INTERNATIONAL JOURNAL OF ADVANCED STUDIES
IN COMPUTER SCIENCE AND ENGINEERING
IJASCSE VOLUME 10 ISSUE 10, 2022 10/31/2022

Accurate Modified Transmission Line Model For Inset-Fed Antennas Array Design

BENDAHMANE Mohammed Fawzi[1*], ABRI Mehadji[2]

[1] Telecommunications Laboratory (Faculty of Technology)
Department of Physic, Faculty of Sciences, Abou-Bekr Belkaïd University, Tlemcen 13000, Algeria

[2] STIC Laboratory (Faculty of Technology)
Department of Telecommunications, Faculty of Technology, Abou-Bekr Belkaïd University, Tlemcen 13000, Algeria

*Corresponding author: mohammedfawzi.bendahmane@univ-tlemcen.dz

Abstract

The work presented in this paper proposes the design of single Inset-fed antenna and antennas array with corporate feed network based on accurate modified transmission line model. The model developed is simple, accurate and takes into account all the characteristics of the antenna array and their feed system. To test this proposed model, the results obtained are compared with those obtained by the moment's method (Agilent Momentum). The paper confirms the validity of the developed model by presenting several simulation results. The results obtained are then exposed and discussed.

Key words: *Printed Inset-fed antenna, antennas array, transmission line model, moment's method (Momentum).*

1. Introduction

Microstrip antennas have received considerable attention to meet the current demand for several applications, counting electromagnetic compatibility (EMC) measurement, radar, detection systems, and broad-band communication systems. The microstrip technology has many advantages such as low volume, light weight, conformal configuration, low cost, compatibility with integrated circuits, and so on. Various kinds of microstrip antennas have been proposed and studied [1-6]. Microstrip antennas that perform as a single element typically have low gain, low radiation efficiency and a relatively large half power beamwidth. In order to enhance these parameters, microstrip antennas are employed in fed array configuration to improve range of the radiating structure and the gain. This configuration gives a very advantageous form of array fabrication because both the feed network and the radiating elements can be made photolithographically [7-8].

Various researchers studied their basic characteristics and great efforts were also consecrated to their determination (the band-width, radiation, resonant frequency, ... etc) by using theoretical models. These models can be allocated into three groups. The transmission line model is a simple model due to its postulates. This leads to a set of low-dimensional linear equations. This dimension increases in the case of cavity model, which converts the open antenna problem into a closed one. Finally, the integral equation model resolves Maxwell's equations directly. The equations are hard to compute and the dimension of the set is very large. The utility of any solution, however, depends on the accuracy of the results, as well as on the simplicity of the method.

In this article, we examine the development and design of single antenna as well as an Inset-fed antennas array with corporate feed network by using a simple, fast and modified accurate transmission line model. This study is a follow-up to a previous work that deals with the development and design of a single antenna [9].

The interest of our design process is the simplicity of the antenna and its feed structure so that the antenna can be produced easily in practice. Therefore, an Inset-fed patch antenna with a microstrip line feed was considered as a basic structure.

2. Three ports model of the proposed Inset-fed antenna

The model used is inspired from the three ports model [10]. On the figure below one presents the suggested configuration:

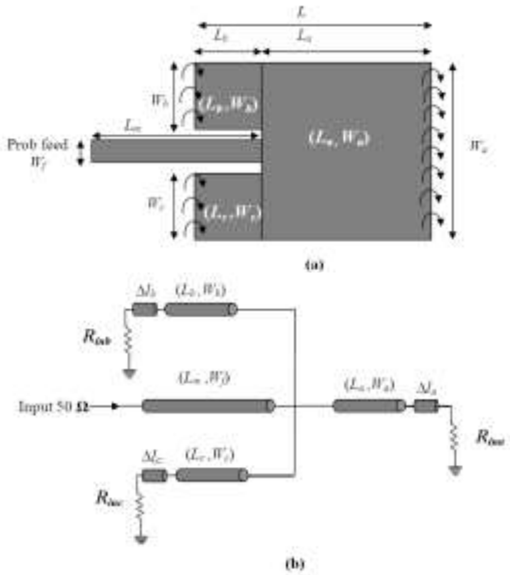


Fig. 1. (a) Inset-fed antenna. **(b)** Equivalent circuit of the proposed antenna.

