Resonant Characteristics of Circular Microstrip Antenna Using Genetic Algorithm Optimization

Sami BEDRA, Siham BENKOUDA
Electronics Department, University of Batna.
Batna 05000, ALGERIA.
bedra_sami@yahoo fr

Imad BENACER, and Tarek FORTAKI
Electronics Department, University of Batna.
Batna 05000, ALGERIA.
t_fortaki@yahoo fr

***Abstract*— in this paper the cavity model analysis along the genetic optimization algorithm (GA) is presented for the design of circular microstrip antenna on composite and suspended substrate. The method studied here is based on the well-known cavity model and the optimization of dimensions of tunable microstrip patch antenna is performed via the genetic optimization algorithm, to achieve an acceptable antenna operation around a desired resonant frequency. The results obtained using this efficient design procedure is compared with measurement and calculated value reported elsewhere. In addition these results are also compared to the results obtained by the commercial electromagnetic simulation tool, HFSS by ANSOFT.**

Keywords- Circular microstrip antennas, genetic algorithm, cavity method.

I. INTRODUCTION

In recent wireless communication applications of microstrip antennas, resonant frequency, bandwidth and input impedance are important design parameters. Circular patch microstrip antennas as important elements of such systems offer various advantages providing circular polarization operation. Their main drawback is narrow bandwidth characteristics, which is considerably avoided by operating the antenna around the resonant frequency. As an alternative, double-layered structure with air gap having adjustable thickness between the substrate and the ground plane is also found to be useful in obtaining the wide band operation.

For both single and double-layered structures, accurate computation of resonant frequency is an important task and takes considerable interest in literature by various authors depending on the usage of various methods and approximations [1-9]. In this study, resonant frequency of double layered circular patch microstrip antenna is accurately determined via cavity analysis, using new and simple effective permittivity and patch radius expressions including modal effects.

The unknown coefficients of the constructed model for effective patch radius are determined by using the genetic optimization algorithm [10-12]. GA is an optimization algorithm for solving continuous-type of optimization problems. It does not require initial guesses, does not use derivatives, and, it is also independent of the complexity of the objective function considered. GA algorithm has successfully been applied in many different problems, and gained a wide acceptance because of its simplicity, robustness, and good convergence properties [10, 11]. The genetic optimization method, which is able to optimize different natural variables, is the most versatile approach. It can optimize the physical (dimension of the patch, thickness of substrate…) and electric parameters.

The proposed design does not require any complicated mathematical functions. This is very simple, efficient, accurate and suitable for CAD applications to design of circular microstrip antenna on composite and suspended substrate.

II. ANTENNA CONFIGURATION AND DESIGN

Double-layered tunable circular microstrip antenna is shown in Figure 1. Resonant frequency of this antenna can be determined from cavity model for various operational modes and structural parameters using proper equivalent model with effective structural parameters [3]. For this purpose, various expressions for effective patch radius a_{eff} and effective relative permittivity ε_{ref} are defined in literature [3, 5, 8, 9]. In this study, effective patch radius expression to approximate the modal effects is taken for the double-layered antenna in the modified form:

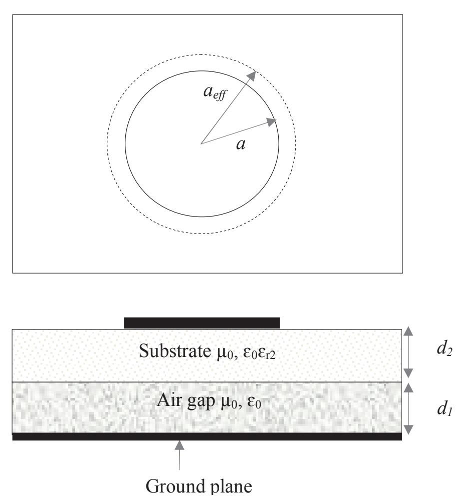

Figure 1. Geometry of a circular microstrip antenna with air gap.

