other criteria, like the desired bandwidth, or the resonant frequencies of the superior modes must be taken into account too. The synthesis was carried out using Quick Basic on 486 DX2 computer. The different calculations were obtained in few seconds.

Thanks to this synthesis, we have deduced the advantages of each shape. We obtain a easy circular polarisation with the disk or the ring antennas. But ring had however smaller dimensions than the disk for a

same given frequency. For the same reason we will be use an ellipse rather than a disk to obtain a larger bandwidth.

## Results

We present figure 4, the theoretical variations of the characteristic size of the radiating element versus the impressed resonant frequency, for different well-known shapes. For each shape, we indicate the given dimension, for example, disc : diameter  $2a$ , ellipse : the major axis  $2a$  (eccentricity  $e = 0.622$ ). The ratio for the ellipse ( $a/b$ ) is equal to 1.5 and for the annular ring  $r_2/r_1 = 2$ . The annular ring takes less space than the other shapes. We have a very good agreement with experiments.

Figure 5 shows the case of an annular ring with a dielectric cover for the first two resonant modes  $TM_{11}$  and  $TM_{21}$ . We give the theoretical ratio ( $r_2/r_1$ ) versus the desired frequency for  $r_1 = 5$  mm and 10 mm. We can notice that the ratio  $r_2/r_1$  decreases strongly for small variations of the resonant frequency. Moreover we can choose, according to our specifications, the ratio that we want at a given frequency.

To validate our model of synthesis, we present, figure 6 the experimental and theoretical variations of the real part of the input impedance versus frequency, for an elliptical radiating element. For the even and odd mode the feed-point (F) is located at 20 mm from the center. The agreement is excellent.

The algorithm gives for example the fed position for the desired real part of the input impedance of the ellipse (for the even mode) (figure 7).

We show figure 8, for different thickness of air-gap, the variation of the eccentricity  $e$  versus the half minor axis  $b$  of the ellipse. The bandwidth increases with increase the thickness  $H_a$ . For example, for  $H_a = 0$  mm we obtain a bandwidth (BW) equal to 1.6 % (SWR = 1.5) and for  $H_a = 5$  mm BW = 8.9%.

## Conclusion

We have presented an original synthesis model for multilayer microstrip antennas of different shapes. We have shown that we can determine, when a set of desired parameters is known, the optimal shape and size of microstrip patch to choose. The knowledge of the advantages and drawbacks of each shape are very important points for synthesis or CAD models. The comparison between theoretical and experimental results shows a very good agreement.