In the present work, the model consists of decomposing the antenna into three areas *a*, *b* and *c*. Consider each part to be an antenna that terminates at its ends with a length ΔL due to the radiation slot and a resistance in series representing the value of this resistance in the antenna extremity. The ameliorated model consists in ignoring the radiations slots between the areas *b* and *c* and the feed line and replace the resistances in series by their true values due only to the areas *b* and *c*. So the resistors will be R_{inb} and R_{inc} rather of only one resistance R_{in}. The various values of the model are given as follows:

The input resistance is given by:

$$\begin{cases} R_{ina} = \dfrac{1}{2(G_{1a}+G_{12a})}\begin{bmatrix} \cos^2(\beta_g L_a)+\dfrac{G_{1a}{}^2+B_{1a}{}^2}{Y_c{}^2}\sin^2(\beta_g L_a) \\ -\dfrac{B_a}{Y_c}\sin(2\beta_g L_a) \end{bmatrix}^{-1} \\ R_{inb} = \dfrac{1}{2(G_{1b}+G_{12b})}\begin{bmatrix} \cos^2(\beta_g L_b)+\dfrac{G_{1b}{}^2+B_{1b}{}^2}{Y_c{}^2}\sin^2(\beta_g L_b) \\ -\dfrac{B_b}{Y_c}\sin(2\beta_g L_b) \end{bmatrix}^{-1} \\ R_{inc} = \dfrac{1}{2(G_{1c}+G_{12c})}\begin{bmatrix} \cos^2(\beta_g L_c)+\dfrac{G_{1c}{}^2+B_{1c}{}^2}{Y_c{}^2}\sin^2(\beta_g L_c)- \\ \dfrac{B_c}{Y_c}\sin(2\beta_g L_c) \end{bmatrix}^{-1} \end{cases} \quad (1, 2, 3)$$

The expressions of G_1 and B_1 are given by the relations below [10]:

$$\begin{cases} G_{1a,b,c} = \dfrac{W_{a,b,c}}{120\lambda_0}\left[1-\dfrac{1}{24}(k_0 h)^2\right] \\ B_{1a,b,c} = \dfrac{W_{a,b,c}}{120\lambda_0}\left[1-0.636\ln(k_0 h)\right] \end{cases} \quad (4, 5)$$

The conductance of a single slot can also be obtained by using the expression field derivative from model cavity. Generally, the conductance is defined by:

$$G_1 = \frac{2P_{rad}}{|V_0|^2} \quad (6)$$

By using the electric field one can calculate the radiated power:

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_0}\int_0^{\pi}\left[\frac{\sin\left(\frac{K_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\, d\theta \quad (7)$$

The self conductance can be calculated using the following expressions:

$$G_1 = \frac{I_1}{120\pi^2} \quad (8)$$

Where I_1 is the integral defined by:

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2} \cos\theta\right)}{\cos\theta} \right]^2 \sin^3\theta \, d\theta \quad (9)$$

The lengths of the slots for each region are given by:

$$\begin{cases} \Delta L_a = \dfrac{1}{2 f_{ra} \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - L_a \\ \Delta L_b = \dfrac{1}{2 f_{rb} \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - L_b \\ \Delta L_c = \dfrac{1}{2 f_{rc} \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - L_c \end{cases} \quad (10, 11, 12)$$

The resonant frequency in this case for each region is given by:

$$\begin{cases} f_{ra} = \dfrac{1}{2L_a \sqrt{\varepsilon_r} \sqrt{\mu_0 \varepsilon_0}} = \dfrac{v_0}{2(L_a + \Delta L_a)\sqrt{\varepsilon_r}} \\ f_{rb} = \dfrac{1}{2L_b \sqrt{\varepsilon_r} \sqrt{\mu_0 \varepsilon_0}} = \dfrac{v_0}{2(L_b + \Delta L_b)\sqrt{\varepsilon_r}} \\ f_{rc} = \dfrac{1}{2L_c \sqrt{\varepsilon_r} \sqrt{\mu_0 \varepsilon_0}} = \dfrac{v_0}{2(L_c + \Delta L_c)\sqrt{\varepsilon_r}} \end{cases}$$

(13, 14, 15)

3. Array design

An array of 6 antennas with corporate feed network is used with as separation of $d = 0.5\lambda_g$ (λ_g is wavelength) to avoid the coupling between the adjacent elements as shown in Fig. 2. To compute the input impedance of the printed antennas array, one supposes to exploit the electric model are equivalent of each aerial element established previously to lead at an electric complete modelling of the entire array.

