Progress In Electromagnetics Research M, Vol. 63, 141–149, 2018

A Dual-Band Slot-Embedded Microstrip Antenna for Dual-Polarization Operation

Muhammad Asad Rahman*, Eisuke Nishiyama, and Ichihiko Toyoda

Abstract—In this study, a new slot embedded microstrip antenna for dual-band dual-polarization operation is proposed. The antenna comprises a single layer structure with a square radiating patch where the feed port is located along a diagonal line of the patch. Two narrow slots parallel and close to the radiating edges of the patch are loaded on the patch. Patch without slots is resonated for X-band and another resonant frequency at Ku-band is obtained by loading the slots. Moreover, the loading of slots helps to produce two orthogonal modes of equal amplitudes at X-band. Furthermore, the feed port along the diagonal line of the square patch makes it possible to radiate different polarization at the two bands. The antenna can radiate circular and linear polarization at X- and Ku-band, respectively. Current distributions of the antenna at both bands are observed to explain the behavior of the antenna and confirm the polarization characteristics at X- and Ku-band. A 3-dB axial ratio bandwidth of 1.35% is achieved. Measured gains of 6.60 dBic and 5.80 dBi with good radiation performances are achieved at X- and Ku-band, respectively. Moreover, good measured cross-polarization levels of 27.6 dB at X-band and 15.6 dB at Ku-band are obtained. The measured performances of the fabricated antenna are consistent with simulated results.

1. INTRODUCTION

Due to the rapid progress of wireless and satellite communication systems, multi-band antennas are very attractive for various communication applications. Furthermore, multi-band microstrip antennas with polarization diversity capability offer the advantages of low profile, low cost, and multi-use capability in different applications. Different techniques and geometries of multi-band antennas have been proposed in the last several years to produce either the same polarization or different polarizations in the frequency bands. One of the main techniques to design dual-band antennas is by inserting slots on the patch; for example, two narrow and parallel slots can be inserted near to the radiating edges of a rectangular patch [1, 2]. A bow-tie microstrip antenna for dual-band operation has been demonstrated in [3]. A pair of narrow slots is embedded close to the radiating edges to achieve dual-frequency operation. Moreover, a pair of step-slots [4] or a pair of properly-bent narrow slots [5] embedded near the non-radiating edges of a rectangular microstrip patch have also been reported. Another dual-band antenna applying two arc-shaped slots integrated close to the edge of the circular microstrip patch has been studied in [6]. These antennas exhibit linear polarization (LP) at both bands. In [7, 8], dual-band circular polarization (CP) antennas have been demonstrated. A slot-loaded square patch with two feeding points has been used in [7], wherein four equal shaped slots are loaded close to the edges of the patch. A small circular patch surrounded by two concentric annular-rings that are loaded by an unequal lateral cross-slot ground plane has been presented for dual-band CP operation [8]. A CP antenna using metamaterial for WiMAX applications has been presented in [9], wherein two split ring resonators (SRR) are implemented

Received 5 October 2017, Accepted 1 December 2017, Scheduled 11 January 2018
* Corresponding author: Muhammad Asad Rahman (asad31@ceng.ec.saga-u.ac.jp).
The authors are with the Graduate School of Science and Engineering, Saga University, 1 Honjo-machi, Saga-shi, Saga 840-8502, Japan.

to realize CP. The SRR structure changes the current path on the antenna to create a loop. Therefore, this structure works in a single band with CP radiation. However, the slot-loaded antennas mentioned in [1–8] act as dual-band antennas because the loaded pair of slots introduces another higher order resonant frequency and modifies the current distribution on the band to obtain a radiation pattern similar to the lower resonant frequency [1]. In [10], an aperture coupled square microstrip patch with a dual-band polarization reconfigurable capability has been described for wireless local area network (WLAN) systems. The frequency ratio of this antenna is adjusted by inserting four shorting posts into the patch and polarization switching among horizontal, vertical, and 45° LP is realized by changing the states of the PIN diodes connected between the center of each edge of the patch and ground. Another dual-band dual-polarization capacitive-fed circular patch antenna operated at 1.575 and 2.4 GHz has been presented in [11], wherein a 90° hybrid coupler chip is used to produce CP at 1.575 GHz and a pair of arc-shaped slots is embedded in the patch to radiate LP at 2.4 GHz. A dual-layer dual-band dual-LP reflectarray antenna using a cross dipole, modified phoenix loop, and square patch has been demonstrated in [12] for Ka- and W-band operation. A planar triple-strip monopole antenna [13] and a CPW-fed inverted-annular shaped antenna [14] have been presented for dual-band dual circular polarization operation.

