The Design of Dual or Multi-Band Microstrip Antennas by Using Disturbing Patches

[1]Yung-Hui Shih, [2]Ke-Nung Huang, [2]Chih-Cheng Lin, [3]Chin-Chia Chen and [2,*]Tung-Hung Hsieh

Abstract

The purpose of this paper is to employ various shapes and numbers of disturbing patches in microstripcavity to design for dual or multiple-band operation. The data shows that even only one disturbing patch can produce two different modes, and the radiation is still within an acceptable range. A triangular disturbing can creates more frequency separation than the one with rectangular disturbing. As two disturbing patches are placed vertically, three acceptable modes can be excited without degrading the antenna radiations. While comparing those data among the patches with different numbers of concaved disturbing, the concaved arrangement can be used to modify cross-polarization radiation without changing their two resonant frequencies too much. Both simulations and experiments well verify the design concept. The arrangement of disturbing patches introduced here is simple and coplanar and easy to fabricate with PCB technology, and it can provide an alternative choice for design.

Keywords: dual band, concaved disturbing, disturbing vertically, microstrip antenna, single disturbing, triple band, triangular disturbing

1. Introduction

The design of antennas with a multiple-band operation has been the major trend in wireless communication systems. Since microstrip antennas have many advantages, they have been popularly used for design [1, 2]. There are many researches related to the design for microstrip antennas with a dual-band application. For an example, placing a VIA in a conventional patch, the change of electric field becomes dramatically in cavity [3, 4]. Although two-band operation can be achieved, the non-coplanar structure is a problem for PCB fabrication. As various geometries of microstrip integrated together, and multiple paths of resonance can make dual-band operation possible [5-8]. However, the coupling of radiation may be interfered with each other as these structures stay too close. Another design is to use T-shape or circular T-shape microstrip patch to meet the similar purpose [9, 10]. The antenna consists of two different lengths for resonance to reach the dual-band function; however, the radiation problem limits its application for a specific frequency band. In contrast to this simple design, as electromagnetic coupling is used with a ring aperture in microstrip structure, two different lengths of a ring can make two different modes for a dual band [11]. However, the coupling between electromagnetic waves also makes the design more difficult. In contrast, if embedded metal strips and filled substrate are applied in a microstrip antenna, the disturbing of originally uniform distributed electric field can create two individual modes with acceptable radiations [12]. Fortunately, this problem on a non-coplanar structure can be improved by using a substrate with specific thickness or dielectric constant [13, 14]. Among these researches for dual bands mentioned earlier, by employing the concept of disturbing on electrical field, antenna structure becomes symmetric. In other word, only half of the antenna structure could just achieve the dual-band function, and design can be thus simplified with only focusing on the same half region. Thus the purpose of this paper is first to investigate the advantage of a disturbing patch in a microstrip cavity. Furthermore, the study is extended to design a dual-band antenna with a more flexible frequency separation and an antenna with multiple bands.

2. Design Concept

According to the study [12], if two metallic patches are placed in a microstrip cavity to distract the electric field, two modes can be excited without changing the antenna radiation too much. Apparently, if there is only a disturbing patch, the electric field can be altered in the antenna cavity. Thus, in this paper, a rectangular metallic strip is first arranged in the same way within the microstrip antenna as shown in Figure 1. Since the interested mode before disturbance is TM01, the uniform distributed electric field will be disturbed into two modes with different

*Corresponding Author: Tung-Hung Hsieh
(E-mail: tonyhs@isu.edu.tw).
[1]Department of Materials Science and Engineering, I-shou University, Kaohsiung, Taiwan 840.
[2]Department of Electronic Engineering, I-shou University, Kaohsiung, Taiwan 840.
[3]Chin-Chia Chen, Antenna Design Department, HTC, Taipei, Taiwan.

distributions. Secondary, in order to enhance the distraction, the originally rectangular metallic patch is modified to a triangular shape as shown in Figure 2, so that the disturbance on the electric field will become much more than ever. Since the resonant frequencies of the two modes in this antenna can be altered much easily so that the separation variation of frequencies becomes possible. After the investigation on disturbing shape, two rectangular metallic strips are placed vertically within an antenna cavity as indicated in Figure 3. Since there are three layers of substrates, the disturbing of the electric field can be done at higher and lower levels. Therefore, more modes can be excited from the original TM01 mode, and radiations will still remain acceptable with this arrangement. Furthermore, the investigation is also on the case of disturbing patch with a concaved structure, such as the one with one concave in Figure 4, with two concaves in Figure 5, and with five concaves in Figure 6. In order to prove the design concept, the results from ENSEMBLE and HFSS simulation tool are provided. In addition, experimental data is used to reconfirm the validity. During the experiment, there are various substrates used, such as Duroid 5880, 4003, FR-4 and air in order to meet the demand of a microstrip antenna with multiple layers. Notice that the substrate of air in experiments is made with a small piece of suspended layer, and this technique is indicated in [15].

3. Results and Comparisons

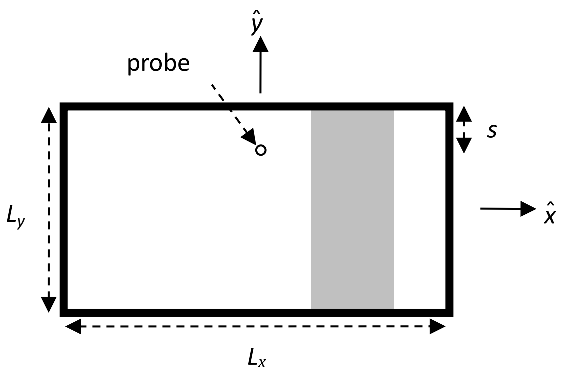
For the antenna with a single disturbing patch in Figure 1, the return loss shows that the resonant frequencies of the lower mode obtained from ENSEMBLE and HFSS are 3.51 and 3.50 GHz, respectively. The higher mode resonates at 4.91 and 4.75 GHz. The frequency differences are within an acceptable range, and the lower-enough return loss shows that these two modes are well matched. Figure 7 demonstrates the simulated electric field along cross section of the cavity. Near the surrounding of disturbing metal, the higher and lower modes have different distributions. This phenomenon due to metallic disturbing reflects the expectation from design concept. Figure 8 shows the radiation pattern of the lower mode. On the major planes, the co-polarization radiation pattern shows an acceptable single beam, and the cross-polarization one is lower enough. For higher mode, the radiation patterns in Figure 9 demonstrate that the patterns of co-polarization fields are also acceptable on both two major planes, and those of cross-polarization is far below co-polarization's. Table 1 shows the resonant frequencies of two modes obtained from experiment, ENSEMBLE and HFSS. The error is only as low as 3%, which may be due to the fringe effect because the data from ENSEMBLE is simulated with an infinite ground. As studied [16], the difference of these resonant frequencies is so limited that similar radiations from experiments should be expected; therefore, they are not presented here for comparison. Since data from two simulations are so close, it proves that the concept of an antenna with a single disturbing patch does work at dual bands. According to the comparisons earlier, it is sure that the simulation tools are eligible for this kind antenna structure with disturbing patches. For the antenna with a triangular patch in Figure 2, the return loss shows that this antenna resonates at 4.36 and 5.1 GHz and the impedance matching for these two modes are only slightly different. These two frequencies are not too far from those of the antenna in Figure 1. Table 2 shows the comparisons of resonant frequency between these two antennas with different disturbing shapes. Notice that the frequency separation offered from the triangular patch is much larger than that from the rectangular one. Note that the computation of the band separation is based on the following formula:

$$\Delta = \frac{B\left(f_2 - f_1\right) - A\left(f_2 - f_1\right)}{A\left(f_2 - f_1\right)}$$

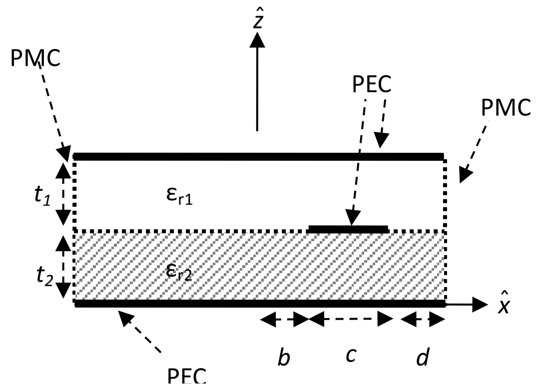
Apparently, a disturbing shape of the metal can be used to adjust frequency separation of two modes for this kind of antenna. Figures 10 and 11 show the radiation of the excited two modes, and the results of co- and cross-polarization are still acceptable. For the antenna with two disturbing patches placed vertically, the results of return loss from ENSEMBLE and HFSS both demonstrate that three individual modes are created at around 1.84, 2.02 and 2.3GHz. The simulated resonant frequencies are slightly different from those from experiments; the difference could be due to the fabrication error. Only the measured second mode resonates slightly from the simulation, the remaining frequencies are pretty close. In order to confirm the design concept, electric field distributions of these three different modes are shown in Figure 12. It shows the electric field distribution of these three modes; that means the vertically disturbing patches do work as expected. Apparently, their distributions are all different with each other so that their resonant frequencies also vary. Since the simulation for radiation patterns from ENSEMBLE has been already verified by HFSS, so only the ENSEMBLE data is shown later on. Figures 13-15 depict the simulated radiation patterns of these three modes; all of the single beam and lower cross-polarization radiation prove that the radiations are well acceptable. It is clear that the design of disturbing patches placed vertically makes tri-band operation possible for antennas. For those antennas with concaved disturbing patches, the result of return loss shows that it resonant at 1.411 and 2.379GHz. The radiation patterns in Figures 16 and 17 prove that these results are with acceptable range. The return loss reveals that the resonant frequencies of the antenna with a two-concaved patch are 1.41 and 2.42GHz. The data between the antennas with one or two concaved patch remains close with each other, but the radiation patterns in Figures 18 and 19 demonstrate that the cross-polarization radiation of the one with a two-concaved patch is much more acceptable. The reason could be due to that the distribution of electric field along concaved axis is disturbed so that the cross-polarization radiation is also changed. This means that the number of concave structure is useful for radiation improvement. As the number of concave increases up to five, the return loss in Figure 20 shows that the resonant frequencies do not vary too much. However, the radiation in Figure 21 reveals that the cross-polarization component becomes slightly out of an acceptable range. Apparently, concave number is good to improve radiation, but this number should not be too high.

4. Conclusion

This paper employs various shapes and numbers of disturbing patches to increase the design freedom of a microstrip antenna with layers of substrates and disturbing patches. The investigation shows that only one disturbing patch can excites two antenna modes, and the radiation is within an acceptable range. The triangular disturbing can creates more frequency separation than the rectangular one. As two disturbing patches are placed vertically, three acceptable modes can be excited without degrading the antenna radiations. For those investigations among the patches with different numbers of concaved disturbing, the concaved arrangement can be used to modify cross-polarization radiation without changing their two resonant frequencies too much. Simulations and experiments both verify design concept. The arrangement of disturbing patch introduced in this paper can provide an alternative choice to design an antenna for dual- or tri-band operation.



(a)



(b)

Figure 1: The microstrip antenna with a rectangular disturbing patch: (a) top view, (b) front-side view.

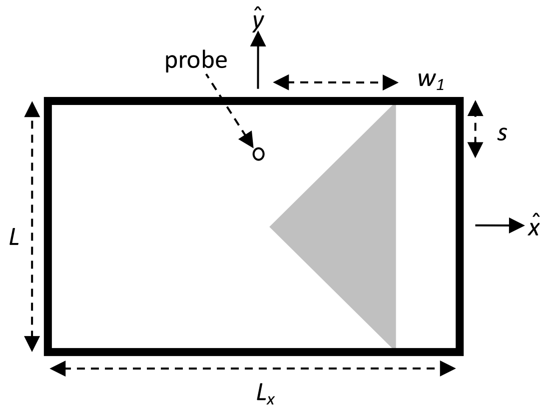


Figure 2: The microstrip antenna with a triangular disturbing patch: top view.

