Mansoura Engineering Journal

Volume 34 | Issue 2 Article 18

11-28-2020

Wideband Log-Periodic Microstrip Slot Array Antenna Using Substrate Integrated Waveguide.

Rania Abdalla
Electrical Engineering Dept., Faculty of Engineering in Port Said, Suez Canal University, Egypt.

Atef Ghuniem
Electrical Engineering Dept., Faculty of Engineering in Port Said, Suez Canal University, Egypt.

Abdelaziz Mitkees
Electronic Engineering Dept., Military Technical College, Egypt.

Recommended Citation

Abdalla, Rania; Ghuniem, Atef; and Mitkees, Abdelaziz (2020) "Wideband Log-Periodic Microstrip Slot Array Antenna Using Substrate Integrated Waveguide.," *Mansoura Engineering Journal*: Vol. 34 : Iss. 2 , Article 18.
Available at: https://doi.org/10.21608/bfemu.2020.125940

Mansoura Engineering Journal, (MEJ), Vol. 34, No. 2, June 2009.

WIDEBAND LOG-PERIODIC MICROSTRIP SLOT ARRAY ANTENNA USING SUBSTRATE INTEGRATED WAVEGUIDE

الهوائي الشريطي عريض النطاق المكون من صف من الشقوق المصممة بالطريقة الدورية اللوغاريتمية باستخدام دليل الموجة المتكامل مع القاعدة

Rania Abdalla[1], Atef Ghuniem [1], and Abdelaziz Mitkees[2]

[1] Electrical Engineering Dept., Faculty of Engineering in Port Said, Suez Canal University, Egypt.
[2] Electronic Engineering Dept., Military Technical College, Egypt.

الخلاصة باللغة العربية:

نسبة كبيرة من الأبحاث الحديثة الخاصة بالهوائيات الشريطية خُصصت لدراسة كيفية توسيع النطاق الترددي لهذه الهوائيات ، و في هذا البحث تم اقتراح تقنية جديدة لهوائي شريطي عريض النطاق باستخدام دليل الموجة المتكامل مع القاعدة. هذا الهوائي يتكون من صف من الشقوق المصممة بالطريقة الدورية اللوغاريتمية لزيادة النطاق الترددي. هذا البحث يقدم تصميما للهوائي المقترح باستخدام برنامج المحاكاة الالكتروني HFSS. من النتائج المستخلصة نجد أن النطاق الترددي يتغير بتغير سمك القاعدة و نوع نهاية الهوائي كما انه يمكننا الحصول على نطاق ترددي واسع بقيمة 41% عند فاقد عودة اقل من -10dB .

ABSTRACT

A new technique for designing wideband microstrip antenna on the basis of the recently proposed substrate integrated waveguide technology is proposed. In this technique, log-periodic slot array antenna on substrate integrated waveguide with different substrate thicknesses and different terminations is presented. The proposed antenna was designed using Ansoft HFSS simulation software package. The antenna is able to achieve an impedance bandwidth of 41 % for a return loss of less than −10 dB.

KEYWORDS: Microstrip antenna, Substrate Integrated Waveguide, Log-periodic.

Accepted June 11, 2009.

1. INTRODUCTION

For many years, the concept of creating microwave antenna using microstrip technology has gained much attention, and many possible practical designs had emerged. Microstrip patch antennas have gained popularity in today's world of wireless technology due to its many advantages such as low-profile, conformability to both planar and non-planar surfaces, low cost, ease of integration with other components, mechanically robust and simple to fabricate [1]. However the main drawback with microstrip patch antenna lies in its narrow bandwidth.

Recently, numerous researches and studies have been proposed as solutions to the bandwidth problem. To enhance the bandwidth of the microstrip patch antenna, general techniques based on lowering the Q-factor are used. The most direct method of decreasing the Q-factor is to use a thick substrate with low permittivity, but this method leads to spurious feed radiation, surface wave generation, or feed inductance [2].

Other techniques for enhancing the bandwidth of the microstrip patch antenna include an optimally designed impedance matching network [3], and an improved feeding method such as L-probe feed [4], L-strip feed [5], three-dimensional microstrip transition feed [6], and proximity-coupled patch in conjunction with a simple stub tuner [7]. Another very popular bandwidth extension technique involves the use of multiple resonances such as coupled patches with slots (e.g. U- and E-shaped) [8, 9], multilayer stacked patches using electromagnetically-coupled or aperture-coupled mechanism [10, 11], and gap or direct coupling of planar multiple resonant patches [12]. Both gap and direct (hybrid) coupling have been used with equilateral triangular to control the coupling and yield the desired broad bandwidth [13]. Also resistive loading technique has been proposed as a potential technique for improving the bandwidth of microstrip patch antennas [14].

