Modeling and Realization of Cavity-Backed Dual Band SIW Antenna

Mehmet A. Belen [1], Peyman Mahouti [2], Alper Çalışkan [2], and Aysu Belen [2]

[1] Department of Electric and Electronic Engineering
University of Artvin Çoruh, Artvin, TURKEY
mehmetalibelen@artvin.edu.tr

[2] Department of Electronics and Communication Engineering
University of Yıldız Technical, Istanbul, TURKEY
pmahouti@gmail.com, acaliskan@gmail.com, aysuyldrm07@gmail.com

Abstract **─** Herein, substrate integrated waveguide technology is applied in order to design high performance dual-band microstrip patch antennas. Two microstrip patch antenna designs were studied and modeled in 3D electromagnetic simulators. The obtained optimal models were then realized and measured. The measurement performance of the proposed antenna designs were then measured for 2.4 and 5.6 GHz. The results suggest that the proposed model consisting of a modified microstrip cavity-backed antenna and a defected ground structure is a high performance and low cost solution for 2.4 and 5.6 GHz applications.

Index Terms **─** Antenna design, defected ground structure, dual band, cavity-backed antenna, Substrate integrated waveguide.

I. INTRODUCTION

Waveguides are metallic transmission lines that are used at microwave frequencies, typically to interconnect transmitters and receivers with antennas. Waveguides are better mediums for delivering low-loss signal transmission as compared to microstrip transmission lines. However, traditional rectangular waveguides are expensive and are considerably large in size. Substrate integrated waveguide (SIW) is a technology that provides the performance advantages of classic waveguide structures, along with the cost and size benefits of planar PCB designs [1]. The brilliant virtue of SIW is its ability to integrate all the components such as active and passive elements, antennas etc., on the same PCB board. SIW also acts as a low-loss feeding network which enhances the performance of antenna design. There has been increasing interest in implementing SIW technology in active circuits and complete systems including active integrated antennas [2–8]. In Fig. 1 (a), a basic SIW structure is presented. SIW technology is essentially a hybrid of microstrip and dielectric-filled waveguide technologies. Surface and ground metal layers of a PCB substrate provide two of the waveguide walls. Two parallel rows of vias form the side walls of the waveguide.

One of the most commonly used circuit stages in PCB board technology is microstrip antennas that have a wide range of applications. These stages are preferred because of their simple designs. By employing SIW technology, it is possible to enhance the many advantages of microstrip antennas such as low cost, smaller size, easy integration of antenna stages to circuit etc. Antennas designed with SIW technology have excellent performance because they suppress the propagation of surface waves, increase the bandwidth, and decrease both end-fire radiation and cross-polarization radiation. The cavity-backed structure of the antenna design can also overcome hitches like heat dissipation and unwanted surface wave modes.

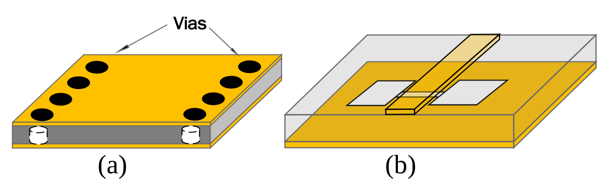

Fig.1. Schematic of: (a) SIW and (b) DGS structure.

Employment of defected ground structures (DGS) has been suggested in order to enhance the performance characteristics of microstrip microwave circuits. DGS are realized by defecting a ground plane on a PCB board with special shapes so as to disturb the shielded current distribution and effect the input impedance, with respect to the shape and its dimension (Fig. 1 (b)) [9]. The positions and lengths of the dumbbell sections control the response and insertion loss attenuation of the design. DGS increases the effective values of dielectric constant of substrates (ε_{eff}).

In the research conducted, by designing and realization of a dual band microstrip patch antenna

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designs had been studied by using DGS and SIW technology. A few modifications were done to the design given in [10] such as splitting the back part of the cavity in order to open the feeding network from the rear and the dumbbell-shaped DGS structures so as to enhance the gain and reflection performances of the models and then applied to antenna designs suitable for 2.4 and 5.6 GHz RF applications. The proposed antennas are prototyped over Rogers 4350 (dielectric constant 3.66, thickness 1.52 mm). In Section II a brief explanation about the design procedure and its parameters is given. Section III presents the simulation and measurement performances of the proposed SIW antenna designs. Finally the last Section presents the conclusions reached.