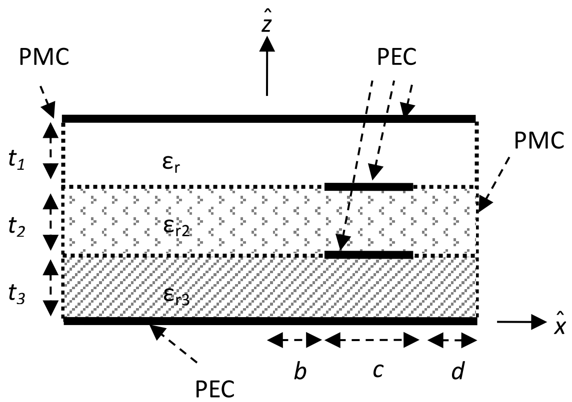


Figure 3: The microstrip antenna with two disturbing patches placed vertically: front-side view

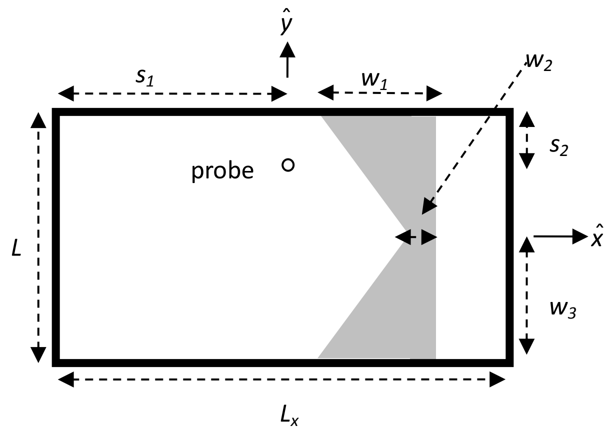


Figure 4: The microstrip antenna with a concaved disturbing patch: top view.

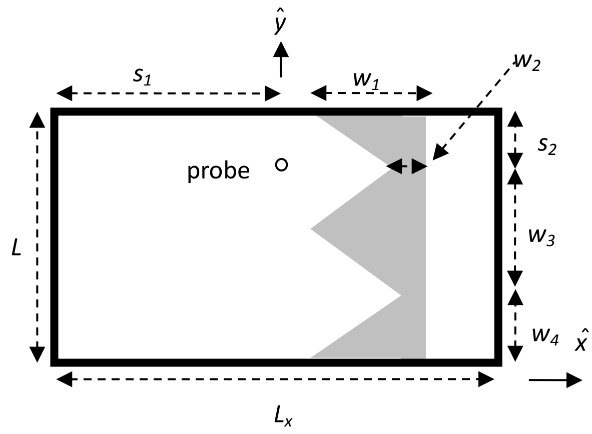


Figure 5: The microstrip antenna with a two-concaved disturbing patch: top view

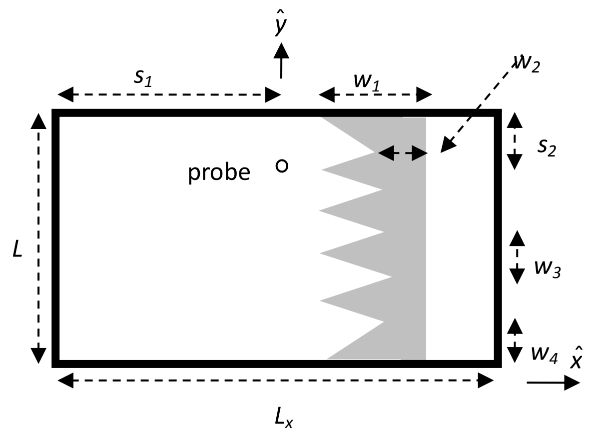


Figure 6: The microstrip antenna with a five-concaved disturbing patch: top view.

Table 1: For the antenna in Figure 1, the resonant frequencies of two interested modes obtained from three different methods, and the structure dimensions: L_x= 4cm, L_y=2.5cm, ε_{r1}=1, ε_{r2}=3.35, 、 s=0.65cm, t_1=t_2=20mils, b=0.5cm, c=1cm, d=0.5cm.

	First mode(GHz)	Second mode(GHz)
Experiment	3.40	4.75
Ensemble	3.51	4.91
HFSS	3.50	4.83

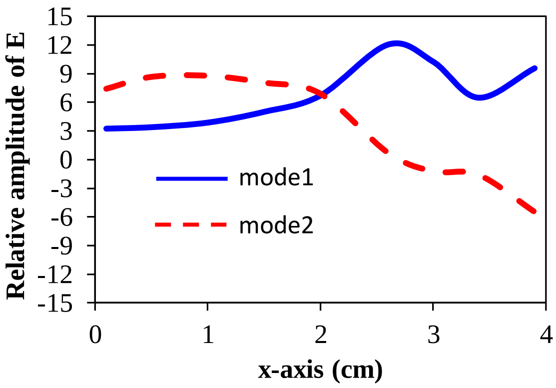
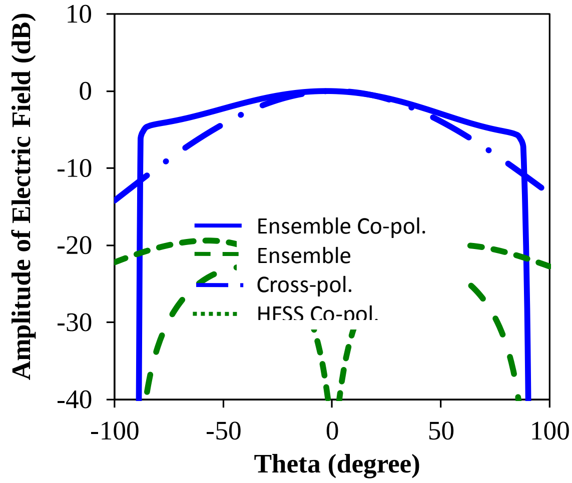
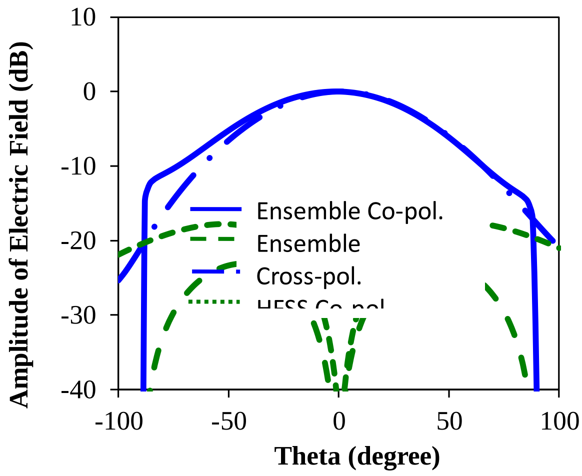


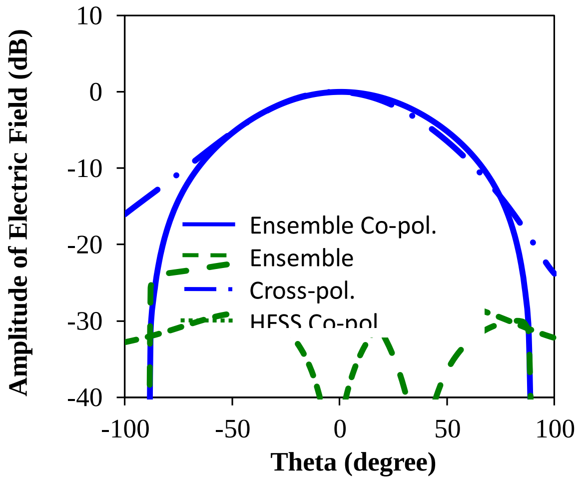
Figure 7: For the two modes of the antenna in Figure1, the distributions of the electric fields on the cross section where y is 0.6cm. The structure dimensions are the same as those in Table 1.



