Communications

A Printed Wide-Slot Antenna With a Modified L-Shaped Microstrip Line for Wideband Applications

Y. Sung

***Abstract*—A printed wide-slot antenna for wideband applications is proposed and experimentally investigated in this communication. A modified L-shaped microstrip line is used to excite the square slot. It consists of a horizontal line, a square patch, and a vertical line. For comparison, a simple L-shaped feed structure with the same line width is used as a reference geometry. The reference antenna exhibits dual resonance (lower resonant frequency f_1, upper resonant frequency f_2). When the square patch is embedded in the middle of the L-shaped line, f_1 decreases, f_2 remains unchanged, and a new resonance mode is formed between f_1 and f_2. Moreover, if the size of the square patch is increased, an additional (fourth) resonance mode is formed above f_2. Thus, the bandwidth of a slot antenna is easily enhanced. The measured results indicate that this structure possesses a wide impedance bandwidth of 118.4%, which is nearly three times that of the reference antenna. Also, a stable radiation pattern is observed inside the operating bandwidth. The gain variation is found to be less than 1.7 dB.**

***Index Terms*—L-shaped feed line, wide square slot antenna, wideband antenna.**

I. Introduction

With the rapid development of wireless communication systems and the expansion of their applications, compact wideband antenna design has become a complex issue [1]. Because wide-slot antennas offer many advantages, such as low profile, ease of fabrication, and wide bandwidth, they have recently been receiving a great deal of attention from researchers [2], [3]. The wide slot antennas used in present-day communication systems usually require broad bandwidth. Various structures have been developed for this purpose, and these can be divided into two categories.

First, there are approaches that improve bandwidth by altering the shape of the slot, which is a radiating element. As is well known, wide bandwidth has been obtained with antennas of various shapes, including circles [4], ellipses [5], and triangles [6]. In [7], a wide operating bandwidth of about 2200 MHz (49.4%) with respect to the center frequency of 4453 MHz was obtained by rotating the slot. However, this bandwidth is still not sufficient to cover additional wireless communication services. In [8], [9], the authors proposed a novel bandwidth-enhancement technique based on fractal shapes for a microstrip-fed wide-slot antenna. However, this approach makes the antenna configuration more complicated.

In the second category, wideband antennas are constructed by using a novel feed structure. Many related studies on improving the impedance bandwidth have been published in the literature [10]–[14]. In [10], a printed wide-slot antenna fed by a microstrip line with a fork-like tuning stub provided broad bandwidth in terms of the appropriate parameters for the tuning stub. In [11], it was shown that introducing an L-shaped slot with a W-shaped feed stub can improve the bandwidth. Bandwidth enhancement for wideband operation can also be obtained by using parasitic elements along the microstrip feed line [14].

In the current study, a novel feed structure is used to obtain wideband characteristics for a wide-slot antenna without structural changes to the square slot resonator (which is a radiating element). The proposed feed structure consists of a horizontal line, a square patch, and a vertical line, linked sequentially in an L-shaped arrangement. A detailed simulation is conducted to understand the antenna's behavior and optimize the feed line for broadband operation. Finally, the proposed design is implemented and measured to validate the design concept. Measured results for the prototype are discussed in Section IV. According to these results, the impedance bandwidth of the proposed antenna (determined from the 10-dB reflection coefficient) extends from 1.21 GHz to 4.72 GHz, with a center frequency of 2.965 GHz. Moreover, a stable radiation pattern can be achieved over the entire operating bandwidth.

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II. Antenna Configuration

The geometry of a wide-slot antenna with a modified L-shaped feed line is illustrated in Fig. 1. The antenna is built on an FR4 dielectric ($\varepsilon_r = 4.4$ and $\tan\delta = 0.02$) with a thickness of 1.6 mm. A wide square slot is printed on one side of the substrate and is fed by a microstrip line printed on the other side. The gray region represents the metal portion, viewed from the relevant side, and the dotted line represents the metal portion on the opposite side. The square slot has side length L. The horizontal and vertical lengths are l_1 and l_2, respectively. The square patch has side length p. The size of the ground plane is denoted by G. At the end of the L-shaped feed line, a shorting via is added to connect the feed line to the ground plane (the bottom layer of the substrate) [15]. The other side of the feed line is connected to the SMA connector. This arrangement will be referred to as type 1 in the present study. Fig. 2 shows a different arrangement, modified from type 1. Instead of using a via, two identical square patches with side length p are placed at the top and bottom so that coupling occurs between the two patches. This will be referred to as type 2. Simulations are carried out using HFSS.

