Progress In Electromagnetics Research C, Vol. 38, 79–88, 2013

DESIGN OF MISSILE-MOUNTED SIW ANTENNA WITH HIGH DIRECTIVITY FOR DATA TRANSMISSION

Wen-Chung Liu[1, *] and Chih-Sheng Chen[2]

[1]Department of Aeronautical Engineering, National Formosa University, 64, Wenhua Road, Huwei, Yunlin 632, Taiwan, R.O.C.

[2]Graduate Institute of Aviation and Electronic Technology, National Formosa University, 64, Wenhua Road, Huwei, Yunlin 632, Taiwan, R.O.C.

Abstract—A substrate-integrated-waveguide (SIW) antenna with high directivity for data transmission between a missile and a control platform, usually an aircraft, is presented. By simply setting vias and loading parasitic elements to a rectangle patch on an FR4 substrate, good resonance with effective concentration of current was therefore achieved. For verification, constructed prototypes of both the proposed SIW antenna and the 2/3 scaled system of the designed SIW antenna mounted on the missile were simulated and measured. Good agreement between both has been obtained The original SIW antenna working at C band has an operating bandwidth of 100 MHz (4.78–4.88 GHz) and an average gain of about 5 dBi as well, whereas the scaled missile-mounted antenna system has an operating bandwidth of 160 MHz (7.17–7.33 GHz) with a gain of about 3 dBi at 7.24 GHz. Also, directive radiation patterns suitable for use on data transmission in a missile-aircraft transceiver system have been measured for the both cases.

1. INTRODUCTION

Recently, the development of precise data transmission between the missile and the control platform, which is usually the aircraft, has received more attention than before. It clearly indicates the track of the missile after projecting should and can be exactly guided to the target by the control platform (aircraft) if the data transceived from the missile can always point to the platform [1]. Therefore, the antenna mounted on the missile should be with a high directivity in radiation

Received 29 January 2013, Accepted 14 March 2013, Scheduled 15 March 2013
* Corresponding author: Wen-Chung Liu (wencliu@nfu.edu.tw).

orientation. With many advantages like low cost, low leakage, low profile, and easy integration etc, the Substrate-Integrated-Waveguide (SIW) structure has been more widely employed to design microwave components such as the filters, power dividers, antennas and so on [2–12]. Especially, the SIW antenna, which has a cavity backed structure to effectively suppress undesired surface-wave mode and thus to provide a highly directional radiation, is very suitable for use in a missile-aircraft transmission system.

In this design, the proposed SIW antenna employing a series of vias and two parasitic elements for producing directive radiation is compatible with the C-band data transmission on a missile-aircraft communication system. Comparing to the reported directive antennas for such application [1], the antenna has a relatively simple structure and is with ability to provide stable patterns and good antenna peak gain over the operating band for practical use.

2. ANTENNA DESIGN AND MEASUREMENT

Figure 1 presents the geometry of the synthesized directive microstrip-fed SIW antenna. It was evolved from an FR4 substrate with dimensions of $L \times W\,\mathrm{mm}^2$ and specified characteristics of 1.6 mm in thickness and 4.4 in relative permittivity. The main radiator, which is a rectangular patch of $L_1 \times W_1\,\mathrm{mm}^2$ printed on the top face of the FR4 substrate, was fed by a 50-Ω microstrip line of width W_2 and length L_2 from the bottom of the patch, whereas the ground plane, its size is $(L - L_2) \times W\,\mathrm{mm}^2$ and was etched on the other side of this substrate.