In this study, a new dual-band dual-polarization microstrip patch antenna for X- and Ku-band applications is proposed. Moreover, this dual-band antenna can be modified to be assigned to global positioning system (GPS) and Wi-Fi applications because CP is vital for GPS antenna to obtain optimal performance, and an LP antenna is enough to support the Wi-Fi communication. Following the basic concept of [1, 2], two narrow and parallel slots are loaded on an X-band patch so that the proposed antenna can simultaneously operate at X- and Ku-band. CP at X-band and LP at Ku-band are achieved by placing the feed port along a diagonal line of the patch. The performances of the antenna are experimentally confirmed, and the design of the antenna along with measured and simulated results is discussed in the subsequent sections.

2. ANTENNA CONFIGURATION

Figure 1 illustrates the design of the proposed antenna. The square patch of length L is designed on a Teflon substrate whose permittivity and thickness are ε_r and h, respectively. Two narrow and parallel slots with equal length S_l and width S_w are incorporated near the radiating edges of the patch. The horizontal and vertical distances of the each slot from the edges of the patch are w and g, respectively.

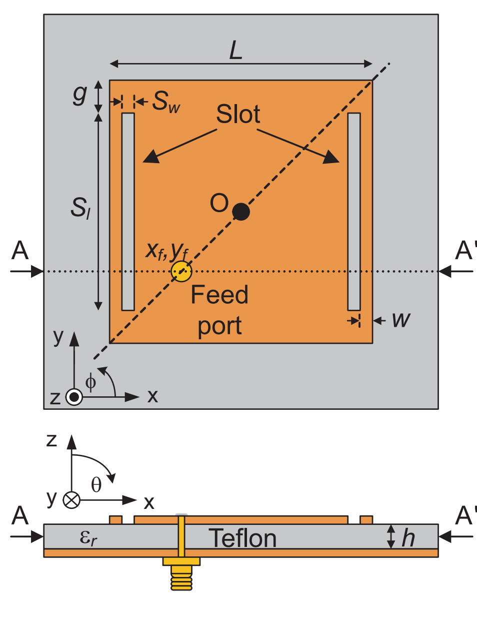

Figure 1. Schematic layout and cross-sectional (A-A′) view of the proposed antenna.

The feed port is placed along a diagonal line of the patch and the feed port position is (x_f, y_f) with respect to the center point O of the patch.

The concept of the proposed antenna has been adapted from the antenna presented in [1, 2]. By comparing both structures, it is noticed that the patch geometry and the feed location of the proposed antenna are altered to obtain dual-band dual-polarization characteristics. A square patch is used in the proposed antenna instead of a rectangular patch used in [1, 2]. Moreover, the feed position is set along a diagonal line of the patch, whereas the feed port in the previous work was along the center line of the patch.

Figures 2 and 3 show the effect of changing slot length S_l on the S_{11} and axial ratio (AR) of the proposed antenna. The unslotted patch is designed for X-band. The size of the slots needs to be adjusted to obtain optimum performance at both frequency bands. In X-band, the slots help to radiate CP, but they do not have any effect on the designed frequency of the patch because the narrow slots loaded near to the radiating patch edges are at a position where the patch current is a minimum. The size of the two parallel slots should be attuned properly to produce two orthogonal modes so that the sense of polarization can be CP, as shown in Fig. 3. In addition, Fig. 2 shows that the loading of the slots on the patch has a very small impact on the resonant frequency at X-band. In contrast, the