II. DESIGN OF DUAL BAND SIW ANTENNA

In [10], a SIW cavity-backed patch antenna design for X band applications is presented. In this study, the design suggested in [10] is tuned by using Eqs. 1-3 [11] to operate at 2.4 and 5.6 GHz bands. The design schematic and parameters of the design are presented in Fig. 2 and Table 1;

$$width = w = \frac{C}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}}, \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left|\frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}}\right|, \tag{2}$$

$$Length = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}\right). \tag{3}$$

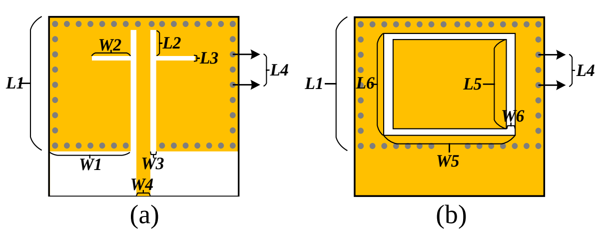


Fig. 2. (a) Top and (b) bottom schematic of SIW antenna.

By placing vias in the edge of the patch area it is possible to create waveguide walls for the SIW design. By using this method it is possible to enhance the reflection coefficient (S_{11}) characteristics of the antenna design; this can be observed from Fig. 3 where the SIW structure has reduced the reflection of the model to -15 dB. The top layer of design consists of a microstrip patch antenna aimed to operate in ISM band applications.

All the antenna models in this work are designed and simulated in the CST 3D simulation environment. The dimension values given in Table 1 are obtained through trial and error and optimization toolbox of CST for obtaining the best realizable design parameters and performance in 2.4 & 5.6 GHz bandwidths.

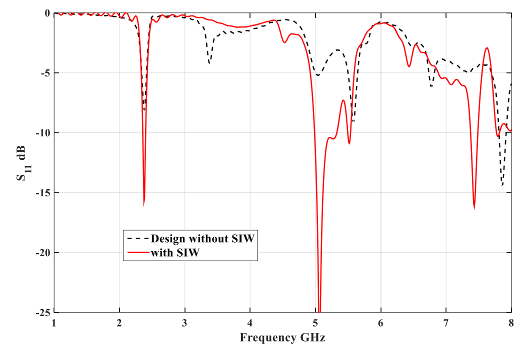
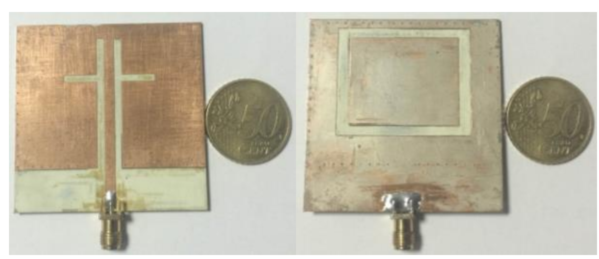


Fig. 3. Simulated reflection coefficient characteristic of antenna design with and without SIW.

Table 1: The dimension values of SIW antenna

Widths (mm)		Lengths (mm)	
W_1	23.5	ℓ_1	41.4
W_2	9.4	ℓ_2	10.5
W_3	1.9	ℓ_3	1.8
W_4	3.1	ℓ_4	6
W_5	37.1	ℓ_5	25
W_6	3.15	ℓ_6	30.3
Via diameter		0.6	

Figure 4 shows the manufactured SIW antenna. A few modifications were done after the manufacturing so as to enhance the performance of the proposed antenna.

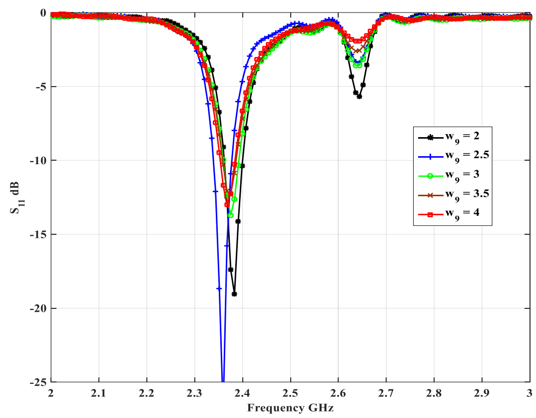


(a) (b)