$$f_r = \frac{\chi_{nm}\upsilon_0}{2\pi a\sqrt{\varepsilon_{req}}} \tag{1}$$

where χ_{nm} is the m^{th} zero of the derivative of the Bessel function of order n , the value of which (χ_{01}=3.832, χ_{11}=1.841, χ_{21}=3.054, χ_{31}=4.201) determines the lowest and higher order modes as TM_{11} ,TM_{21} ,TM_{01} , and TM_{31} modes. υ_0 is the velocity of light in free space, a is the patch radius, and ε_{req} is the substrate relative permittivity of the equivalent structure which can be determined from the cavity model [4]

$$\varepsilon_{req} = \varepsilon_{r2}(d_1 + d_2)/(\varepsilon_{r2}d_1 + d_2) \tag{2}$$

To account for the fact that small fraction of the field exists outside the dielectric; it is customary to use effective permittivity ε_{eff} in place of ε_{eq}

$$\varepsilon_{eff} = \varepsilon_{req} - 0.9\varepsilon_{req}\left[\frac{2d}{a} + \left(\frac{d}{a}\right)^2\right] \tag{3}$$

Where $d=d_1+d_2$ and, ε_{r2} is the relative permittivity of dielectric substrate.

To account fringe field effects, the circular patch radius a given in Eq. (1) should be replaced by its effective value. In this letter, a new effective patch radius expression is presented to compute the resonant frequency of a circular MSA with thin and without air gap for providing better accuracy. By utilizing the experimental data reported elsewhere [13–16], after many trials, the following model, depending on ε_{eff} , a and d, which produces good results, was chosen

$$a_{eff} = a + \left[\left(\beta_1 + \left(\frac{\beta_2}{\varepsilon_{eff}^{\beta_3}}\right)\right)d + \left(\frac{\beta_4}{a}\right)d^2\right] \tag{4}$$

where the unknown coefficients $\beta_1, \beta_2, \beta_3$ and β_4 are determined by a genetic optimization algorithm. It is evident from (4) that the effective patch radius, a_{eff} is larger than the physical patch radius, a, provided the conditions $0 < \beta_1 + \left(\beta_2/\varepsilon_{eff}^{\beta_3}\right) < 1$ and $0 < \beta_4 < 1$ are satisfied. In the following section, the genetic optimization algorithm used in this work is described and then the application of the genetic algorithm to the problem is explained.

III. GENETIC ALGORITHM

The GA [11, 12] is based on the evolution theory where weak species face extinction but strong ones survive and pass their genes to the next generation. However for the strong species to survive there is also a requirement for random injection of genes. As GA mainly manipulates matrices it is normally implemented using Matlab software. The step by step procedure of generating the software program is shown below.

Step 1: Each variable is assigned a number of binary digits so that the required accuracy of this variable is obtained in the final solution.

Step 2: All the variables in their binary form are grouped into a string which is called a chromosome.

Step 3: Matlab is used to select a fixed number of random chromosomes called a population out of all possible number of chromosomes that are present. This is called the current generation.

Step 4: Converting the digital value of each variable in a chromosome to an analogue value, the objective function (F) is evaluated and the relative fitness of each chromosome (Pi) determined. This relative fitness is defined as [13]:

$$F = \sum_{i=1}^{n} eval_i[P_i] \tag{5}$$

Step 5: The selective probability is determined by:

$$P_{si} = \frac{eval_i[P_i]}{F} \tag{6}$$

The cumulative probability of the chromosomes is given as:

$$q_i = \sum_{j=1}^{n} P_{sj} \tag{7}$$

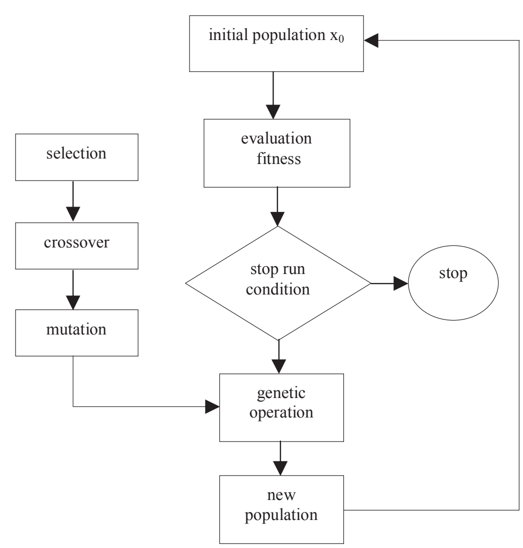

Figure 2. Flow chart of genetic algorithm.