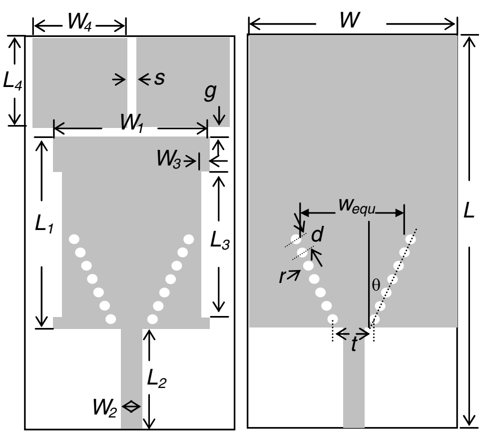

Figure 1. Geometry of the proposed directive SIW antenna.

In this design, for concentrating the current distribution on a portion of the patch to thus result in a directive radiation, three skills were adapted. First, dual symmetrical via arrays with a start separation t between both were set on the radiating patch for making the radiation structure as an open SIW cavity. The diameter of each via and distance between any two neighbor vias are r and d, respectively. Meanwhile the flare angle between the via array and the vertical line is θ. Secondly, a slot with dimension of $L_3 \times W_3\,\mathrm{mm}^2$ was embedded into each of the two sided edges of the patch radiator. Finally, two patch elements, each having dimensions of $L_4 \times W_4\,\mathrm{mm}^2$ were parasitically loaded to the radiating patch. The spacing between the two parasitical elements and the gap distance from the radiation patch to the parasitical elements are s and g, respectively. For the SIW structure, based on the rules presented in [13], the relation between the desired resonant frequency f_c and the equivalent waveguide width w_{equ} for TE_{10} can be estimated by

$$f_c = \frac{c}{2w_{equ}\sqrt{\varepsilon_\gamma}} \tag{1}$$

where c is the speed of light and ε_γ the substrate's permittivity. Meanwhile, the width w_{equ} of the SIW in this design (c.f. Figure 1) can be calculated from the following equation

$$w_{equ} \approx 2(6d + r)\sin\theta + t - r \tag{2}$$

In this design, except using Equations (1) and (2), the full-wave analysis tool of HFSS was also conducted to tackle the more rigorous determination of values of the geometrical parameters. After some trials, the final dimensions of the proposed SIW antenna with optimal impedance matching and good directive radiation were obtained and listed in Table 1.

Table 1. Dimensions for the optimal directive SIW antenna.

Par.	L	L_1	L_2	L_3	L_4	r	s	θ
mm	60.75	29.4	15.6	22.5	13.8	0.75	1.45	23°
Par.	W	W_1	W_2	W_3	W_4	d	g	t
mm	30	22.5	3	0.75	13.4	2.25	1.5	6

Thereafter, the obtained antenna has been constructed and experimentally studied. Figure 2 presents the simulated and measured frequency responses of the return loss for the proposed SIW antenna. Obviously, for simulation, the antenna provides an impedance bandwidth of about 100 MHz (4.74–4.84 GHz) at a main resonant frequency of 4.8 GHz, whereas for the measurement, the main

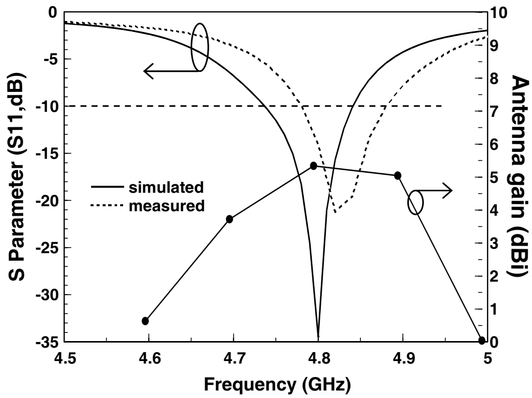

Figure 2. Frequency response of simulated, measured return loss, and measured peak antenna gain.