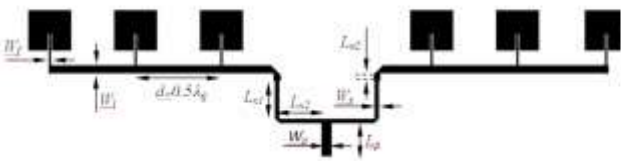


Fig. 2. The mask layout for the antennas array with corporate feed network.

4. Simulation results and discussions

In this section, simulations were established on an Inset-fed antenna.

4.1. Inset-fed operating at the resonant frequency 2.3 GHz

Fig. 3 represents a mask layout of an Inset-fed antenna operating at 2.3 GHz.

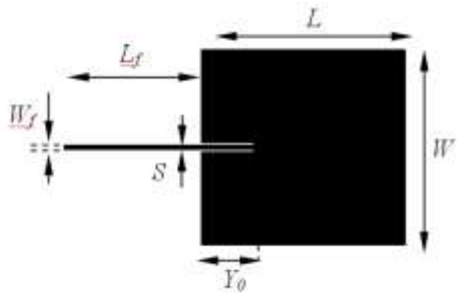
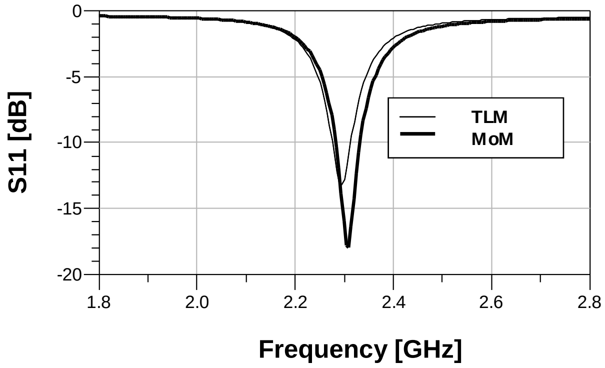


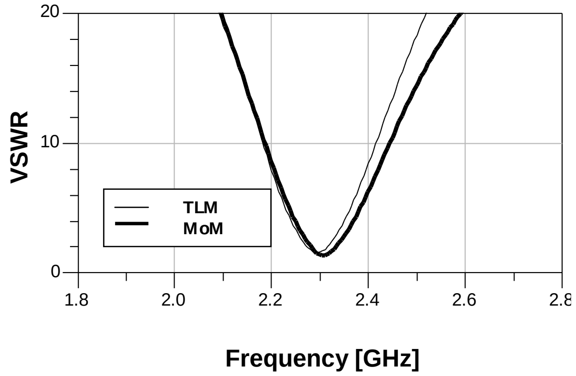
Fig. 3. The mask layout of the Inset-fed patch antenna design.

The antenna is to be designed on substrate which has a relative permittivity ε_r of 4.32, a dielectric thickness *H* of 1.6 mm, a loss tangent of about 0.018 and 0.035 mm conductor thickness. Using the transmission line model, the antenna was designed to operate with a center frequency of 2.3 GHz. The antenna input impedance must be matched to the feed line by choosing the correct position for the feed point. As the antenna must be powered by the microstrip, connection to a point inside the metal patch requires the use of an inset. The inset-feed technique combines a patch antenna with a microstrip feed on a single planar substrate. The input impedance of the insert-fed patch varies, similar to the coaxial probe-fed patch, as the feed line insertion depth changes.

Simulated input return loss of the Inset-fed antenna is shown for frequencies between 1.8 to 2.8 GHz in Fig. 4.



(a)



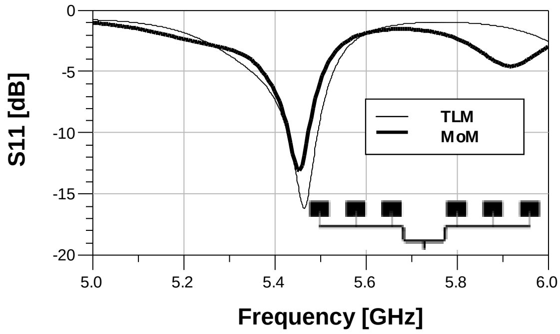
(b)

Fig. 4. Simulated input antenna return loss. The parameters are set to: W=29.4 mm, L=30.9 mm, H=1.6 mm, S=0.57 mm, W_f=0.57 mm, Y_0=7.9 mm.