Finally, the concept of log-periodic antenna has been applied to microstrip antenna to obtain a multi-octave bandwidth [15]. Since there have been lots of designs proposed for bandwidth enhancement, the examples that were reviewed above are only some of those designs.

In this paper, a new microstrip broadband antenna is proposed. This antenna was designed using Ansoft High Frequency Structure Simulator (HFSS) software package [16]. The investigated antenna uses array of log-periodic slots on substrate integrated waveguide (SIW), which is fed by a microstrip line to widen the bandwidth. The slot array and the feeding microstrip line were synthesized on a single substrate. As a result, not only the size, weight and cost of the proposed antenna are reduced, but also the manufacturing repeatability and reliability are enhanced [17]. A parametric study using a trial-and-error approach was performed to optimize the proposed design.

2. SUBSTRATE INTEGRATED WAVEGUIDE

Recently, a new concept "Substrate Integrated Waveguide (SIW)" has already attracted much interest in the design of microwave and millimeter-wave integrated circuits. The SIW, also called post-wall or laminated waveguide [18], is a synthetic rectangular waveguide (RWG) formed by the top and bottom metal plates of a dielectric slab and two sidewalls of metallic via-holes.

Unlike the metallic waveguide components with bulky size and high manufacturing cost, the SIW can be fabricated on the printed circuit boards (PCBs) or the low-temperature co-fired ceramics (LTCCs) to reduce size, weight, and cost [16]. As the SIWs are operated in the TE_{n0} modes, they preserve the characteristics of conventional rectangular waveguides [19] and the propagation energy of modes is almost confined in the substrate. Therefore, the SIWs have a higher Q-factor [20] and lower loss than other planar guided-wave structures such as microstrip lines and coplanar waveguides (CPWs). Using the SIW technique also takes advantage of easily integrating millimeter-wave passive and active components on a single substrate as a compact and high performance subsystem. Also, SIW can easily be connected to microstrip or coplanar circuits using simple transitions [17].

As shown in Fig. 1, the SIW is equivalent to a conventional RWG filled with dielectric and hence it can be analyzed just by using the width of the equivalent waveguide.

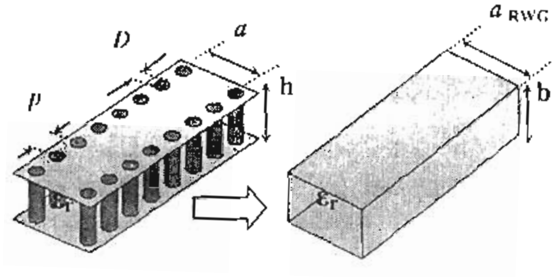


Fig. 1. SIW and the equivalent RWG.

The width of the broad wall of the equivalent RWG (which has the same cutoff frequency) can be calculated by the experimental formula [21].

$$\bar{a} = \xi_1 + \frac{\xi_2}{\frac{p}{D} + \frac{(\xi_1 + \xi_2 - \xi_3)}{(\xi_3 - \xi_1)}} \tag{1}$$

where

$$\xi_1 = 1.0198 + \frac{0.3465}{\frac{a}{p} - 1.0684}$$

$$\xi_2 = -0.1183 - \frac{1.2729}{\frac{a}{p} - 1.2010}$$

$$\xi_3 = 1.0082 - \frac{0.9163}{\frac{a}{p} + 0.2152}$$

$$a_{RWG} = a\bar{a} \tag{2}$$

where a_{RWG} is the width of the broad wall of the equivalent RWG, a is the center to center distance between parallel sets of via-holes, D is the via-hole diameter, and p is the inter via spacing or pitch of adjacent via-holes in the linear array. The relative error of the formula is below 1%.

In the previous equations, two design rules related to the post diameter and pitch are formulated to neglect the radiation loss

These rules have been deducted from simulation results of different SIWs

$$\begin{aligned} D &< \lambda_g / 5 \\ p &\leq 2D \end{aligned} \tag{3}$$

where λ_g is the guided wavelength in the SIW. These two rules ensure that the radiation loss is kept at a very low level and SIW can be modeled by a conventional RWG [22].