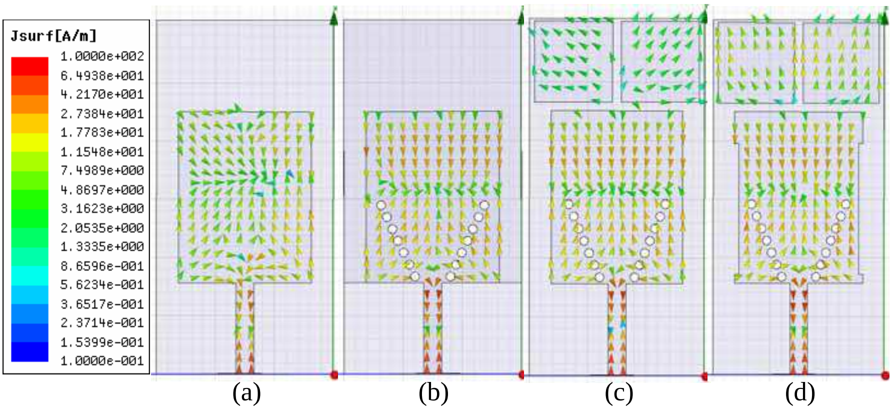

Figure 3. Simulated results of the surface current distributions at 4.8 GHz for the antenna studied in Figure 1, (a) initial patch only; (b) patch with via arrays; (c) patch with via arrays and parasitic elements; (d) patch with via arrays, parasitic elements, and sided slots.

resonant frequency is shifted to 4.82 GHz with a bandwidth of also 100 MHz (4.78–4.88 GHz). Clearly, the deviation of the main resonant frequency is 0.02 GHz, which is about 0.4% with respect to 4.8 GHz, and this shows a good agreement between the simulation and the measurement. Also plotted in Figure 2 is the measured peak antenna gain for frequencies across the operating band, 4.78–4.88 GHz. Clearly, an average gain of more than 5 dBi has been obtained. To further verify the effectness of the skills we adapted for this design, the results of surface current distributions on the antenna when operating at 4.8 GHz were also simulated and presented in Figure 3. According to the change of current distribution caused from the initial patch with different loads such as via arrays, parasitic elements, and sided slots, it clearly shows that by use of the adapted skills the current can be effectively concentrated on the radiating patch to thus produce a good directive radiation. Figure 4 then gives the simulated and measured far-field E-plane radiation patterns at frequency of 4.8 GHz for the proposed SIW antenna. The results agree well and the patterns of both are directive with a front-to-back ratio (F/B) more than 10 dB. Obviously, from these results, the proposed SIW antenna with good directivity is suitable for use in a missile-aircraft transceiving system on data transmission when operating at C band.

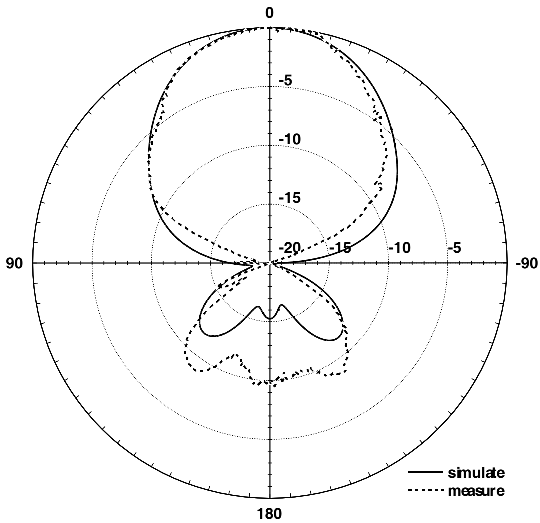

Figure 4. Simulated and measured E-plane radiation patterns of the proposed antenna at 4.8 GHz.

3. SCALE MODEL OF MISSILE-MOUNTED ANTENNA

In experimental verification, electromagnetic performance of the proposed directive SIW antenna mounted on a missile should be tested in an anechoic chamber. However, considering the size limitation of our chamber, which is about $7\,\mathrm{m}\,(L) \times 3\,\mathrm{m}\,(W) \times 3\,\mathrm{m}\,(H)$, the real size of the designed SIW directive antenna mounted on the missile can not be fully set in the test chamber. For this, the scale-model technology should be applied. Therefore, we adapted a scaling factor of 2/3 for this system. It means that both the missile and the SIW antenna were scaled to be a size of two-thirds of the original one. Based on this scaling, the operating frequency has to be increased to about 7.2 GHz, which is about 3/2 times to the original resonant frequency of 4.8 GHz.