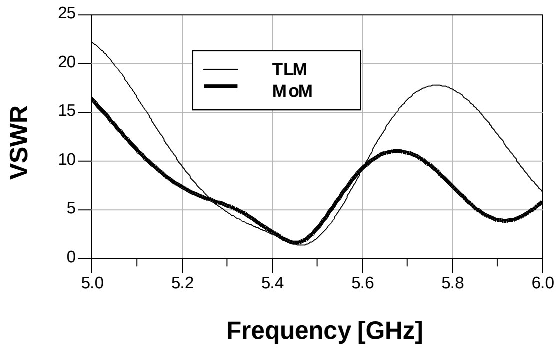
As shown in Fig. 4 (a), notice that the curves are almost same the only difference reside in the peak level, it is of about -13 dB by the transmission line model and of about -17.5 dB by the moment method. The two curves predict correctly the resonant frequency which is of about 2.3 GHz. Notice according to Fig 4 (b) representing the computed VSWR that the two curves are almost identical. In the neighbourhood of the resonance frequency, the VSWR is close to unity, which corresponds to an ideal matching.

4.2. Inset-fed Antennas array operating at the resonant frequency 5.45 GHz

The antennas array should be designed on substrate which has a dielectric thickness H of 0.444 mm, a relative permittivity ε_r of 4.6, a loss tangent of about 0.005 and 0.05 mm conductor thickness. The Inset-fed antennas array architecture is shown in the figure below. Simulated input return loss of the antennas array is shown for frequencies between 5.0 to 6.0 GHz in Fig. 5. (a).



(a)



(b)

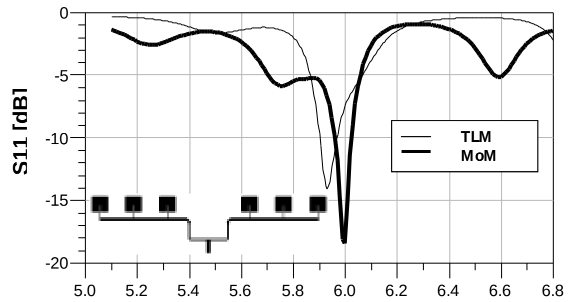
Fig. 5. Inset-fed antennas array. **(a)** Computed return loss of the Inset-fed antennas array. **(b)** Computed VSWR. The parameters are set to: W=16.28 mm, L=12.7 mm, S=0.42 mm, W_f=0.42 mm, Y_0=4 mm, W_l=1.75 mm, d=29.19 mm, L_{a2}=1.04 mm, L_{x1}=8.35 mm, L_p=5.29mm, W_p=1.75 mm.

According to the obtained result, one notices that there is a good matching at the input Inset-fed antennas array for the two models since the amplitudes level is lower than -13 dB.

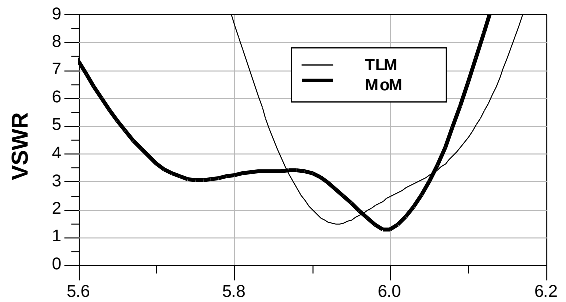
The simulated VSWR represented on the Fig. 5. (b) justified the obtained results by the computed return loss.

4.3. Inset-fed Antennas array operating at the resonant frequency 6 GHz

In this section, other geometry is analyzed to confirm the validity of the proposed method. The permittivity and the substrate thickness are 4.6 and 0.444 mm respectively and the operation frequency is 6 GHz. A probe of 50 Ohm is employ to feed the antennas array. The optimized antennas array layout is shown in the figure below.
The simulated input return loss of the Inset-fed antennas array is displayed for frequencies between 5.0 to 6.8 GHz in Fig. 6. (a).



(a)



(b)

Fig. 6. Inset-fed antennas array. **(a)** Computed return loss of the Inset-fed antennas array. **(b)** Computed VSWR. The parameters are set to: W=12.4 mm, L=11.7 mm, S=0.8 mm, W_f=0.8 mm, Y_0=4.7 mm, W_l=2.42 mm, L_a=24.16 mm, L_{a2}=1.04 mm, L_{x1}=11.27 mm, L_p=9.19 mm, W_x=1.3mm, W_p=2.99 mm.