## References

- [1] G. Shuxi, M. Yukuan, Z. Shunshi, "The accurate calculation of resonant frequencies of covered circular microstrip disk antennas", *Int. Symp. on Antennas and EM theory, (ISAE 85)*, Beijing, China, Aug. 85, pp.205-210
- [2] A. K. Bhattacharya, "Characteristics of circular patch on thick substrate and superstrate", *IEEE Trans.*, 1991, vol. AP-39, No. 9, Sept. 1991, pp.1338-1341
- [3] A.K. Verma, Z. Rostamy, "Modify Wolff model for determination of resonance frequency of dielectric covered circular microstrip patch antenna", *Electron. Lett.*, 1991, vol. 27, n° 24, pp.2234-2236
- [4] F. Abboud, J.P. Damiano, A. Papiernik, "A new model for calculating the input impedance of coax-fed circular microstrip antennas with and without airgaps", *IEEE Trans.*, 1990, vol.AP-38, pp.1882-1885
- [5] J.P. Damiano, A. Papiernik, "A simple and accurate model for the resonant frequency and the input impedance of printed antennas", *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, 1993, vol.3, n° 4, pp. 350-361
- [6] J. Vrba, "Dynamic permittivity of microstrip ring resonator", *Electron. Lett.*, 1979, vol.15, n°16, pp.504-505
- [7] A. Das, S.K. Das, "Input impedance of a probe excited circular microstrip ring antenna", *IEE Proc.*, 1985, vol.132, Pt.H, No. 6, pp.384-390
- [8] Z. Fan, K.-F. Lee, "Input impedance of Annular-Ring Microstrip Antennas with a Dielectric Cover", *IEEE Trans.*, 1992, vol.AP-40, No. 8, Aug. 92, pp.992-995
- [9] Z. Fan, K.-F. Lee, J. S. Dahele, "Computer-aided design formulas for resonant frequencies of annular-ring microstrip antennas with superstrate", *IEEE AP Int. Symp.*, Seattle, USA, 19 - 24 June 1994, pp.1884-1887
- [10] P. M. Morse, H. Feshbach, "Methods of theoretical physics", *McGraw-Hill*, New-York, 1953
- [11] S.R. Rengarajan, "Resonance frequency of elliptical microstrip antennas", *Electron. Lett.*, 1993, vol.29, n°12, pp.1066-1067
- [12] M. C. Bailey, M. D. Deshpande, "Analysis of elliptical and circular microstrip antennas using moment method", *IEEE Trans.*, 1985, vol.AP-33, No. 9, pp.954-959
- [13] Jan G. Kretzschmar, "Wave propagation in hollow conducting elliptical waveguides", *IEEE Trans.*, 1970, vol.MTT-18, No. 9, pp 547-553
- [14] Liang C. Shen, "The elliptical microstrip antenna with circular polarization", *IEEE Trans.*, 1981, vol.AP-29, No. 1, pp 90-94
- [15] Stuart A. Long, Mark W. McAllister, "The impedance of an elliptical printed-circuit antenna", *IEEE Trans.*, 1982, vol.AP-30, No. 6, pp 1197-1200
- [16] R. Staraj, J.P. Damiano, "Simple CAD model for the analysis of disc, elliptical and various ring multilayer microstrip antennas", *ICEAA*, Turin, Italy, 14 -17 Sept. 93, pp.431 - 434
- [17] R. Staraj, J.M. Ribero, J.P. Damiano, "Accurate synthesis model for microstrip antennas with automatic choice of the shape versus physical and geometrical criteria", *24<sup>th</sup>EuMC*, Cannes, France, 5 - 7 Sept. 94

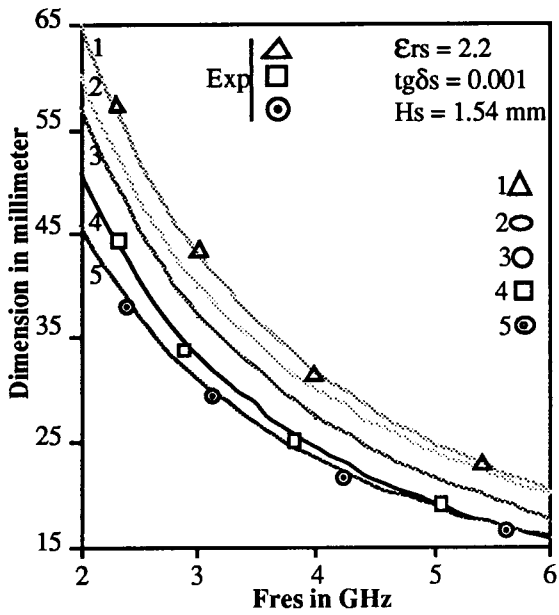


Figure 4 : Variations of the synthesis size of the radiating element versus resonant frequency