(a)

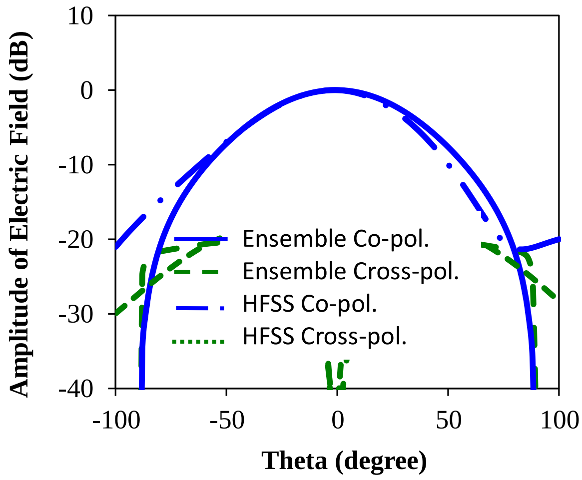


(a)



(b)

Figure 8: For the first mode of the antenna in Figure1, the simulated radiation patterns on different planes obtained from ENSEMBLE and HFSS: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Table 1.

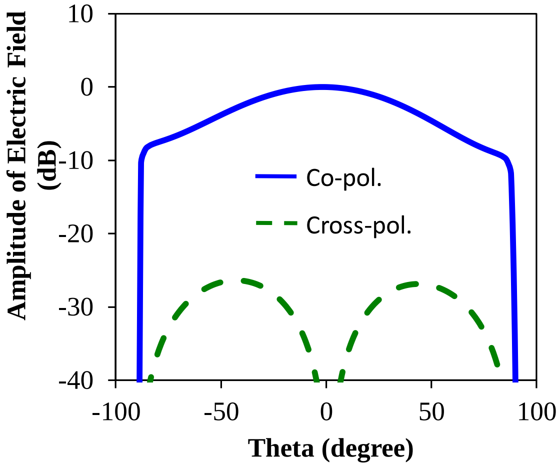


(b)

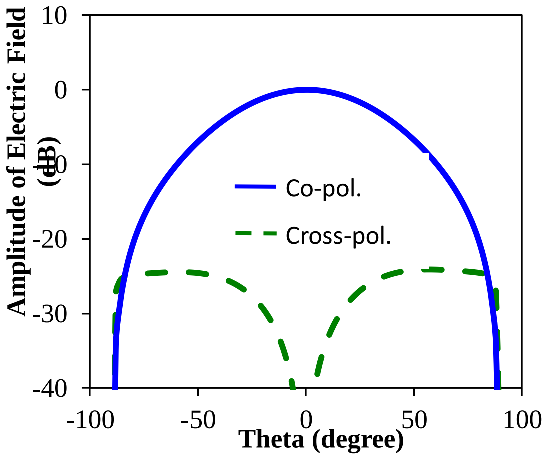
Figure 9: For the second mode of the antenna in Figure1, the simulated radiation patterns on different planes obtained from ENSEMBLE and HFSS: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Table 1.

Table 2: For the antennas in Figures 1 and 2, the comparison of frequency separation obtained from simulation.

Disturbing Type	Mode1(GHz)	Mode2(GHz)	Reduction rate (Δ)
Rectangular	3.51	4.91	0%
Triangular	4.36	5.1	Δ_2=47%

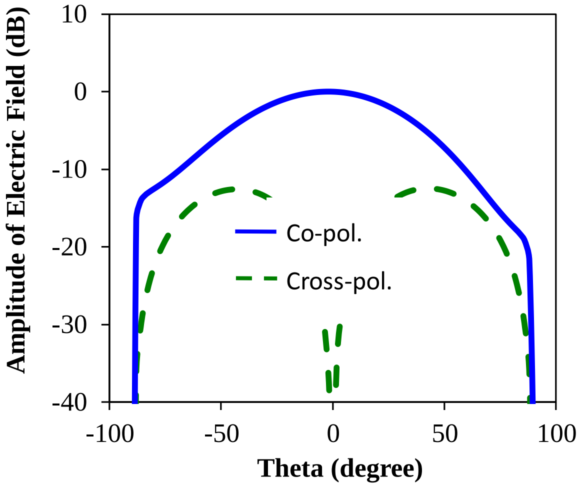


(a)

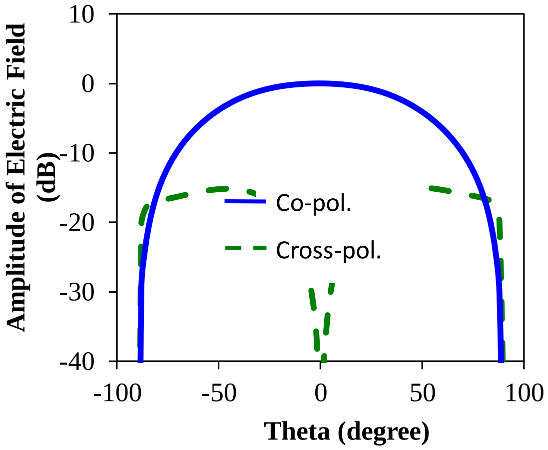


(b)

Figure 10: For the first mode of the antenna in Figure 2, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are L_x=4cm, L_y=2.5cm, ε_{r1}=1, ε_{r2}=3.35, w_1=1.5cm, d=0.5cm, s=0.65cm, t_1=t_2=20mils, the resonant frequency is 4.36GHz.



(a)



(b)

Figure 11: For the second mode of the antenna in Figure 2, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 10, the resonant frequency is 5.1GHz.