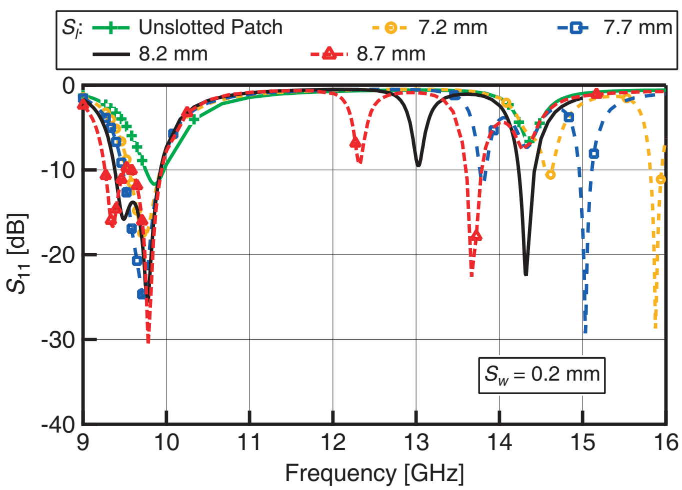

Figure 2. Effect of the slot length S_l on the S_{11} of the antenna.

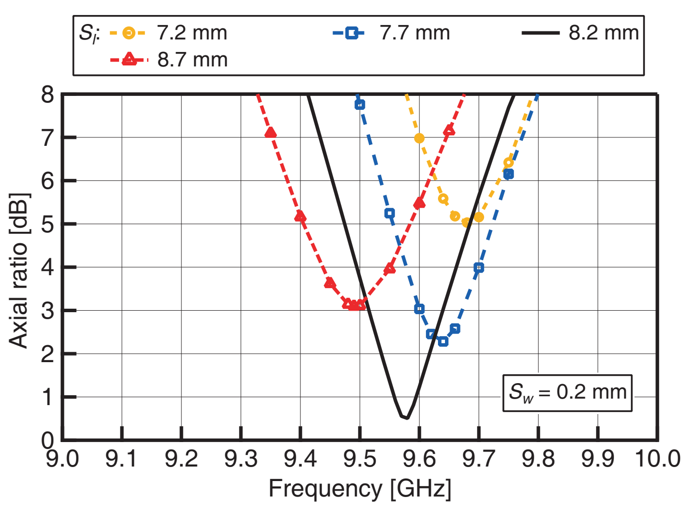

Figure 3. Effect of the slot length S_l on the axial ratio of the antenna.

loading of slots introduces another resonant frequency at Ku-band where the polarization sense is LP. The length of the slots S_l has an impact in introducing this resonant frequency. In addition, a higher order undesired mode causes another resonant frequency at the Ku-band.

Figures 4 and 5 illustrate the effect of the variation of slot width S_w on the S_{11} and AR of the antenna. According to the figures, the slot width S_w has no effect on the resonant frequency at two bands. Though the slot width S_w does not affect the resonant frequencies, the slot width S_w should be adjusted to obtain minimum AR at X-band. Therefore, an optimum slot size must be determined to achieve the optimal performances from the antenna at both bands.

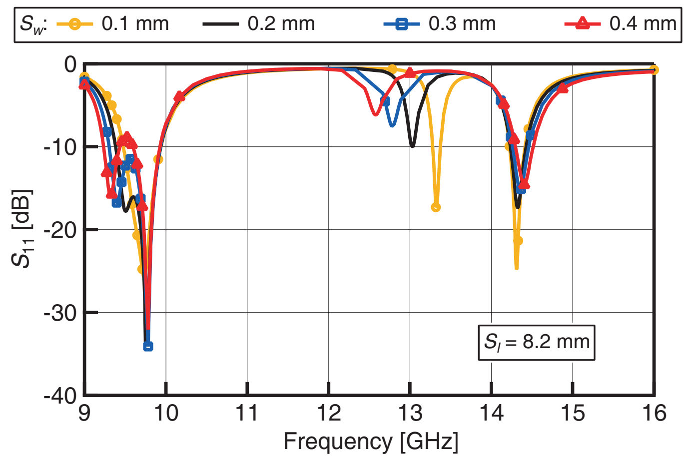

Figure 4. Effect of the slot width S_w on the S_{11} of the antenna.