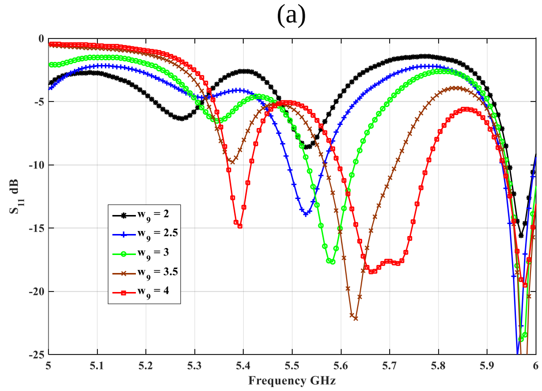
Fig. 4. Top view of the manufactured SIW antenna: (a) top layer and (b) bottom layer.

The schematic view and the parameters of the modified SIW antenna are given in Fig. 6 and Table 2. The rear part of the cavity is split in two sections in order to open the feeding network from behind and configure the reflection coefficient characteristic of the antenna so that the resonance at 5 GHz shifted to

5.6 GHz. The effect of gap on the cavity back (w_9) to the reflection performance of design can be seen from Fig. 5. The positions and lengths of the dumbbell sections control the response and insertion loss attenuation of the design.



(a)



(b)

Fig. 5. The effect of gap on the cavity back (w_9) to the reflection characteristic.

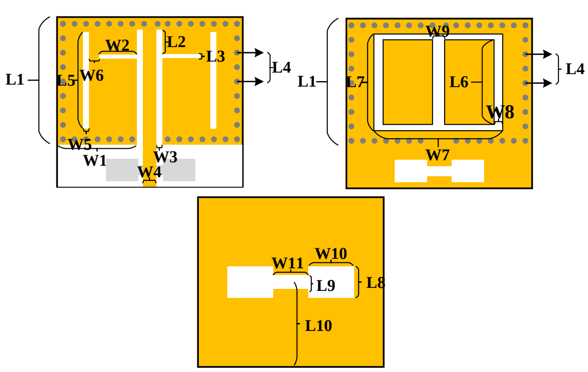


Fig. 6. Schematic of modified SIW antenna.

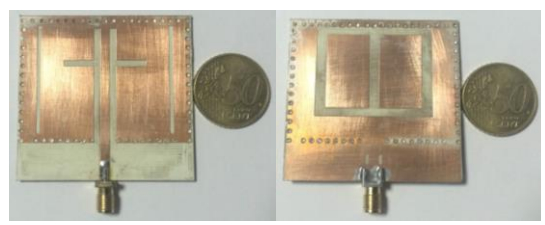
The two defected areas (w_5, l_5) are added to the top layer, thus achieving a higher radiation efficiency at 5.6 GHz. The DGS will affect the disturbance at the shielded current distribution which, in turn, will influence the input impedance of the design. In the next section, the experimental and simulation results of both SIW antenna designs are presented.

Table 2: The dimension values of modified SIW antenna

Widths (mm)		Lengths (mm)	
W_1	23.5	ℓ_1	41.4
W_2	9.4	ℓ_2	10.5
W_3	1.9	ℓ_3	1.8
W_4	3.1	ℓ_4	6
W_5	1.5	ℓ_5	25
W_6	7	ℓ_6	30.3
W_7	37.1	ℓ_7	25
W_8	3.15	ℓ_8	3
W_9	3	ℓ_9	0.3
W_{10}	1	ℓ_{10}	6.57
W_{11}	3.2	Via diameter	1

III. SIMULATION AND MEASUREMENTS

In this section, the measurement results of the prototyped designs given in Fig. 7 are compared with the simulated results.



(a) (b)

Fig. 7. Top view of the manufactured modified SIW antenna: (a) top layer and (b) bottom layer.

Both, the simulation as well as measurement results of the reflection performance of the manufactured antennas are given in Fig. 8.

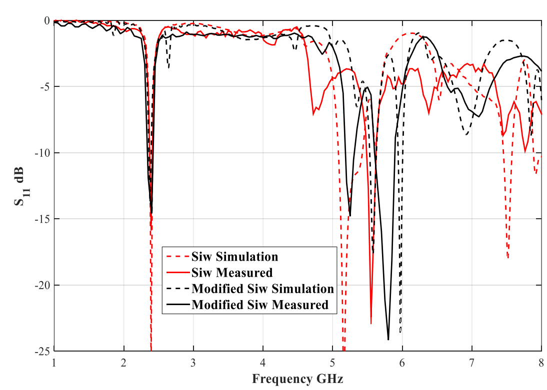


Fig. 8. Simulated and measurement reflection performance.