Then a random number 'r' is generated in the range 0 to 1.If $q_{i-1} \leq r \leq q_i$ then select P_{si}.

Step 6: Crossover is applied for random chromosomes between the parent and next generation to produce new off springs.

Step 7: The population is mutated by changing in a random way the value of the genes with the least significant bit having the highest probability of mutation and the most significant the least. The flowchart of GA is shown in Figure 2.

The next generation now becomes the parent generation and the above process is repeated until the genetic variation in the population is below a certain threshold.

As the number of generations increases both the cross over rate and the mutation rate are gradually reduced.

where $\beta_1, \beta_2, \beta_3$ and β_4 are given in the above equation are the coefficients to be determined by GA so as to minimize the following total absolute errors (TAE)

$$TAE = \sum \left| f_{me} - f_{ca} \right|$$

where f_{me} and f_{ca} are, respectively, the measured and calculated resonant frequency of circular MSA.

The unknown coefficient values of the model given by (4) are optimized by the genetic optimization algorithm just described. The optimum values found are

$$\beta_1 = 0.12, \;\; \beta_2 = 2.54, \;\; \beta_3 = 3.65, \;\; \beta_4 = 0.23 \qquad (8)$$

The following effective patch radius expression, a_{eff} , is obtained by substituting the coefficient values given by (8) into (4)

IV. RESULTS

A. Comparison of Numerical Results

The theoretical resonant frequency results obtained by using the genetic algorithm are in very good agreement with the experimental results reported elsewhere has been analyzed from Tables, 1 and 2.

In "Fig. 3" we have compared our computed values with measured values done by *Dahele* [2] and excellent agreements are revealed between them for all modes and all values of air gaps. So, the present model is closer to the measurements compared to the others models for all modes and air gaps.

B. Air Gap Effect on the Resonant Characteristics

The effect of air gaps in between substrate and ground plane are depicted in "Fig. 4" and Table II. The resonant frequency increases with the increase of air gap is seen from the "Fig. 3".

TABLE I. RESULTS AND COMPARISON OF THE RESONANT FREQUENCIES OF MEASURED AND CALCULATED FOR THE FUNDAMENTAL MODE TM_{11} OF A CIRCULAR ANTENNA AND THE NO GAP CASE.

Physical and Electrical Parameters			Measured f_r (GHz)	Calculated Frequencies f_r (GHz)			Our results (GHz)	Measured By
d (mm)	ε_{r2}	*a(mm)*		*[14]*	*[17]*	*[18]*	f_r –*GA*	
1.588	2.5	34.93	1.57	1.592	1.555	1 559	1.557	[14]
3.175	2.5	34.93	1.51	1.592	1.522	1 529	1.522	
2.35	4.55	49.5	0.825	0.832	0.827	0.827	0.824	[17]
2.35	4.55	39.75	1.03	1.037	1.027	1.027	1.023	
2.35	4.55	29.9	1 36	1.378	1.358	1 360	1.355	
2.35	4.55	20	2.003	2.060	2.009	2.012	2.007	
2.35	4.55	10.4	3.75	3.962	3.743	3.737	3.750	
2.35	4.55	7.7	4.945	5.352	4.938	4 924	4.947	
1.5875	2.65	11.5	4.425	4.695	4.414	4.438	4.416	[13]
1.5875	2.65	10.7	4.723	5.046	4.724	4.750	4.723	
1.5875	2.65	9.6	5.224	5.625	5.228	5 258	5.223	
1.5875	2.65	8.2	6.074	7.297	6.049	6.086	6.034	
1.5875	2.65	7.4	6.634	6.585	6.646	6.687	6.620	

TABLE II. COMPARISON OF THE RESONANT FREQUENCIES OF MEASURED AND CALCULATED OF A CIRCULAR ANTENNA HAVING AN AIR GAP; $a = 50\text{mm}, \varepsilon_r = 2.32, d_2 = 1.59\text{mm}$.