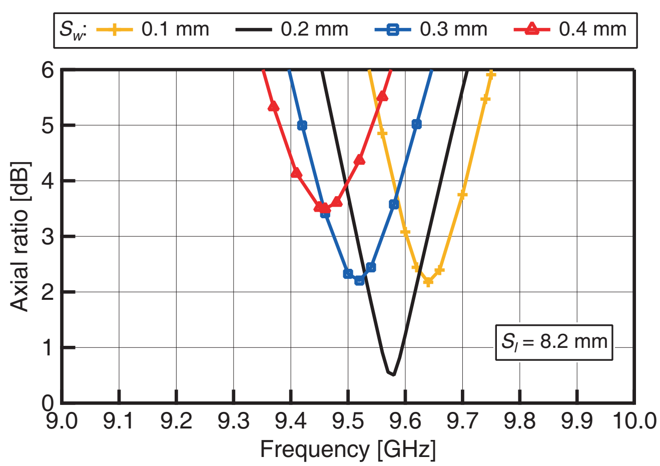

Figure 5. Effect of the slot width S_w on the axial ratio of the antenna.

Figure 6 shows the simulated current distribution of the proposed antenna for different polarizations at different phases. For the surface current shown in Fig. 6(a), the embedded slots do not affect the current at 9.56 GHz, and the field rotation is in a clockwise direction. Consequently, the polarization sense in this band is left-handed CP (LHCP). In contrast, at 14.46 GHz, the maximum current is accumulated around the slots. Therefore, these slots introduce another resonant frequency in this band. As the slots provide a shorter horizontal electrical current path than that of the vertical path, LP is radiated.

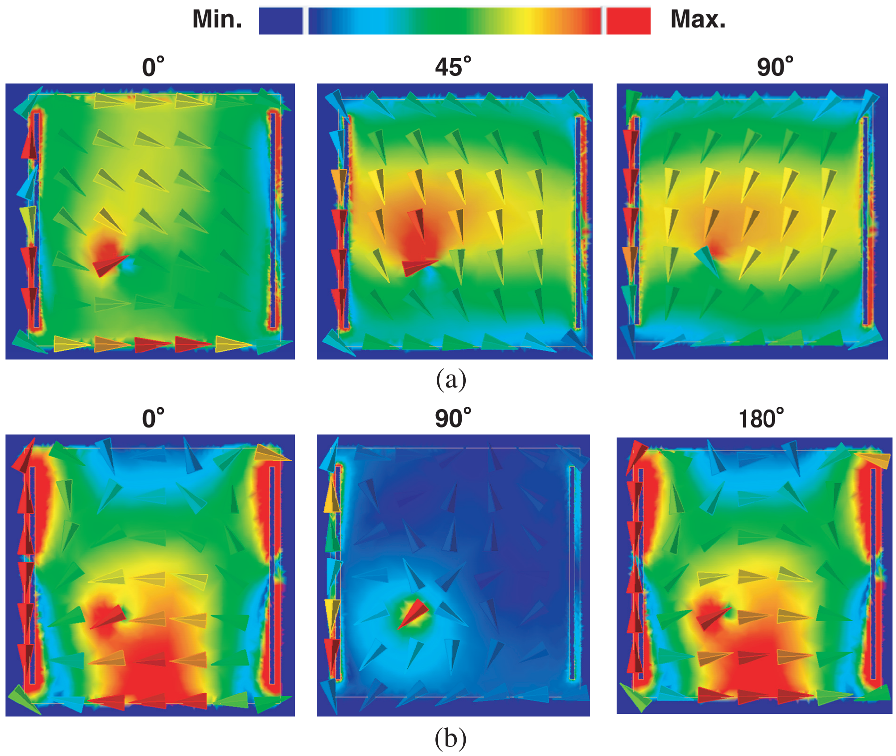

Figure 6. Current distribution of the proposed antenna at different phases. (a) $f = 9.56\,\text{GHz}$ (CP). (b) $f = 14.46\,\text{GHz}$ (LP).

3. ANTENNA PERFORMANCES

Figure 7 shows the top and bottom views of the fabricated antenna. The antenna is etched on a 0.8-mm thick Teflon substrate with a permittivity of 2.15. The dimension of the ground plane of the antenna is 28.8 mm × 28.8 mm. The various dimensions of the fabricated antenna are as follows: $L = 9.6\,\text{mm}$, $S_l = 8.2\,\text{mm}$, $S_w = 0.2\,\text{mm}$, $g = 0.7\,\text{mm}$, $w = 0.2\,\text{mm}$, and $x_f = y_f = 1.5\,\text{mm}$. Initially the antenna has been designed and simulated using Momentum of Keysight Technologies' Advanced Design System (ADS) and after that the performances has been validated using FEM of EMPro. The performances of the fabricated antenna have been investigated by using a HP8510C network analyzer.