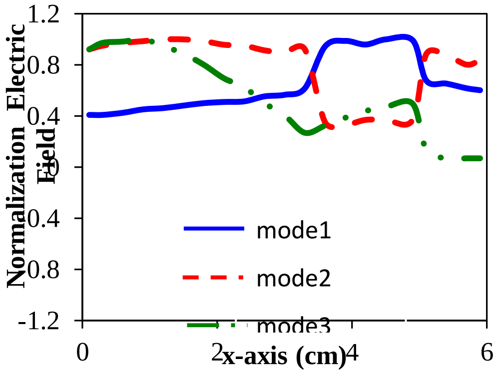
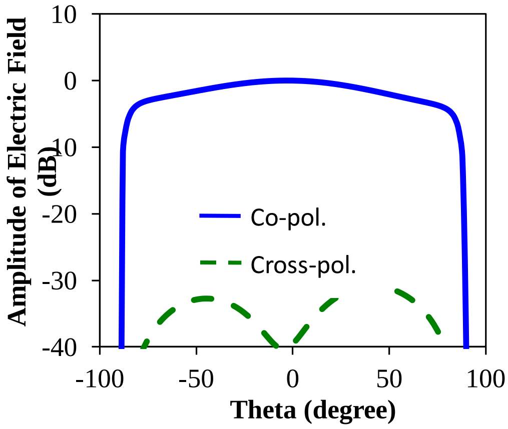
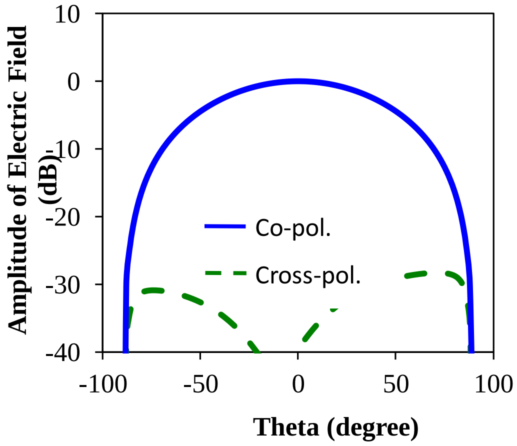


Figure 12: **For the three modes of the antenna in Figure 3, the distributions of electric field on the cross section where y is 0.65cm. The structure dimensions: L_x =6cm, L_y=4cm, ε_{r1}=2.2, ε_{r2}=3.35, ε_{r3}=4.4, s=1.4cm, t_1=31mils, t_2=20mils, t_3=1.6mm, b =0.5cm, c =1cm, d =1.5cm.**

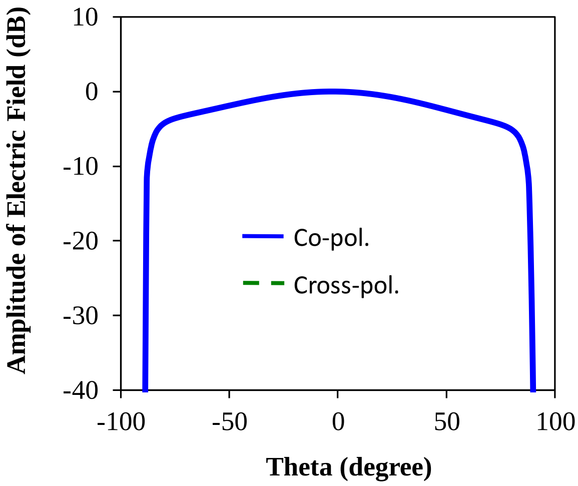


(a)

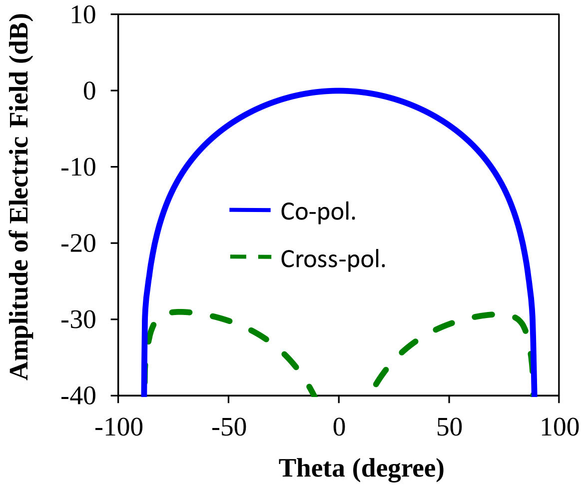


(b)

Figure 13: **For the first mode of the antenna in Figure 3, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 12, the resonant frequency is 1.84GHz.**



(a)



(b)

Figure 14: **For the second mode of the antenna in Figure 3, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 12, the resonant frequency is 2.02GHz.**

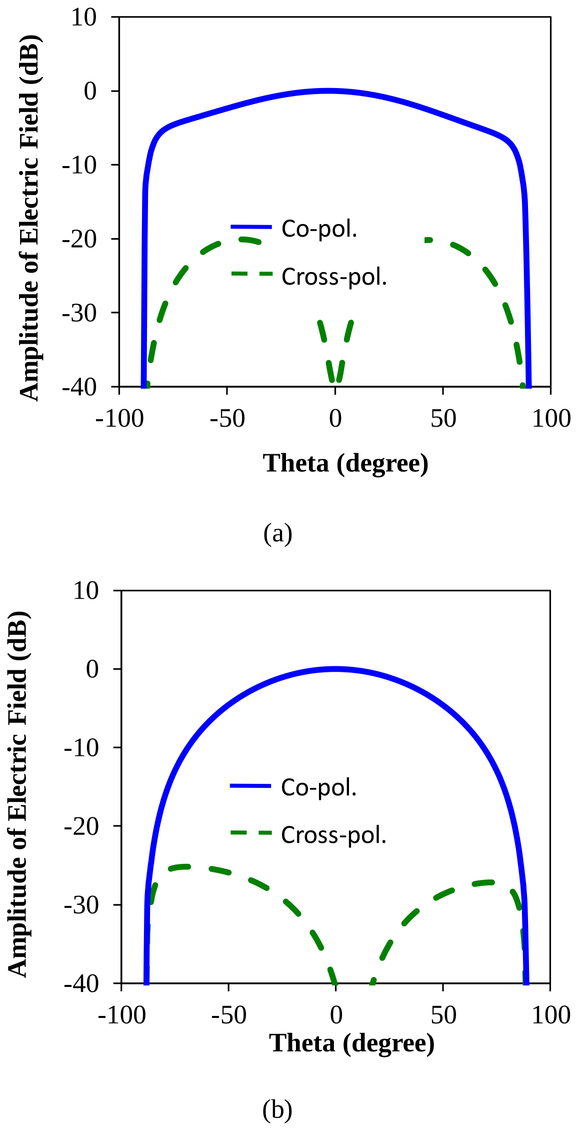


Figure 15: For the third mode of the antenna in Figure 3, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 12, the resonant frequency is 2.3GHz.