3. WIDEBAND MICROSTRIP TRANSITION

Several transitions have been presented over the last years. The microstrip transition presented by Deslandes and Wu [23] as shown in Fig. 2 has demonstrated a low insertion loss over a large bandwidth and is therefore well suited for this application to transform the quasi-TEM mode of the microstrip line into the TE_{10} mode in the waveguide.

Using the equivalent waveguide, the taper is analyzed using a commercial package HFSS and optimized using trial-and-error approach with the purpose of minimizing the return loss.

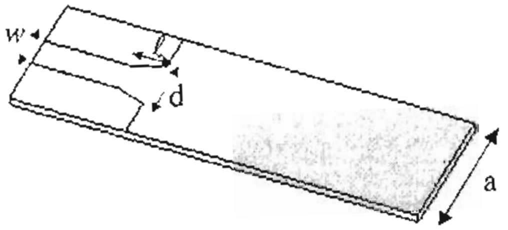


Fig. 2. Configuration of the transition of microstrip line to rectangular waveguide

4. ANTENNA STRUCTURE AND SIMULATION RESULTS

In this paper, the principle of the log-periodic antenna has been applied to a slot array antenna on SIW. It requires scaling of all dimensions of the slot array in a log-periodic manner.

A full-wave finite element method based commercial software package HFSS is used to carry out our simulations.

The structure of the proposed antenna, as shown in Fig. 3, consists of the log-periodic slot array on SIW which is fed by tapered microstrip line.

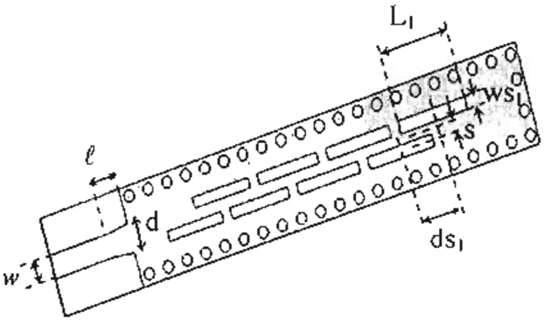


Fig. 3. Configuration of log-periodic slot array antenna on SIW with tapered microstrip transition

The lengths of the slots, widths and distances between them are related by [24],

$$\begin{aligned}\tau &= L_{n+1}/L_n \\ &= ws_{n+1}/ws_n \\ &= ds_{n+1}/ds_n \qquad (4)\end{aligned}$$

where, τ is the geometric ratio (<1), n=1:N, N is the number of slots, L_n is the n^{th} slot length, ws_n is the n^{th} slot width, and ds_n is the spacing between the n^{th} and $(n+1)^{th}$ slots.

The offset s between the slot center and the axis of the structure is optimized to get maximum bandwidth (s = 2.25 mm).

Table 1 shows the trial-and-error optimized dimensions of $N=8$ elements log-periodic slot array antenna with (τ = 0.972, $L_1 = 0.5\lambda_0$, $ws_1 = 2.5$ mm and $ds_1 = 9.5$ mm).

Table 1. Dimensions of the log-periodic slot array

n	L_n (mm)	ws_n (mm)	ds_n (mm)
1	16.67	2.5	9.5
2	16.19	2.43	9.23
3	15.74	2.36	8.97
4	15.29	2.29	8.72
5	14.86	2.23	8.48
6	14.44	2.17	8.24
7	14.03	2.10	8.01
8	13.64	2.05	

The frequency spectrum for the proposed log-periodic slot array is taken from $(\frac{c}{\lambda_0})$ to $\frac{1}{\tau^{N-1}}(\frac{c}{\lambda_0})$, where the first slot resonates at a frequency of 9 GHz.

At operating frequency of 10 GHz, SIW is simulated on the Duroid (tm) substrate ($\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$) and covered with 0.5-oz copper. For an operational bandwidth, the optimized parameters are: $a = 15.89$ mm, $D/p = 0.5$, and $D = 2.4$ mm. The width of the broad wall of the equivalent RWG a_{RWG} can be calculated by the experimental formula, equation (2), which gives $a_{RWG} = 14.4$ mm.

The equivalent RWG height b is the same as the thickness h of the SIW. Design and simulation are taken out for two different substrate thicknesses. These thicknesses are assumed as follows: h=0.7874mm (31mil) and h=1.5748mm (62 mil).

To feed this array, a tapered microstrip line having a characteristic impedance of 50 ohm was used as shown in Fig. 2. The dimensions of the microstrip line depend on the height and dielectric constant of the substrate. Table 2 shows the trial-and-error optimized dimensions of the tapered transition (transmission line width w, taper length ℓ, and taper width d) for different substrate thicknesses h.