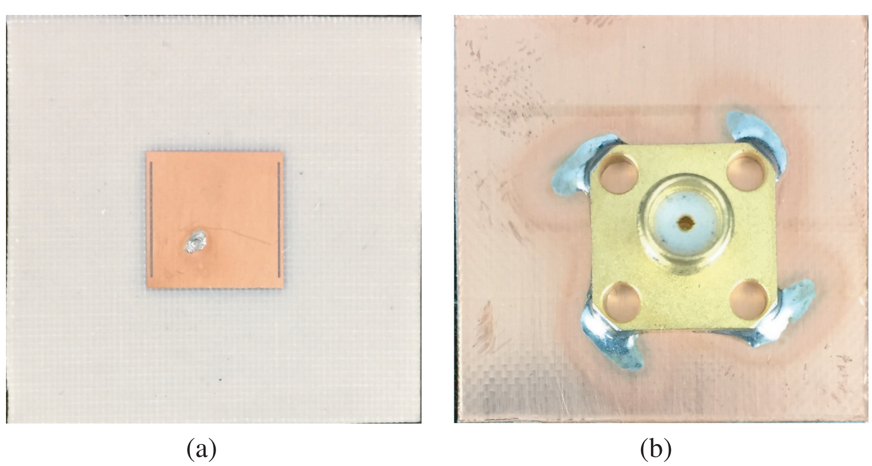

Figure 7. Photograph of the fabricated antenna (28.8 mm × 28.8 mm). (a) Top view. (b) Bottom view.

Figure 8 presents the measured and simulated reflection coefficients of the antenna. The measured 10-dB impedance bandwidths of the antenna at X- and Ku-band are 5.17% and 1.15%, respectively. The measured and simulated results show almost similar reflection coefficients with a slight frequency shift in the measured result at Ku-band. As shown in Fig. 2, the slot length affects the resonant frequency. Therefore, this frequency shift is caused by the slot length imperfection that occured during fabrication. Moreover, simulation imperfection can be another reason for this mismatch because a frequency shift is also observed in the comparison between ADS and EMPro simulation results.

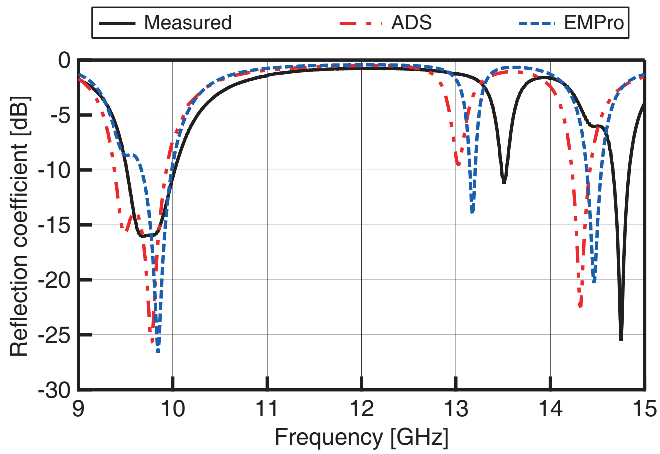

Figure 8. Reflection coefficient of the antenna.

Figure 9 shows the measured AR of the antenna with simulated results. A measured 3-dB AR bandwidth of 1.35% is obtained with a minimum value of 0.23 dB at 9.64 GHz. The measured and simulated AR performances are well matched.

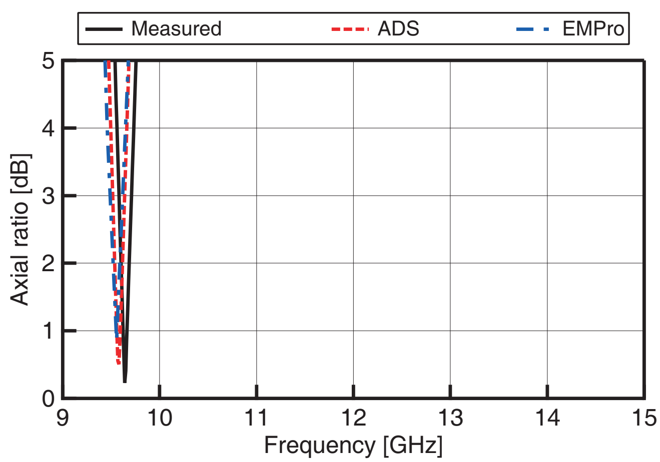

Figure 9. Axial ratio of the proposed antenna.