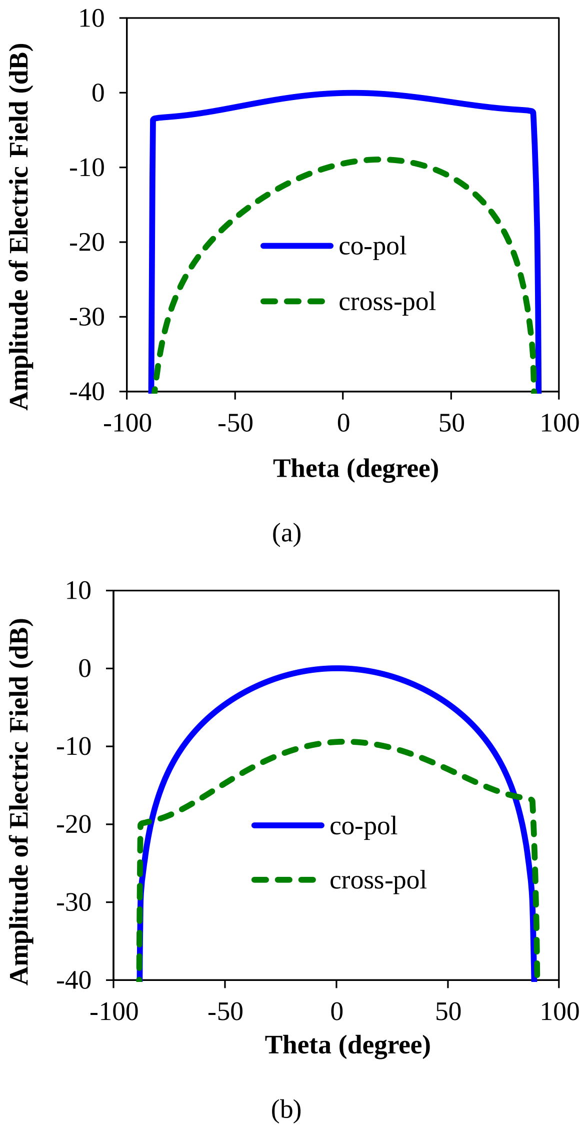
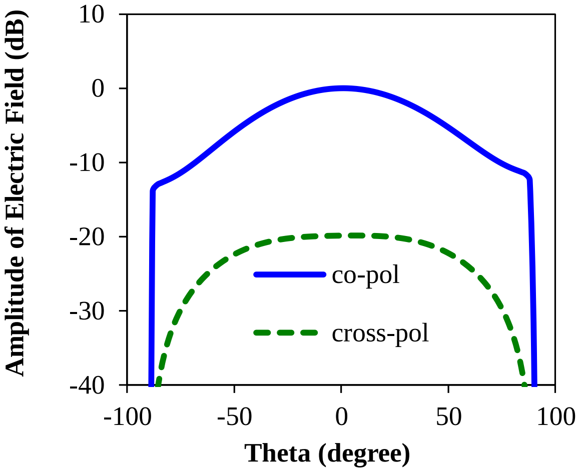
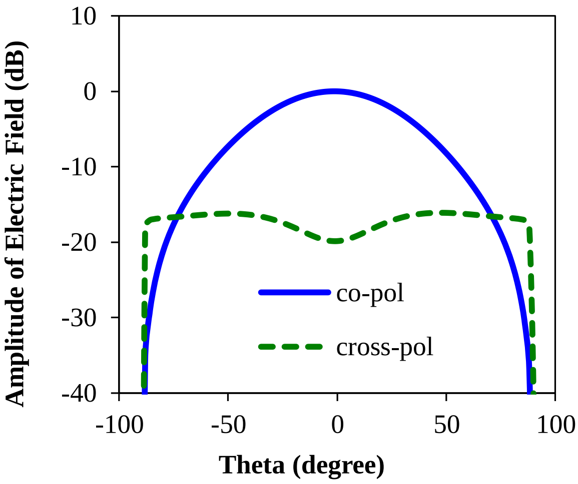


Figure 16: For the first mode of the antenna in Figure 4, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions: L_x=8cm, L_y= 5cm, w_1=1.125cm, w_2=0.375cm, w_3=2.5cm, s_1=5.31cm, s_2=1.4cm, the resonant frequency is 1.411GHz.

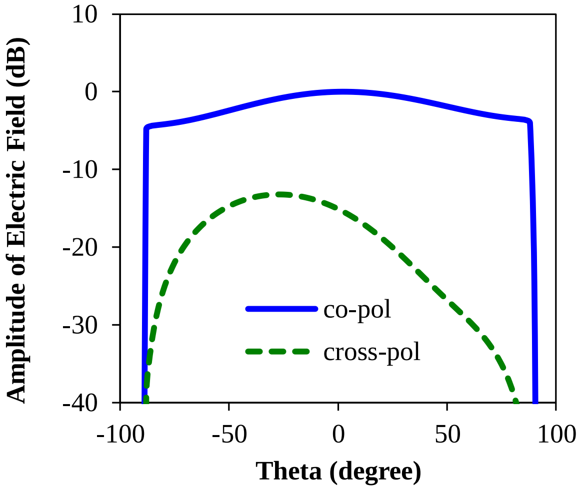


(a)

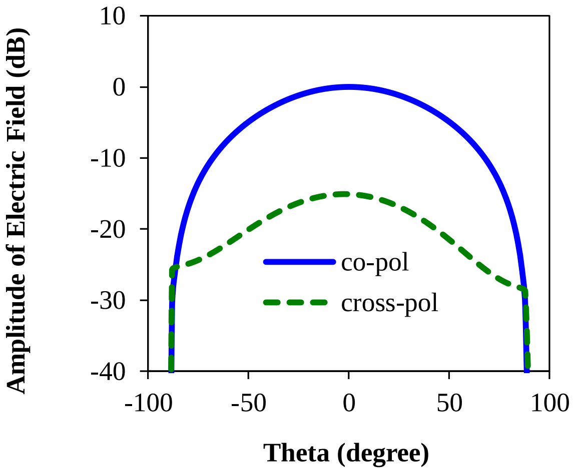


(b)

Figure 17: For the second mode of the antenna in Figure 4, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 16, the resonant frequency is 2.379GHz.