We present the results for short-terminated, open-terminated, and matched SIW with two different substrate thicknesses from the return loss and antenna parameters points of view.

Table 2. Dimensions of tapered transition for different substrate thicknesses h

	w mm	ℓ mm	d mm
h=1.5748 mm	4.82	5	6
h=0.7874 mm	2.4	14.44	11

Simulated results of the proposed antenna with different substrate thicknesses and different terminations are depicted in Figs. 4 (a-f), which show the plots of S_{11} in dB (return loss) versus frequency in GHz.

From Figs. 4 (a, b), the results illustrate that for $S_{11} \leq -10$dB, 34% impedance bandwidth can be achieved for h=1.5748mm and 13.4% impedance bandwidth for h=0.7874mm when the antenna is short-terminated (the spacing between the center of the first slot and the short circuited end of SIW is equal $3\lambda_g/4$). The antenna with open-circuit termination gives impedance bandwidth of 11.9% for h=1.5748mm and 3.2% for h=0.7874mm as shown in Figs. 4 (c, d). The difference between short-terminated antenna structure and open-terminated antenna structure is a distance of $\lambda_g/4$ between the center of the first slot and antenna termination.

Figs. 4 (e, f) present the return loss and insertion loss of the antenna with a matched load. The antenna yields around 41.6% bandwidth for h=1.5748mm and 31.3% for h=0.7874mm. The simulated antenna parameters and bandwidths are summarized in the next table.

The power radiated by the antenna P_r can be obtained by integrating the real part of the Poynting vector over a sphere [25].

The antenna radiation efficiency e_r is defined as the ratio of actual power radiated to the power applied at the input terminal, it does not include the losses occur within the antenna due to reflections (mismatch between transmission line and antenna) [1].

Table 3. Summary of simulated antenna parameters and impedance bandwidths with different thicknesses h and different terminations

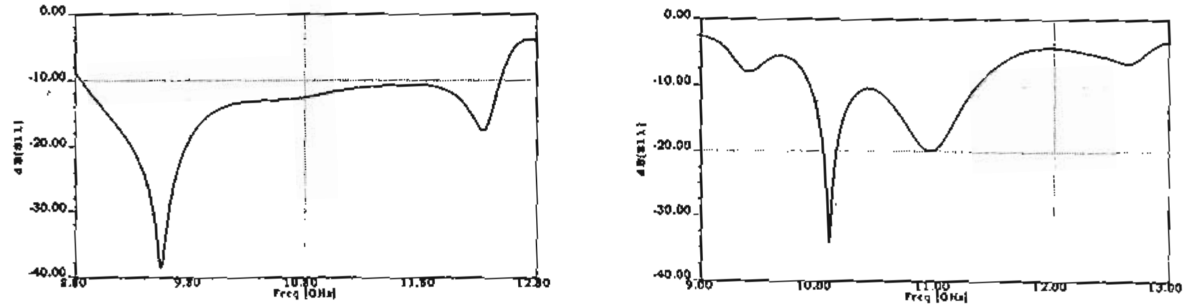
	h=1.5748 mm	h=0.7874 mm
Short-terminated antenna		
BW %	34.03	13.4
Directivity	11.04	13.08
P_r (watt)	0.9039	0.954
e_r	0.9274	0.959
Open-terminated antenna		
BW %	11.9	3.2
Directivity	9.9421	9.843
P_r (watt)	0.9327	0.8965
e_r	0.9499	0.9295
Matched load antenna		
BW %	41.6	31.3
Directivity	12.155	13.993
P_r (watt)	0.8114	0.8983
e_r	0.9289	0.9833

From the previous results, it is found that the impedance bandwidths obtained when h=1.5748 mm is better than the bandwidths when h=0.7874 mm. Also the bandwidth of the proposed antenna with short termination is wider than that with open termination, this is due to the additional shift of all slots by $\lambda_g/4$ from its original position.

Antenna with a matched load is a traveling-wave antenna which avoids the standing waves on antenna with short and open terminations. Figs. 4 (e, f) (return loss and insertion loss of a matched load antenna) show an increase in the bandwidth. On the other hand the simulated antenna parameters of a matched load antenna listed in table 3 show a decrease in radiation. This decrease in radiation is due to the losses dissipated in the load.