Figure 10 shows the measured and simulated radiation performances of the antenna at 9.64 GHz for both x-z and y-z planes. The measured and simulated gains of the antenna are around 6.60 dBic and 8 dBic, respectively. At both planes, the gains of the antenna are almost same.

Figure 11 illustrates the CP radiation performance of the antenna at 9.64 GHz for the x-z plane. The proposed antenna radiates LHCP, and the measured cross-polarization CP component is below -27.6 dB that indicates good CP performance of the antenna at X-band. As the simulated AR is minimum at 9.56 GHz, the measured and simulated CP radiation performances are plotted in this graph at each frequency of its minimum AR value for good understanding.

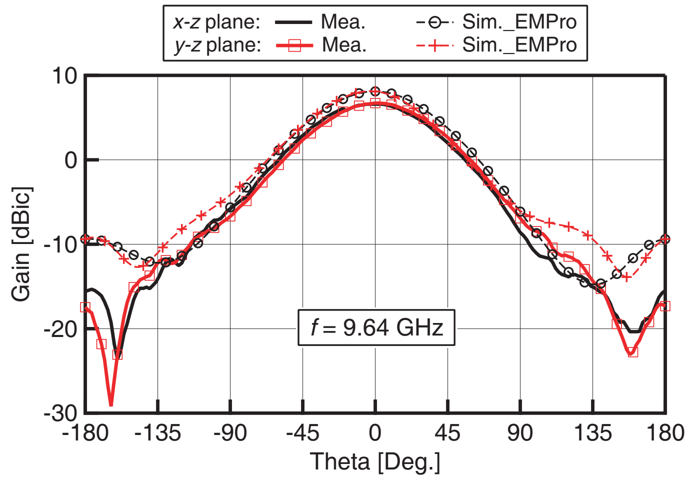

Figure 10. Gain of the antenna at X-band.

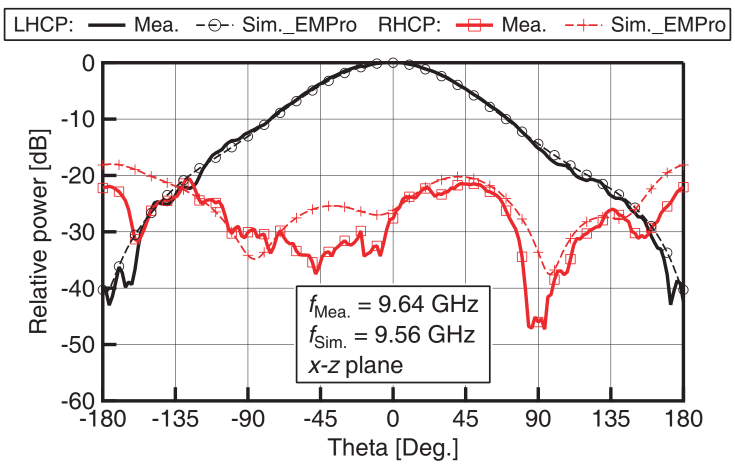

Figure 11. CP radiation performance at X-band. The measured and simulated results are plotted for the frequencies where the AR is minimum.

Figures 12 and 13 present the radiation performance of the antenna at Ku-band for x-z and y-z planes, respectively. In this frequency band, the antenna radiates LP. The measured gain of the antenna at Ku-band is about 5.80 dBi for both planes, whereas simulated gain is around 3.90 dBi. Although a good impedance matching is obtained at 14.75 GHz, the simulated S_{11} is above -10 dB at the same frequency as shown in Fig. 8. This might be the main reason for the discrepancy between the measured and simulated gains. The cross-polarization level is better than 13.7 and 15.6 dB at the x-z and y-z planes, respectively.