Figure 5 shows the 2/3-scaled system of the directive SIW antenna mounted on the missile. The location of antenna is sited very close to the tail of the missile. The scaled system has then been simulated using HFSS and measured in the anechoic chamber. Figure 6 gives the frequency responses of simulated return loss, measured return loss and peak antenna gain for case of the scaled antenna isolated from the missile. For return loss, the simulated and measured results indicate that the proposed scaled SIW antenna when isolated from the missile resonates at 7.19 and 7.24 GHz, respectively, and has a respective impedance bandwidth of 170 MHz (7.09–7.26 GHz) and 160 MHz (7.15–

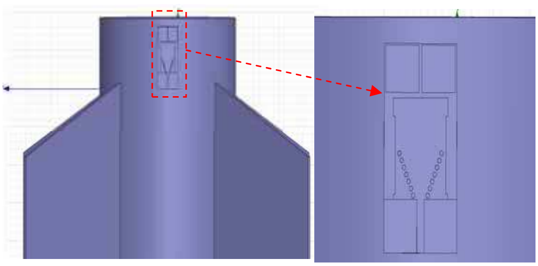

Figure 5. 2/3-scaled system of the proposed directive SIW antenna mounted on a missile.

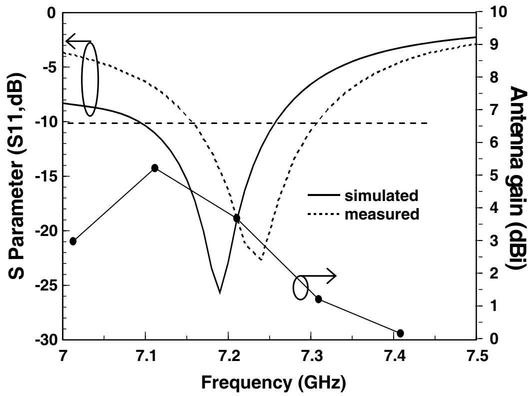

Figure 6. Frequency responses of simulated, measured return loss and peak antenna gain for the proposed scaled SIW antenna isolated from the missile.

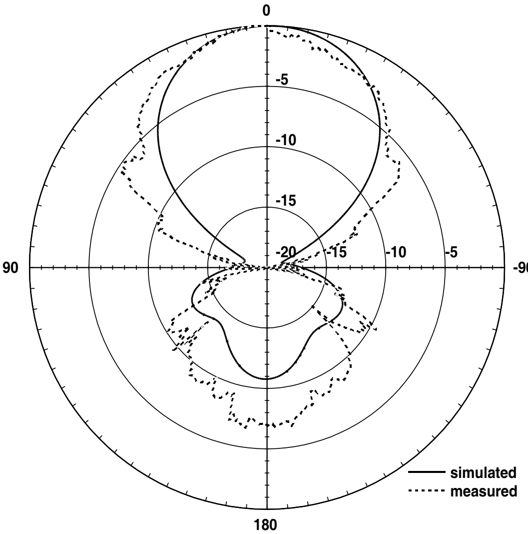

Figure 7. Simulated and measured E-plane radiation patterns of the proposed scaled SIW antenna when isolated from the missile and operating at 7.24 GHz.