Mode TM_{nm}	d_1(mm)	Measured f_r (GHz)	Calculated Frequencies f_r (GHz)				Our results (GHz)
		Dahele [2]	*Abboud [3]*	*Gurel [6]*	*Guha [7]*	*HFSS [19]*	f_r-*GA*
TM_{11}	0	1.128	1.159	1.129	1.130	1 162	1.134
	0.5	1.286	1.298	1.281	1.274	1 334	1.283
	1	1.350	1.368	1.359	1.344	1.435	1.349
TM_{21}	0	1.879	1.927	1.876	1.881	1 934	1.881
	0.5	2.136	2.167	2.128	2.119	2 203	2.130
	1	2.256	2.280	2.258	2.235	2 353	2.239
TM_{31}	0	2.596	2.665	2.584	2.594	2 356	2.588
	0.5	2.951	2.994	2.930	2.921	2.645	2.927
	1	3.106	3.150	3.109	3.080	2.829	3.080

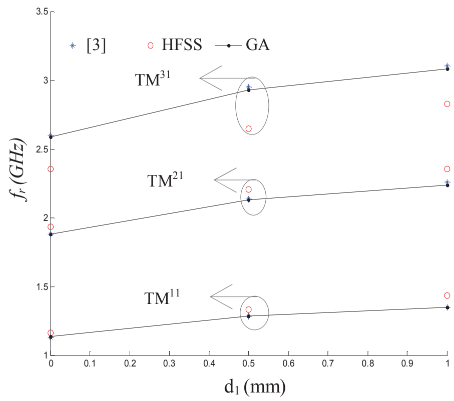

Figure 3. Theoretical and experimental change of resonant frequency with the change of air gaps for different modes; *a= 50 mm,d₂=1.59mm.*

So, antenna tuning is possible by introducing the air gap without changing the antenna parameters. 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_{1fmax}.

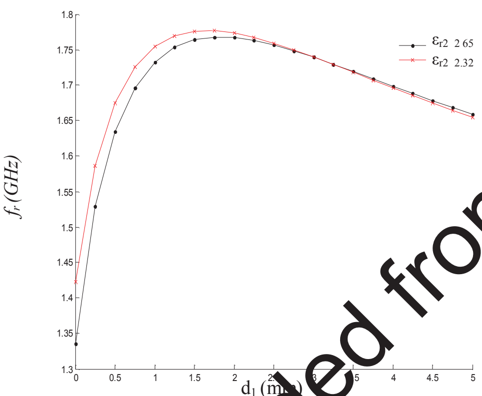

Figure 4. Resonant frequency of tunable circular microstrip antenna versus the air separation; a=40 mm,d_2=1mm.

Note that the effect of the air gap is more pronounced for small values of d_1 show "Fig. 4". When the air separation exceeds d_{1fmax}, increasing the air gap width will decrease slowly the resonant frequency. Extreme care should be taken when designing an antenna with thin air gap; since small uncertainty in adjusting $d_1$can result in an important detuning of the frequency.

We show in Figure 5 the equivalent relative permittivity of the composite two-layer structure, computed from Reference [3], Equation(2), versus air separation for the structures considered in Figure 4.

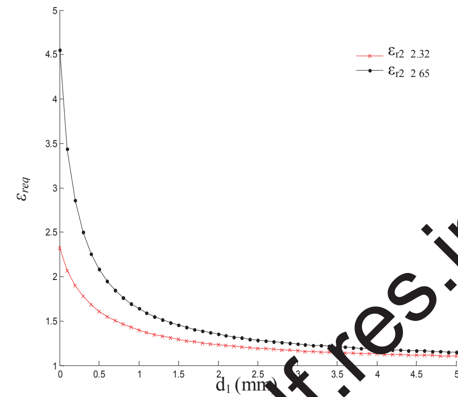

Figure 5. Variation of the equivalent permittivity of the structure with the gap width.

It is seen that when d_1 increases, ε_{req} decreases rapidly. This observation can well justify the very fast increase in the resonant frequency shown in Figure 4.