The maximum far field gain of the proposed SIW antennas is measured using the measurement setup shown in Fig. 9. By using two identical antennas given in [12], the far field gain and radiation pattern results of the proposed antennas are obtained.

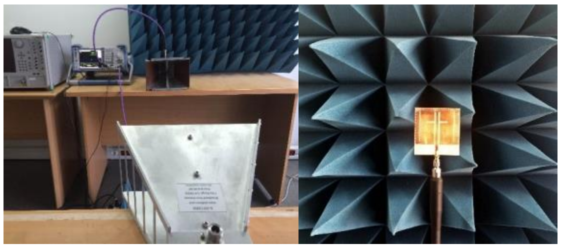


Fig. 9. Measurement setup for maximum far field gain.

The measured far field gain and radiation pattern of the fabricated antennas are given in Fig. 10 and Fig.11. As is seen from Fig. 10, the maximum far field gain of the proposed modified SIW antenna design is almost 1.5 dB and 1 dB higher than the other design at 2.4 and 5.6 GHz bands with a simple design modification to the primary antenna model.

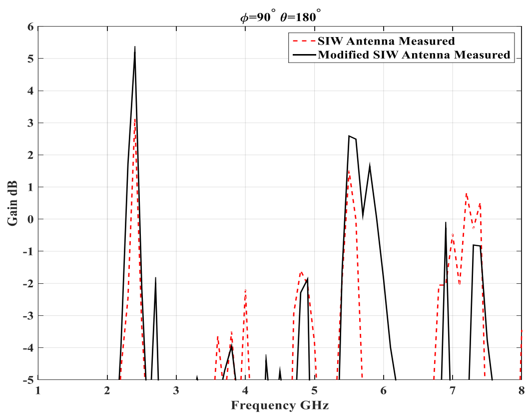
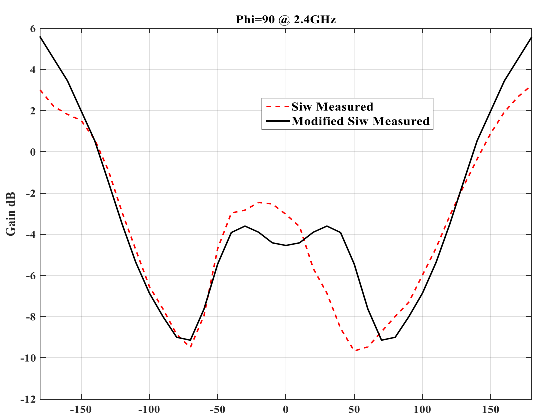
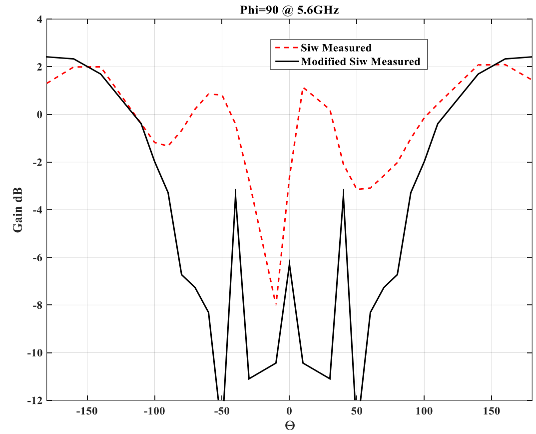


Fig. 10. Measurement results for maximum far field gain.



(a)



(b)

Fig. 11. Measurement results for radiation pattern: (a) 2.4 GHz and (b) 5.6 GHz.

In Fig. 11, the measured far field gains of prototyped antenna models are given. As is evident, the propagation directions of both antenna designs are from the back. The modified antenna design has almost 3 dB @ 2.4 GHz and 1.5 dB @ 5.6 GHz gain improvement as compared to the counterpart model.

IV. CONCLUSION

As is seen from measurement and simulation results, the proposed dual band antennas designed with SIW technology deliver high performances; further, by adding modifications such as defecting top layers or adding DGS to the design, it is possible to enhance its total performance. The design techniques presented here suggest that the proposed antenna model is a feasible, low cost, high performance dual band antenna design that can easily be integrated in wireless communication systems for ISM band applications.