Table 1 presents a comparison between the proposed antenna and previously reported slot-embedded dual-band antennas. Most of the antennas related to slot-loaded dual-band antennas without using any active and/or passive devices radiate the same polarization in the both bands. The antennas compared with this work in Table 1 are linearly polarized in both bands. Besides, the antenna reported in [7] radiates CP in the two bands by embedding four slots and two feed ports. There is no slot-loaded antenna without integrating active and/or passive devices where the two resonant frequencies have different polarizations. In contrast, the antenna proposed in this study shows distinct polarization in the two different bands.

Finally, the proposed dual-band antenna is compared with a conventional X-band CP antenna and a Ku-band LP antenna. For proper comparison, a Ku-band LP square patch antenna with a center frequency of 14.75 GHz is designed. Besides, an X-band perturbed type CP antenna is designed to have

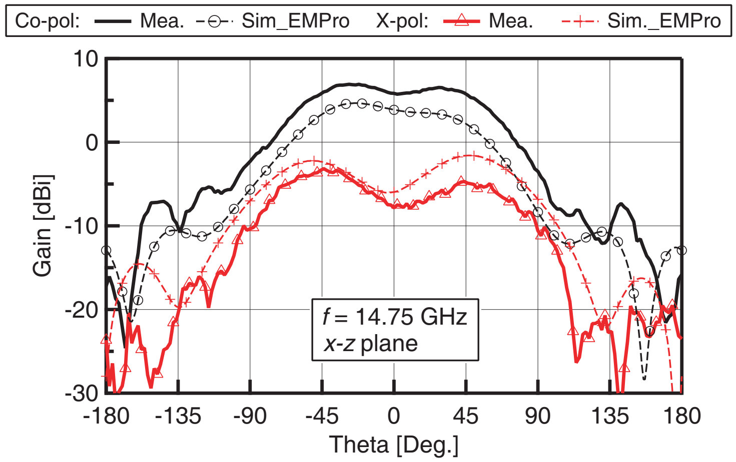

Figure 12. Gain of the antenna at Ku-band for x-z plane.

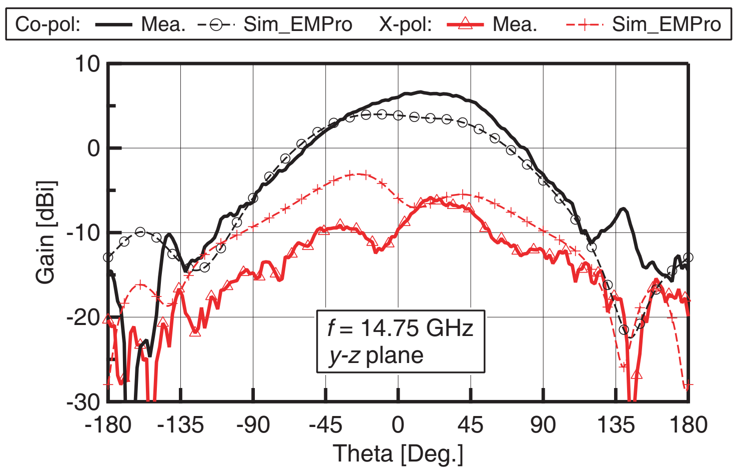

Figure 13. Gain of the antenna at Ku-band for y-z plane.

Table 1. Comparison of the proposed antenna with the previously reported slot-loaded antennas.

Antennas	Bands	Technique	CP/LP	Impedance BW (< -10 dB)	AR BW (< 3 dB)
[1]	C, X	Pair of line slots	LP	0.80%, 1.20%	-
[3]	L, S	Slot-loaded bow-tie antenna	LP	1.32%, 1.15%	-
[4]	L, S	Pair of step slots	LP	1.76%, 1.42%	-
[5]	L, S	Pair of bent slots	LP	1.56%, 1.38%	-
[6]	L, S	Pair of arc-shaped slots	LP	1.60%, 1.38%	-
[7]	S	Four slots & two feed ports	CP	-	-
This work	X, Ku	Pair of line slots	CP/LP	5.17%, 1.15%	1.35%

a minimum AR at 9.63 GHz. The impedance bandwidths of the X-band CP antenna and Ku-band LP antenna are 5.5% and 4.75% whereas a 3-dB AR bandwidth of 1.45% is achieved at X-band. The gains of these antennas are around 7.06 dBic at 9.63 GHz and 7 dBi at 14.75 GHz. The proposed antenna has similar performances at X-band to the conventional X-band CP antenna. However, the antenna performances are worse than the conventional Ku-band LP antenna because the proposed antenna is originally an X-band antenna that is optimized to radiate at Ku-band by loading a pair of slots. Thus, these slots change the current distribution that is not similar to that of conventional Ku-band LP antenna. Therefore, the performances of the proposed antenna at Ku-band are deteriorated than a conventional antenna.