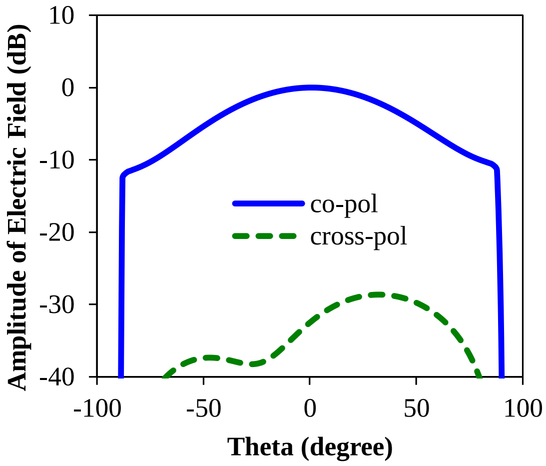


(a)

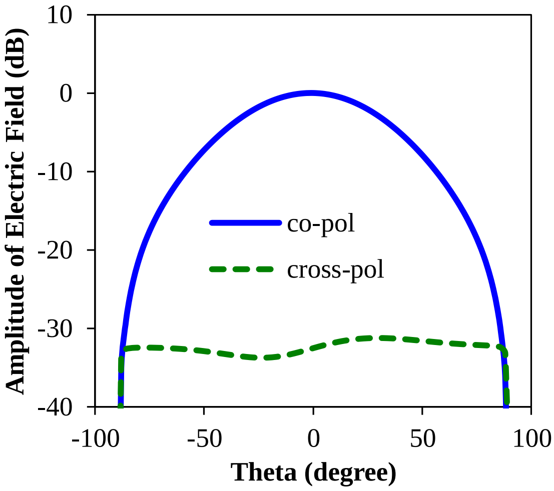


(b)

Figure 18: For the first mode of the antenna in Figure 5, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are: L_x=8cm, L_y=5cm, w_1=1.125cm, w_2=0.375cm, w_3=2.5cm, w_4=1.25cm, s_1=5.5cm, s_2=1.4cm, the resonant frequency is 1.41GHz.

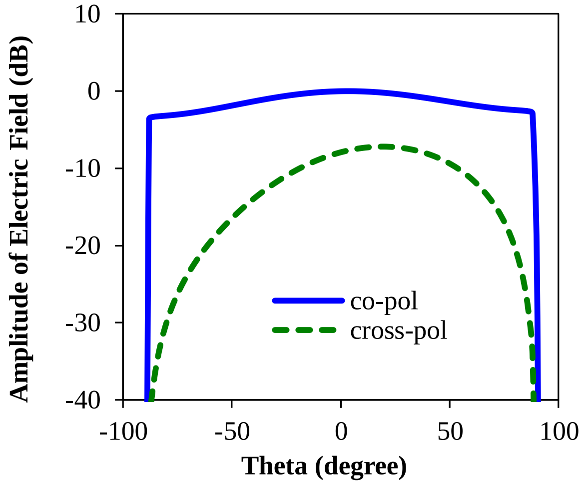


(a)

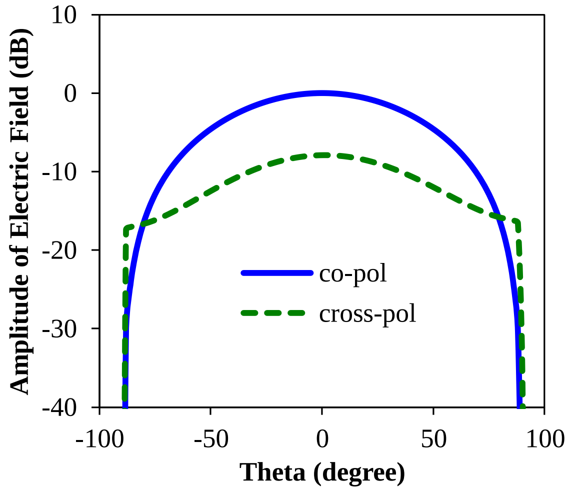


(b)

Figure 19: For the second mode of the antenna in Figure 5, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 18, the resonant frequency is 2.42GHz.

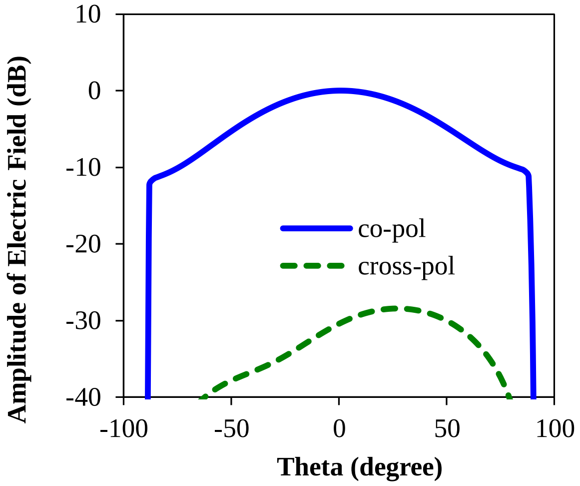


(a)

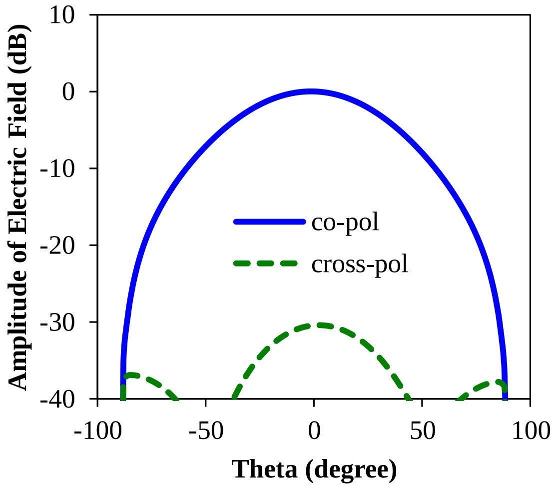


(b)

Figure 20: For the first mode of the antenna in Figure 6, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are: L_x=8cm, L_y=5cm, w_1=1.125cm, w_2=0.375cm, w_3=1cm, w_4=0.5cm, s_1=5.9cm, s_2=1.4cm, the resonant frequency is 1.32GHz.