It is well observed that the resonance of the antennas array is correctly predicted to 6 GHz with a light shift by the improved model which is of about 5.9 GHz. It is a shift of 0.1 GHz. Notice according to Fig. 6. (b) representing the computed VSWR that the two curves are almost identical. Near the resonance frequency, the VSWR is close to unity which corresponds to an ideal matching.

5. Conclusion

In this work, a highly flexible and computationally efficient transmission line model is developed to analyze the Inset-fed antenna array. The results show that the transmission line model can be successfully used to design the inset feed antennas array and though the model is conceptually simple, it always produces accurate results in a relatively short period of computing time. The results obtained showed excellent agreement between the transmission line model and the moment's method. A comparison of the results made up by the final model with the data from the moment's method showed the validity of the proposed model. That permits the analysis of very large arrays much on a rather small computer. Based on these characteristics, the proposed antennas array can be useful for EMC applications.

References

[1] R. A. Sainati, 1996, "CAD of Microstrip Antenna for Wireless Applications", *Artech House*, Icc.

[2] S. Gao and A. Sambell, 2006, "A Simple Broadband Printed Antenna", *Progress in Electromagnetics Research*, PIER 60, pp. 119–130.

[3] P. M. Mendes, M. Bartek, J. N. Burghartz, J. H. Correia, 2003, "Design and Analysis of a 6 GHz Chip Antenna on Glass Substrates for Integration with RF/Wireless Microsystems", *IEEE proceeding*.

[4] Wi. Sang-Hyuk, 2007, "Wideband microstrip patch antenna with U-shaped

parasitic", *IEEE Trans Antennas Propag*, 55(4):1196-9.

[5] D. M. Pozar and D.H. Schaubert (eds.), 1995, "Microstrip Antennas, the Analysis and Design of Microstrip Antennas and Arrays", *IEEE Press*, New York, NY.

[6] C.A. Balanis, 1997, "Antenna Theory Analysis and Design, Second Edition". *United States of America. John Wiley & Sons*, p734.

[7] Abri M., Boukli-hacene N., Bendimerad. F.T. & Cambiaggio E. , May 2006, "Design of a Dual Band Ring Printed Antennas Array", *Microwave journal*, vol. 49, n. 5, pp. 228-232.

[8] S. Yang, , E. Adel, S. Lin, A. E. Fathy, A. Kamel, and H. Elhennawy, 2007, "A highly efficient Vivaldi antenna array design on thick substrate and fed by SIW structure with integrated GCPW feed", *IEEE Antennas and Propagation Society International Symposium*, pp. 1985–1988.

[9] M.F. Bendahmane, M. Abri, F.T. Bendimerad and N. Boukli-Hacene, September 2010, "A Simple Modified Transmission Line Model for Inset-fed Antenna Design", *International Journal of Computer Science Issues* (*IJCSI*), ISSN (Online): 1694-0784, vol. 7, Issue 5, pp. 331-335.

[10] J. F. Zurcher & F. E. Gardiol, "Broadband Patch Antenna", *Artech House*, Boston. London.

[11] M. Abri, H. Abri Badaoui, M. A. Belhadi and I. Kalai, 2012, "Log periodic Bow-Tie Antennas (LPA) Design Using the Transmission Line Model", *Journal of Radio Electronics*, N°7.

[12] S. Didouh, M. Abri, and F.T. Bendimerad, 2012, "Corporate-Feed Multilayer Bow-Tie Antenna Array Design Using a Simple Transmission Line Model", *Modelling and Simulation in Engineering*, Volume 2012, Article ID 327901, doi:10.1155/2012/327901, 8pages.

[13] M. Abri, H. Abri Badaoui, H. Dib and A. S. E. Gharnaout, July 2012, "Bi-Band Bow-Tie antennas array design using a simple equivalent transmission line model", *International Journal of Computer Networks & Communications* (*IJCNC*), Vol.4, No.4, pp. 279-290.

[14] M. Abri, N. Boukli-hacene, F.T. Bendimerad and M. Bousahla, March 2010, "A flexible transmission line model for series-line antennas array design", *International Journal of Microwave and Optical Technology*, Vol.5, No.2, pp. 69-75.

[15] EO. Hammerstad, 1975, "Equations of Microstrip Circuit Design", *Proc. Fifth European Microwave Conf.*, pp. 268-272.