V. Conclusion

In this work, a new effective patch radius formula constructed by utilizing GA for determining the resonant frequency of circular microstrip antenna with and without air gap is presented. The proposed formula can be used by a MSA designer practically without any background in sophisticated mathematical techniques.The resonant frequency results obtained in this study are compared with the available experimental and theoretical values in the literature. It is shown that the formulation for effective radius provides accurate results within lower percentage error values with respect to the previous analyses. Thus, the accuracy and validity of this new formula for the tunable circular microstrip antenna has been verified.

References

[1] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] K.F. Lee, K.Y. Ho, and J.S. Dahele, "Circular disk microstrip antenna with an air gap", IEEE Trans Antennas Propag 32 (1984), 880–884.

[4] J.S. Dahele and K.F. Lee, "Theory and experiment on microstrip antennas with air gap", Proc IEE 132 (Part H) (1985), 455–460.

[5] F. Abboud, J.P. Damiano, and A. Papiernik, "A new model for calculating the input impedance of coax-fed circular microstrip antennas with and without air gap", IEEE Trans Antennas Propag 38 (1990), 1882–1885.

[6] J.S. Joy and B. Jecko, "A formula for the resonance frequencies of circular microstrip patch antenna satisfying CAD requirements", Int J RF Microwave Comp Aided Eng 3 (1993), 67–70.

[7] K. Guney, "Resonant frequency of electrically-thick circular microstrip antenna", Int J Electron 77 (1994), 377–385.

[8] F. Benmeddour, C. Dumond, F. Benabdelaziz, and F. Bouttout, "Improving the performances of a high Tc superconducting circular microstrip antenna with multilayered configuration and anisotropic" Progress In Electromagnetics Research C, Vol. 18, 169-183, 2011.

[9] D. Guha, "Resonant frequency of circular microstrip antennas with and without air gaps", IEEE Trans Antennas Propag 49 (2001), 55–59.

[10] T. Gunel, "Continuous hybrid approach to the modified resonant frequency calculation for circular microstrip antennas with and without air gaps", Microwave Opt Tech Lett 40 (2004), 423–427.

[11] C¸ .S. Gurel, E. Aydın, and E. Yazgan, "Modified resonant frequency calculation for two-layered circular patch microstrip antenna", Microwave Opt Tech Lett 49 (2007), 2263–2267.

[12] O. Ozgun, S. Mutlu, M.I. Aksun, and L. Alatan, "Design of dualfrequency probe-fed microstrip antennas with genetic optimization algorithm", IEEE Trans Antennas Propag 51 (2003), 1947–1954.

[13] S.D. Rogers, C M. Butler, and A.Q. Martin, "Design and realization of GA-optimized wire monopole and matching network with 20:1 bandwidth", IEEE Trans Antennas Propag 51 (2003) 493–502.

[14] Y. Rahmat-Samii and E. Michielssen, Eds., "Electromagnetic Optimization by Genetic Algorithms". New York: Wiley, 1999.

[15] T. Itoh and R. Mittra, Analysis of a microstrip disk resonator, AEU Int J Electron Commun 27 (1973), 456–458.

[16] J.Q. Howell, Microstrip antennas, IEEE Trans Antennas Propagat AP-23 (1975), 90–93.

[17] S.A. Long, L.C. Shen, M.D. Walton, and M R. Allerding, Impedance of a circular disk printed- circuit antenna, Electron Lett 14 (1978), 684–686.

[18] S. Yano and A. Ishimaru, A theoretical study of the input impedance of a circular microstrip disk antenna, IEEE Trans Antennas Propagat AP-29 (1981), 77–83.

[19] F. Abboud, J.P. Damiano, and A. Papiernik, "New determination of resonant frequency of circular disc microstrip antenna: application to thick substrate", Electron Lett 24 (1988), 1104–1106.

[20] Q. Liu and W.C. Chew, "Curve-fitting formulas for fast determination of accurate resonant frequency of circular microstrip patches", IEE Proc Microwave Antennas Propagat Pt H 135 (1988), 289 –292.

[21] HFSS: High Frequency Structure Simulator-Ansoft Corp.