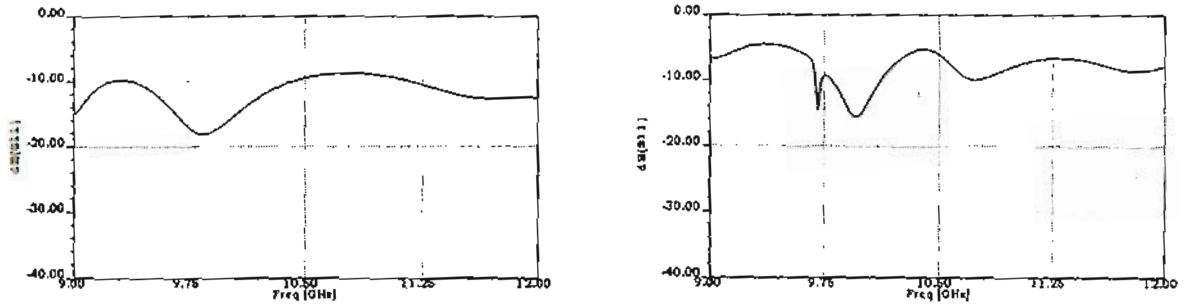
CONCLUSION

A new and simple technique for designing wideband log-periodic slot array antenna based on SIW technique is presented. It is found that SIW structure has similar properties as the conventional RWG. Also it can be easily connected to microstrip using simple transition. The log-periodic technique is applied on the array of eight slots in order to widen the bandwidth. This antenna was designed using Ansoft HFSS simulation software package. It was found that the bandwidth of the antenna depends highly on the substrate thickness and antenna termination. The antenna impedance bandwidth decreases with decreasing substrate thickness h. An impedance bandwidth in excess of 41% can be obtained. The proposed antenna with large bandwidth and simple structure seems to be a potential radiator for wireless communication, where large bandwidth is an essential requirement.



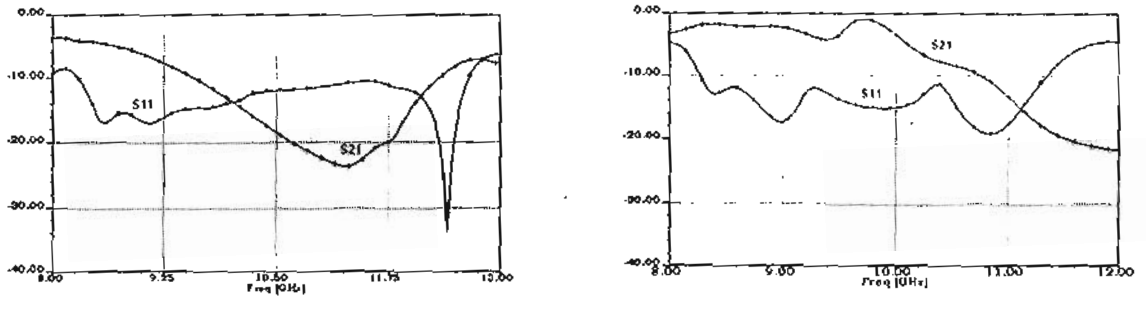
(a) S_{11} of short-terminated antenna with h=1.5748mm

(b) S_{11} of short-terminated antenna with h=0.7874mm



(c) S_{11} of open-terminated antenna with h=1.5748mm

(d) S_{11} of open-terminated antenna with h=0.7874mm



(e) S_{11} and S_{21} of matched load antenna with h=1.5748mm

(f) S_{11} and S_{21} of matched load antenna with h=0.7874mm

Fig. 4. Simulated results of the proposed antenna with different substrate thicknesses and different terminations

REFERENCES

01. C. A. Balanis, *Antenna Theory: Analysis and Design*, John Wiley & Sons, Inc, new York, 1997.

02. D. M. Pozar, "Microstrip antennas," Proceedings of the IEEE, Vol. 80, No. 1, Jan. 1992, pp. 79-91.

03. H. F. Pues and A. R. Van de Capelle, "An impedance matching technique for increasing the bandwidth of microstrip antennas," IEEE Transactions on Antennas and Propagation, Vol. AP-37, No. 11, Nov. 1989, pp. 1345-1354.

04. C. L. Mak, K. M. Luk, K. F. Lee, and Y. L. Chow, "Experimental Study of a Microstrip Patch Antenna With an L-Shaped Probe," IEEE Transactions on Antennas and Propagation, Vol. 48, No. 5, May 2000, pp. 777-783.