(a)



(b)

Figure 21: For the second mode of the antenna in Figure 6, the simulated radiation patterns on different planes obtained from ENSEMBLE: (a) E-plane, (b) H-plane. The structure dimensions are the same as those in Figure 20, the resonant frequency is 2.4GH

References

[1]. C. A. Balanis, Antenna Theory: Analysis and Design, 3rd Edition, John Wiley & Sons., 2005.

[2]. Y. T. Lo, D. Solomon and W. F. Richards, "Theory and Experiment on Microstrip Antennas," IEEE Transaction on Antenna and Propagation, vol.27, no. 2, March 1979.

[3]. R. B. Waterhouse, N. V. Shuley, "Dual Frequency Microstrip Rectangular Patches," Electronics Letters, vol. 28, no. 7, pp. 606-607, March 1992.

[4]. S.-C. Pan, K.-L. Wong, "Dual-Frequency Triangular Microstrip Antenna with a Shorting Pin," IEEE Transaction on Antennas and Propagation, vol. 45, no. 12, pp. 1889-1891, December 1997.

[5]. W. Zhao, M. Hu, Q. Zhang, "A Novel Dual-Mode and Dual-Frequency Microstrip-Antenna," Synthetic Aperture Radar, pp. 145-147, November 2007.

[6]. K. G. Thomas, M. Sreenivasan, "A Simple Dual-Band Microstrip-Fed Printed Antenna for WLAN Applications," IET Microwaves, Antennas & Propagation, vol. 3, no. 4, pp. 687-694, June 2009.

[7]. S. H. S. Esfahlani, A. Tavakoli, P. Dehkhoda, "A Compact Single-Layer Dual-Band Microstrip Antenna for Satellite Applications," IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 931-934, 2011.

[8]. X. Hu, Y. Li, W. Chen, H. Z. Tan, Y. Long, "Novel Dual-FrequencyMicrostrip Antenna with Narrow Half-Ring and Half-Circular Patch," IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 3-6, 2013.

[9]. C.-L. Tai, T-H. Hsieh, H.-T. Cheng , "T-Shape Microstrip Antenna for Dual-Band Operation," 2009 Telecom . Conference, pp. 193, National University of Kaohsiung, Taiwan, 2009.

[10]. Y.-C. Lin, T.-H. Hsieh, P.-W. Chen, C.-C. Wu, "The investigation of Circular T-Shape Microstrip Antenna for Dual-Band Operation," 2011 ETS, pp. 16, I-Shou University, Kaohsiung, Taiwan, 2011.

[11]. A. R.Shahrouzkhah, H. R.Hassani,B. Rahmati, " Compact Dual Band Sinusoidal Annular-Slot Antenna," EUCAP Antennas and Propagation, pp. 1-4, March 2012.

[12]. C. S. Lee, V. Nalbandian, F. Schwering, "Dual-Frequency Microstrip Antenna with Inhomogeneously Filled Dielectric Substrate," Microwave and Optical Technology Letters, vol. 6, no. 11, pp.629-632, September 1993.

[13]. C. S. Lee, V. Nalbandian, and F. Schwering, "Planar Dual-band Microstrip Antenna," IEEE Trans. on antennas and propagation, vol. 43, no. 8, pp. 892-894, August 1995.

[14]. W.-R. Yang, T.-H. Hsieh, P.-W. Chen, Y.-C. Lin, C.-C. Chen, "Multiple-layer and coplanar microstrip antenna for dual-band operation," 2010 ETS, pp. 13, I-Shou University, Kaohsiung, Taiwan, 2010.

[15]. W.-R. Yang, T.-H. Hsieh, P.-W. Chen, "Circular Planar multi-layer Microstrip Antenna for Dual-band operation," International Academic Conference 2011, Ming Chuan University, pp.7, Taipei, Taiwan, March 2011.

[16]. C.-C. Chen, "Using a Single Disturbing Patch to Design Microstrip Antennas for Dual or Multi-Band Operation", Master thesis, I-Shou University, Kaohsiung, Taiwan, 2013.

Yung-Hui Shih was born in Taipei, Taiwan in 1964. He received the bachelor degree in physics and the master degree in materials science and engineering, both from the National Tsing Hua University, Taiwan, in 1986 and 1988, respectively. In 1993, he received the Ph.D. degree in materials science and engineering from the North Carolina State University, Raleigh, NC, USA. His research work involved the electromagnetic properties of materials. Since 1993, he joined the I-Shou University, Kaohsiung, Taiwan, and was an associated professor of materials science and engineering. His main interest of research is in the field of microstrip antenna analysis.

Ke-Nung Huang (M'03) received the B.S. degree from the Department of Biomedical Engineering, Chung Yuan Christian University, Chung Li, Taiwan, in 1992 and the Ph.D. degree from the Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan, in 2003. Since 2003, he has been with the Department of Electronic Engineering, I-Shou University, Kaohsiung, Taiwan, where he is currently an Associate Professor in logic design and measurement theory. His research interests include microcomputer-based control system and intelligent instrumentation design.

Chin-Cheng Lin was born in Pintung, Taiwan in 1990. He received the B.S. degree in Electronic Engineering from I-Shou University in 2013. He is currently pursuing the M.S. degree in Electronic Engineering at I-Shou University, Kaohsiung, Taiwan.

Chih-Chia Chen was born in Tainan, Taiwan in 1988. He received the B.S. and M.S. degrees in Electronic Engineering from I-Shou University in 2011 and 2013, respectively. The topic of his Master thesis is related to the design of microstrip antenna for dual- or multiple-band operation. Mr. Chen is currently working in antenna design department at HTC, Taipei, Taiwan.

Tung-Hung Hsieh received the B.S. degree in engineering science from National Cheng Kung University, Tainan, Taiwan in 1987, the M.S. degree in electrical engineering from Washington University, St. Louis, Missouri, in 1990, and the Ph.D. degree in electrical engineering from Southern Methodist University, Dallas, Texas in 1998. In 2000 and 2001, he worked in the OSE, Kaohsiung, Taiwan, and USI, Nantou, Taiwan, respectively. Dr Hsieh is currently an Assistant Professor in the department of electronic engineering at I-Shou University, Kaohsiung, Taiwan. His research interests include computational electromagnetics and design of microstrip antennas.