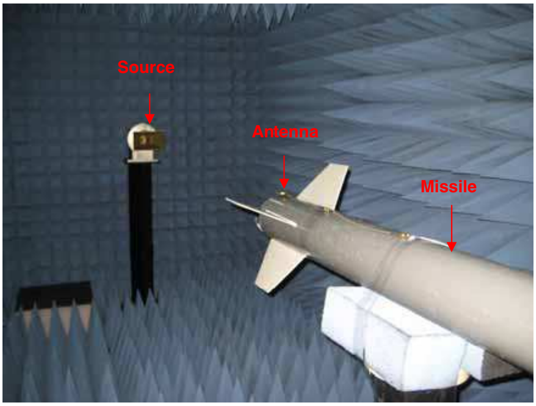

Figure 8. Photograph of experiment setup for the SIW antenna mounted on the scaled missile.

7.31 GHz). As for the peak antenna gain, the measurement explores a value of about 3.7 dBi when the system operating at 7.24 GHz. The simulated and measured far-field E-plane radiation patterns for the scaled SIW antenna when isolated from the missile and

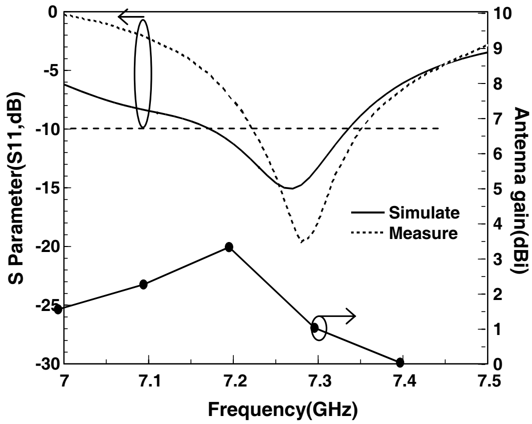

Figure 9. Frequency responses of simulated, measured return loss and peak antenna gain for the proposed scaled SIW antenna mounted on the scaled missile.

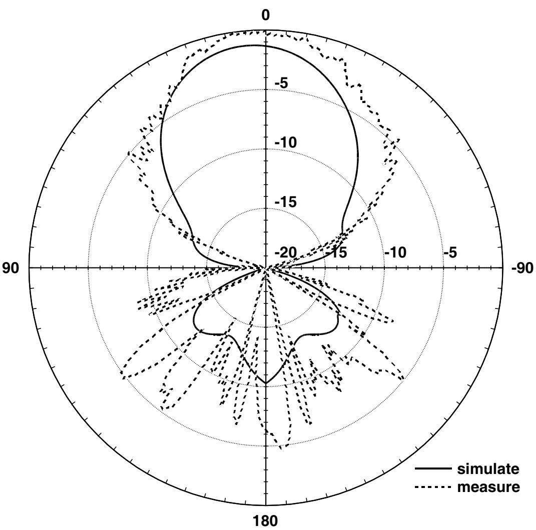

Figure 10. Simulated and measured E-plane radiation patterns of the proposed scaled SIW antenna mounted on the scaled missile when operating at 7.24 GHz.

operating at 7.24 GHz are presented in Figure 7 The measured pattern with a directive characteristic agrees well with the simulated result. Thereafter, as the photograph shown in Figure 8, the scaled system was set up and experimentally studied in the chamber. It should be noted that in this scaled system a thin spacer exists between the SIW antenna and the missile body for isolation. Figure 9 simultaneously gives the frequency responses of simulated return loss, measured return loss and peak antenna gain for this scaled system. The best resonances obtained from the simulation and the measurement occur at 7.28 and 7.27 GHz, respectively, accompanying with a respective impedance bandwidth of 130 MHz (7.22–7.35 GHz) and 160 MHz (7.17–7.33 GHz). As for the peak antenna gain, the measurement explores a value of about 3.0 dBi when the system operating at 7.24 GHz. Finally, Figure 10 shows the radiation patterns of the scaled system as it operates at the same frequency, 7.24 GHz. As the results obtained from the full-scale system (shown in Figure 3), the E-plane patterns of the scaled system are also quite directive and agreement between the simulation and measurement is in general good as well.