REFERENCES

[1] M. Petersen, "High performance microwave antennas using SIW technology," Aug. 2017, Available at: http://www.antennasonline.com/main/blogs/high-performance-microwave-antennas-using-siw-technology

[2] M. Esquius-Morote, B. Fuchs, J. Zurcher, and J. R. Mosig, "Novel thin and compact H-plane SIW horn antenna," *In Antennas and Propagation, IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 2911-2920, 2013.

[3] M. Bozzi, A. Georgiadis, and K. Wu, "Review of substrate-integrated waveguide circuits and antennas," *IET Microwaves, Antennas & Propagation*, vol. 5, pp. 909-920, 2011.

[4] Z.-C Hao, W. Hong, J.-X Chen, X.-P Chen, and K. Wu, "Compact super-wide bandpass substrate integrated waveguide (SIW) filters," *IEEE Trans.*

on Microwave Theory and Techniques, vol. 53, pp. 2968-2977, 2005.

[5] Y.-J. Cheng, W. Hong and K. Wu, "Millimeter-wave substrate integrated waveguide multibeam antenna based on the modified r-kr lens," *Microwave Symposium Digest, IEEE MTT-S International*, Atlanta, GA: IEEE, pp. 703-706, 15-20 June 2008.

[6] F. Giuppi, A. Georgiadis, A. Collado, M. Bozzi, and L. Perregrini, "Tunable SIW cavity backed active antenna oscillator," *Electron. Lett*., vol. 46, pp. 1053-1055, 2010.

[7] J. Liu, D. Jackson, and Y. Long, "Substrate integrated waveguide (SIW) leaky-wave antenna with transverse slots," *IEEE Trans. on Antennas and Propagation*, vol. 60, pp. 20-29, Jan. 2012.

[8] E. Arnieri, G. Amendola, L. Boccia, and G. D. Massa, "Substrate integrated radiating waveguides with a coaxial feed," *Antennas and Propagation, The Second European Conference, IEEE*, Edinburgh, pp. 1-4, 11-16 Nov. 2007.

[9] P. Mahouti, M. A. Belen, H. P. Partal, S. Demirel, and F. Günes, "Miniaturization with dumbbell shaped defected ground structure for power divider designs using sonnet," *Applied Computational Electromagnetics*, Williamsburg, VA, USA: IEEE, pp. 1-2, 22-26 Mar. 2015.

[10] R. D. Portilla, "X-band substrate integrated waveguide cavity-backed patch antenna self-oscillating mixer," *Universitat Politècnica de Catalunya Pontificia Universidad Católica del perúcentretecnològic de telecomunicacions de catalunya*, Spain, 2010.

[11] Pasternack's Microstrip Patch Antenna Calculator, August 14, 2017. https://www.pasternack.com/t-calculator-microstrip-ant.aspx

[12] LB8180, 0.8-18 GHz broadband horn antenna, August 14, 2017. Available at: http://www.ainfoinc.com/en/p_ant_h_brd.asp

Mehmet Ali Belen received his M.Sc. degree in Electronics and Communication Engineering from the Süleyman Demirel University in 2011. He has been currently in the Ph.D. program of Yıldız Technical University. His current research interests are in the areas of multivariable network theory, device modeling, computer aided microwave circuit design, monolithic microwave integrated circuits, and antenna arrays.

Peyman Mahouti received his Ph.D. degree in Electronics and Communication Engineering from the Yıldız Technical University in 2016. He has been currently working as a Teaching Assistant in the Yıldız Technical University. The main research areas are optimization of microwave circuits, device modeling, and computer-aided circuit design and antenna designs.

Alper Çalışkan received his M.Sc. degree in Electronics and Communication Engineering from the Yıldız Technical University in 2013. He has been currently in the Ph.D. program of Yıldız Technical University. The main research areas are optimization of microwave circuits, broadband antenna designs, and device modeling.

Aysu Belen received her M.Sc. degree in Electronics and Communication Engineering from the Yıldız Technical University in 2016. She has been currently in the Ph.D. program of Yıldız Technical University. Her main research areas are optimization of microwave circuits, circuits, device modeling, and computer aided circuit design and microwave amplifiers.