05. J. S. Jeon, "Design of Wideband Patch Antennas for PCS And IMT-2000 Service," Technical Feature, Second-generation digital mobile communications services, Microwave Journal, July 2002.

06. N. Herscovici, "A Wide-Band Single-Layer Patch Antenna," IEEE Transactions on Antennas and Propagation, Vol. 46, No. 4, April 1998, pp. 471-474.

07. D. M. Pozar and B. Kaufman, "Increasing the bandwidth of a microstrip antenna by proximity coupling," Electronics Letters, Vol. 23, No. 8, Mar. 1987, pp. 368-369.

08. J. A. Ansari and R. B. Ram, "Broadband Stacked U-Slot Microstrip Patch Antenna," Progress In Electromagnetics Research Letters, Vol. 4, 17–24, 2008.

09. B. K. Ang and B. K. Chung, "A Wideband E-Shaped Microstrip Patch Antenna for 5–6 GHz Wireless Communications," Progress In Electromagnetics Research, PIER 75, 397–407, 2007.

10. H. M. Jafar, S. M. Saleem, and M. J. Asad, "Design of Two Layers Electromagnetically Coupled Broad-Band Circular Disc Microstrip Patch Antenna," 2nd International Bhurban Conference on Applied Science and Technology, Bhurban, Pakistan, June 2003.

11. S. D. Targonski, R. B. Waterhouse and D. M. Pozar, "Wideband aperture coupled stacked patch antenna using thick substrates," IEE , Electronics Letters, August 1996, pp. 1941-1942.

12. G. Kumar and K. P. Ray, *Broadband Microstrip Antennas*, Artech House, Inc, Boston, 2003.

13. K. P. Ray. G. Kumar, and H. C. Lodwal, "Hybrid-Coupled Broad-Band Triangular Microstrip Antennas," IEEE Transactions on Antennas and Propagation, Vol. 51, No. 1, January 2003, pp. 139-141.

14. S. V. Hum, J. Chu, R. H. Johnston, and M. Okoniewski, "Improving the bandwidth of microstrip patch antennas using resistive loading," Antennas and Propagation Society International Symposium, 2003. IEEE vol.2, June 2003 Page(s):276 - 279 .

15. P. S. Hall, "Multi-Octave Bandwidth Log-Periodic Microstrip Antenna Array," IEE Proc. Microwaves, Antennas Propagation, Pt. H, Vol. 133, No. 2, April 1986, pp. 127–138.

16. Ansoft HFSS, Version 9.1, Ansoft Corporation, 2003.

17. M. T. Rashid and A. R. Sebak, "Design and Modeling of a Linear Array of Longitudinal Slots on Substrate Integrated Waveguide," 24th National Radio Science Conference (NRSC 2007), March 13-15, 2007.

18. D. Deslandes and K. Wu, " Accurate Modeling, Wave Mechanisms, and Design Considerations of a Substrate Integrated Waveguide," IEEE Transaction on microwave theory and techniques, vol. 54, no. 6, June, pp:2516-2526, 2006.

19. F. Xu and K. Wu, "Guided-Wave and Leakage Characteristics of Substrate Integrated Waveguide," IEEE Transaction on microwave theory and techniques, vol. 53, no. 1, January, pp:66-73, 2005.

20. D. Deslandes and K. Wu, "Integrated transition of coplanar to rectangular Waveguides," Microwave Symposium Digest, 2001 IEEE MTT-S International, vol. 2, pp : 619 - 622, 2001.

21. L. Yan, W. Hong, G. Hua, J. Chen , K. Wu, and T. Cui, "Simulation and Experiment on SIW Slot Array Antennas," IEEE Microwave and Wireless Components Letters, vol. 14, no. 9, pp : 446-448, 2004.

22. K. Wu, D. Deslandes and Y. Cassivi "The Substrate Integrated Circuits - A New Concept for High-Frequency Electronics and Optoelectronics ," Mikrotalasna revija, December 2003, vol. 9, no. 2, pp: 2-9.

23. D. Deslandes, and K. Wu, " Integrated Microstrip and Rectangular .Waveguide in Planar Form," IEEE Microwave and Wireless Components Letters, vol. 11, no. 2,pp : 68-70, 2001.

24. J. R. James, and P. S. Hall, *Handbook of Microstrip Antennas,* Peter Peregrinus Ltd., London, 1989.

25. T. A. Milligan, *Modern Antenna Design*, John Wiley & Sons, Inc, new Jersey, 2005.