[16] Ying Hu, David R. Jackson, Jeffery T. Williams, Stuart A. Long, and Varada Rajan Komanduri, October 2008, "Characterization of the Input Impedance of the Inset-Fed Rectangular Microstrip Antenna", *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 10, pp. 3314-3318.

[17] M. Ramesh and K.B. Yip, 12 December 2003, "Design inset fed microstrip antenna", *Microwaves and RF Letters*, 42.

[18] M. Dwivedi et al., July 2012, "Design of a wideband inset feed microstrip patch antenna", *International Journal of Engineering Science and Technology* (*IJEST*), Vol. 4, No. 7, pp.3212-3218.

[19] Priya Upadhyay and Richa Sharma, January 2013, "Design and study of inset feed square microstrip patch antenna for S-band application", *International Journal of Application or Innovation in Engineering & Management* (*IJAIEM*), ISSN: 2319-4847, Vol. 2, Issue 1, pp. 256-262.

[20] N. Hassaine, September 2001, "Conception de modèles équivalents pour

analyse et synthèse d'antennes microrubans en réseaux périodiques et non périodiques", *Thèse de Magister*, Faculté de Technologie - Université de Tlemcen (Algérie).

[21] H. Pues and A. Van de Capelle, December 1984, "Accurate transmission line model for the rectangular microstrip antenna", *IEE Microwaves, Optics and Antennas Proceedings*, Vol. 131, No. 6, pp.334-340.

[22] B.C. Wadell, 1991, "Transmission line design handbook", *Artech House*, Boston, London.

[23] Y.M. Jo, 1998, "Theoretical analysis of microstrip patch antenna using transmission line models", *ASL Technical Report*, Florida Institute of Technology, No. 17.

[24] Y.T. Lo, D. Solomon and W.F. Richards, March 1979, "Theory and experiment on microstrip antenna", *IEE Microwaves, Antennas and Propagation Proceedings*, Vol. AP-27, No. 2, pp.137-145.

[25] A. G. Derneryd, November 1976, "Linearly Polarized Microstrip Antennas", *IEEE Trans. AP.*, pp. 846-851.

[26] AG. Derneryd, 1978, "A Theoretical Investigation of the Rectangular Microstrip Antenna", *IEEE Trans AP*, 26(4), pp. 532-535.

[27] JM. Ribero, R. Staraj, JP. Damiano, 1997, "Analytical models for fast analysis and synthesis of various printed Antennas", *Antennas and associated systems for mobile satellite communication*, pp. 508-515.

[28] K. F. Lee and W. Chen, 1997, "Advances in Microstrip and Printed Antennas", *Wiley & Sons*.

[29] Y. Hu, D.R. Jackson et al. , October 2008, "Characterization of the Input Impedance of the Inset-Fed Rectangular Microstrip Antenna", *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 10, pp.3314-3318.

[30] R. Q. Lee, K. F. Lee, 1990, "Experimental study of the two-layer electromagnetically coupled rectangular patch antenna", *IEEE Trans Antennas Propag.*, Vol. 38, pp. 1298–1302.

[31] Z. Liu, P. Kooi, L. Mook-Seng, 1999, "A method for designing broad-band microstrip antennas in multilayered planar structures", *IEEE Trans Antennas Propag.*, Vol. 47, pp. 1416–1420.

[32] A. Hongming, K. J. C. Nauwelaers, A. R. Van de Chapelle, 1994, "Broadband active microstrip antenna design with the simplified real frequency technique". *IEEE Trans Antennas Propag.*, Vol. 42, pp. 1612–1619.

[33] M.A. Matin and A.I. Sayeed, January 2010, "A Design Rule for Inset-fed Rectangular Microstrip Patch Antenna", *WSEAS Transactions on Communications*, ISSN: 1109-2742, Vol. 9, Issue 1, pp. 63-72.

[34] M. M. Alam, August 2009, "Design and performance analysis of microstrip array antenna", *In Progress in Electromagnetic Research Symposium Proceedings*, Moscow, Russia.

[35] M. Himdi, J. P. Daniel, C. Terret, 1989, "Transmission line analysis of aperture-coupled microstrip antenna", *Electronics Letters*, Vol. 25, No. 18, pp. 1229–1230.

[36] S.-C.Wu, N.G. Alexopoulos, O. Fordham, October 1992, "Feeding structure contribution to radiation by patch antennas with rectangular boundaries", *IEEE Trans. Antennas Propag.*, Vol. 40, pp. 1245–1249.