4. CONCLUSION

A square microstrip patch antenna geometry comprising two parallel and narrow slots close to the radiating edges on the patch has been demonstrated to produce dual-polarization at two different frequency bands. Two different polarizations are achieved by placing the feed position along the diagonal line of the patch. CP and LP radiation can be obtained using this antenna at X- and Ku-bands, respectively. The performances of the antenna are verified and demonstrated using measurement, and good performances are found at both frequency bands.

ACKNOWLEDGMENT

The authors would like to thank Dr. Takayuki Tanaka, Saga University for his fruitful discussions.

REFERENCES

1. Maci, S., G. B. Gentili, P. Piazzesi, and C. Salvador, "Dual-band slot-loaded patch antenna," *IEE Proceedings — Microwaves, Antennas and Propagation*, Vol. 142, No. 3, 225–232, 1995.
2. Maci, S., G. B. Gentili, and G. Avitabile, "Single-layer dual frequency patch antenna," *Electron. Lett.*, Vol. 29, No. 16, 1441–1443, 1993.
3. Wong, K.-L. and W.-S. Chen, "Slot-loaded bow-tie microstrip antenna for dual-frequency operation," *Electron. Lett.*, Vol. 34, No. 18, 1713–1714, 1998.
4. Lu, J.-H., "Single-feed dual-frequency rectangular microstrip antenna with pair of step-slots," *Electron. Lett.*, Vol. 35, No. 5, 354–355, 1999.
5. Wong, K.-L. and J.-Y. Sze, "Dual-frequency slotted rectangular microstrip antenna," *Electron. Lett.*, Vol. 34, No. 14, 1368–1370, 1998.
6. Wong, K.-L. and G.-B. Hsieh, "Dual-frequency circular microstrip antenna with a pair of arc-shaped slots," *Microw. Opt. Technol. Lett.*, Vol. 19, No. 6, 410–412, 1998.
7. Avitabile, G., S. Maci, F. Bonifacio, and C. Salvador, "Dual band circularly polarized patch antenna," *Proc. IEEE Antennas Propag. Soc. Int. Symp. and URSI National Radio Science Meeting*, 290–293, Seattle, WA, USA, 1994.
8. Wong, K.-L. and G.-B. Hsieh, "Dual-frequency circular microstrip antenna with a pair of arc-shaped slots," *Microw. Opt. Technol. Lett.*, Vol. 19, No. 6, 410–412, 1998.
9. Kuhestani, H., M. Rahimi, Z. Mansuri, F. B. Zarrabi, and R. Ahmadian, "Design of compact patch antenna based on metamaterial for WiMAX applications with circular polarization," *Microw. Opt. Technol. Lett.*, Vol. 57, No. 2, 357–360, 2015.
10. Qin, P. Y., Y. J. Guo, and C. Ding, "A dual-band polarization reconfigurable antenna for WLAN systems," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 11, 5706–5713, 2013.
11. Chen, J., K. F. Tong, A. Al-Armaghany, and J. Wang, "A dual-band dual-polarization slot patch antenna for GPS and Wi-Fi applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 15, 406–409, 2016.
12. Wang, Q., Z. H. Shao, Y. J. Cheng, and P. K. Li, "Ka/W dual-band reflectarray antenna for dual linear polarization," *IEEE Antennas Wireless Propag. Lett.*, Vol. 16, 1301–1304, 2016.
13. Hsu, C. W., M. H. Shih, and C. J. Wang, "A triple-strip monopole antenna with dual-band circular polarization," *Proc. 2016 IEEE 5th Asia-Pacific Conf. Antennas Propag. (APCAP)*, 137–138, Kaohsiung, Taiwan, 2016.
14. Wu, C., C. Lu, J. Shen, and Z. Ye, "A CPW-fed slot antenna with dual band and dual circular polarization," *Proc. 2016 Int. Symp. Antennas Propag. (ISAP)*, 810–811, Okinawa, Japan, 2016.