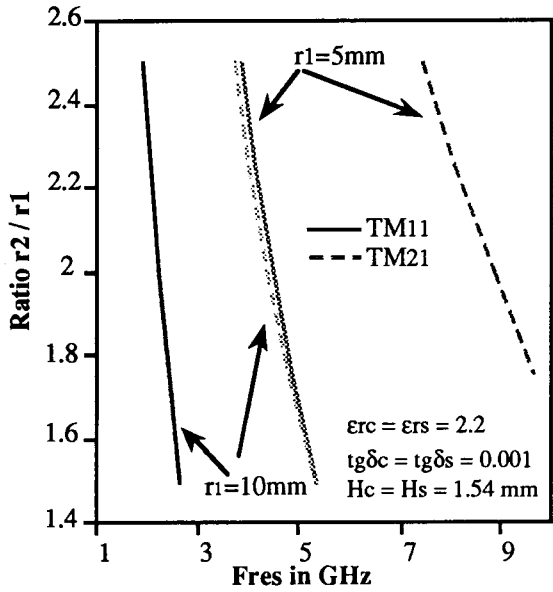


Figure 5 : Ratio  $r_2 / r_1$  of annular ring with dielectric cover for  $TM_{11}$  and  $TM_{21}$  versus resonant frequency

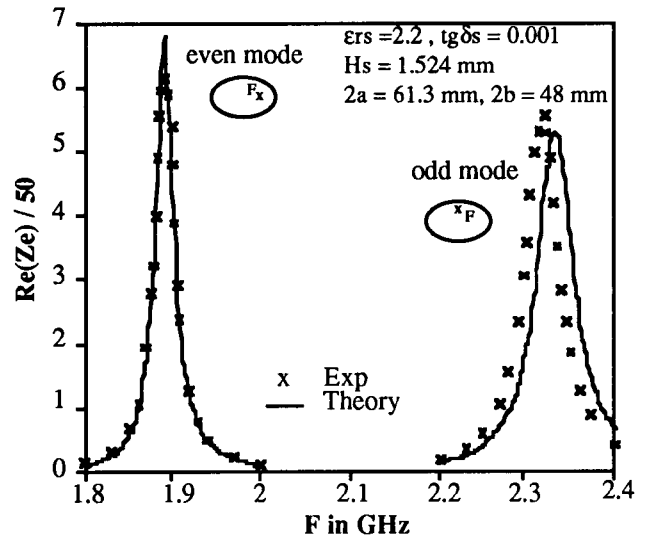


Figure 6 : Real part of the input impedance of ellipse versus frequency

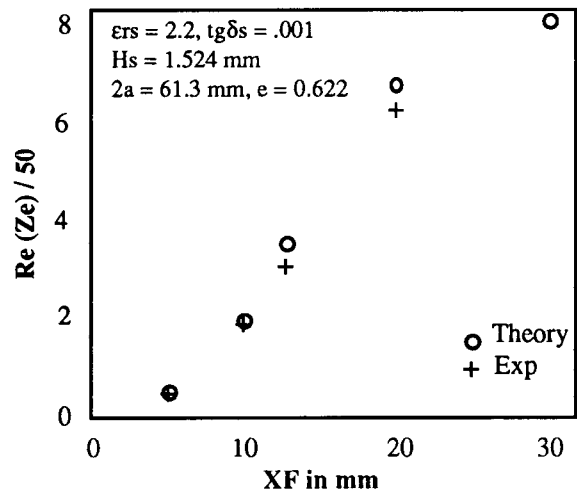


Figure 7 : Maximum real part of input impedance versus the fed-position for the ellipse

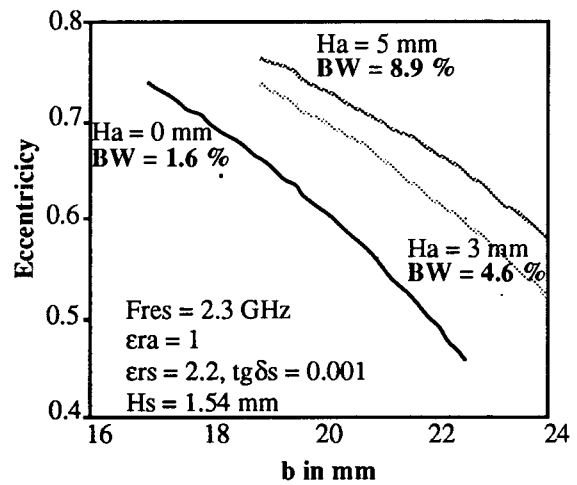


Figure 8 : Variations of eccentricity for different thickness of air-gap versus half minor axis  $b$  of the ellipse