4. CONCLUSIONS

Design of an SIW antenna with high directivity for mounting on a missile is presented. Electromagnetic model of both the antenna and the antenna mounted on a missile have been simulated and constructed. In addition, a scale model for the antenna-missile system has been tested. The measured results agree well with the HFSS simulation. Finally, the proposed antenna design shows it has good bandwidth and high directional radiation, and is suitable for data transmission in a missile-aircraft system at frequency of C-band.

ACKNOWLEDGMENT

This work was supported by the National Science Council of the Republic of China under Grant NSC 100-2221-E-150-046-. The simulation software HFSS was supported by the National Center for High-performance Computing.

REFERENCES

1. Chen, C., J. Zhang, L. Li, and H. Chen, "Research of the missile and aircraft base mounted antennas for data transmission," *Int. Conf. Microwave Millimeter Wave Technol.*, 392–394, 2010.
2. Xu, Z.-Q., Y. Shi, P. Wang, J. X. Liao, and X.-B. Wei, "Substrate integrated waveguide (SIW) filter with hexagonal resonator," *Journal of Electromagnetic Waves and Applications*, Vol. 26, Nos. 11–12, 1521–1527, 2012.

3. Zhang, Q.-L., W.-Y. Yin, S. He, and L.-S. Wu, "Evanescent-mode substrate integrated waveguide (SIW) filters implemented with complementary split ring resonators," *Progress In Electromagnetics Research*, Vol. 111, 419–432, 2011.
4. Hizan, H. M., I. C. Hunter, and A. I. Abunjaileh, "Integrated SIW filter and microstrip antenna," *European Microwave Conf.*, 184–187, 2010.
5. Hu, G., C. Liu, L. Yan, K. Huang, and W. Menzel, "Novel dual mode substrate integrated waveguide band-pass filters," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 11–12, 1661–1672, 2010.
6. Masa-Campos, J.-L., P. Rodriguez-Fernandez, M. Sierra-Péerez, and J.-L. Fernandez-Jambrina, "Monopulse circularly polarized siw slot array antenna in millimetre band," *Journal of Electromagnetic Waves and Applications*, Vol. 25, Nos. 5–6, 857–868, 2011.
7. Zeng, Z., W. Hong, Z. Kuai, H. Tang, and J. Chen, "The design and experiment of a dual-band omni-directional SIW slot array antenna," *Asia-Pacific Microwave Conf.*, 1–4, 2007.
8. Guang, H., H., Wei, H. S. Xing, and H. X. Zhou, "Design of an omnidirectional line array with SIW longitudinal slot antenna," *Int. Conf. on Microwave and Millimeter Wave Technol.*, 1114–1117, 2008.
9. Liu, B., W. Hong, Z. Kuai, X. Yin, G. Luo, J. Chen, H. Tang, and K. Wu, "Substrate integrated waveguide (SIW) monopulse slot antenna array," *IEEE Trans. Antennas Propag.*, Vol. 57, 275–279, 2009.
10. Lin, S., S. Yang, A. E. Fathy, and A. Elsherbini, "Development of a novel UWB vivaldi antenna array using SIW technology," *Progress In Electromagnetics Research*, Vol. 90, 369–384, 2009.
11. Wahab, W. M. A., D. Busuioc, and S. Safavi, "A substrate-integrated-waveguide (SIW) quadrature hybrid-junction for low cost millimeter-wave planar antenna array," *IEEE Int. Symp. on Antennas and Propag.*, 1–4, 2010.
12. Smith, N. A. and R. Abhari, "Microstrip-fed circular substrate integrated waveguide (SIW) cavity resonator and antenna," *IEEE Int. Symp. Antennas and Propag.*, 1–4, 2010.
13. Deslandes, D. and K. Wu, "Design consideration and performance analysis of substrate integrated waveguide components," *Microwave Conf.*, 1–4, 2002.