Fig. 3 shows the simulated reflection coefficients of the two types of structures (type 1 and type 2). A comparison is performed for patch side lengths of 16 mm and 18 mm. The values of the other parameters of the simulated structures are $l_1 = 19$ mm, $l_2 = 20.5$ mm, $w = 1$ mm, $L = 54$ mm, and $G = 80$ mm. Type 1 and type 2 show largely similar frequency responses, with two noticeable differences. First, for type 2, the capacitance resulting from the coupling between the two patches causes a slight downward shift in the frequency response. Second, whereas type 1 has only three resonance modes, type 2 exhibits a fourth resonance mode at 4.3 GHz when p is 16 mm and at 4.1 GHz when p is 18 mm. This leads to a difference in the frequency responses of the two types in the higher frequency band. Due to the addition of the fourth resonance, the upper edge frequency of type 2 shows a slight increase. Also, type 2 is easier to manufacture than type 1, as it does not require a via. In light of these advantages, type 2 is chosen for the parameter study of Section III.

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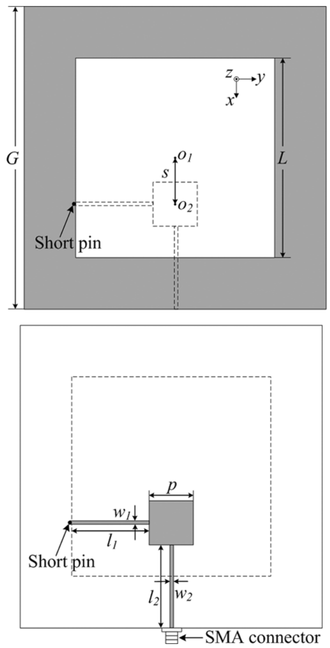

Fig. 1. Geometry of an L-shaped microstrip line-fed slot antenna (type 1). (a) Top layer. (b) Bottom layer viewed from above.

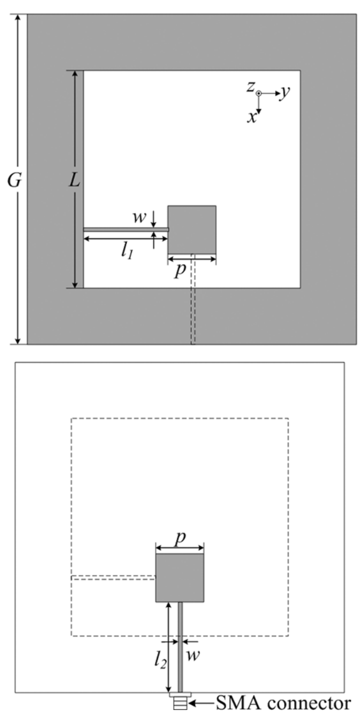

Fig. 2. Geometry of an L-shaped microstrip line-fed slot antenna without via (type 2). (a) Top layer. (b) Bottom layer viewed from above.

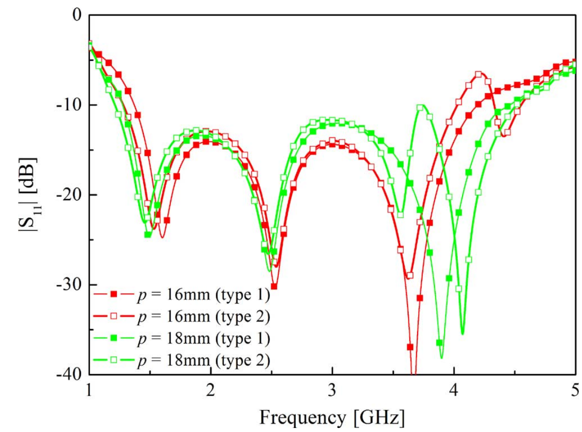

Fig. 3. Simulated reflection coefficient comparison between structures with and without a via.

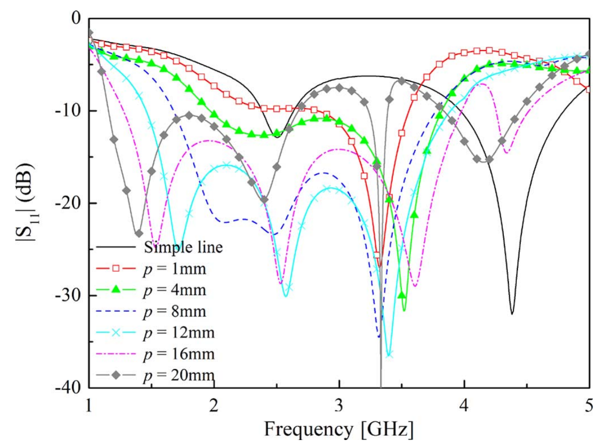

Fig. 4. Simulated reflection coefficients of square slot antennas with various feed structures.

III. Parameter Study

Fig. 4 shows the simulated reflection coefficients of square slot antennas with a simple feed line structure and an L-shaped feed line structure with a square patch. The simple line represents the I-shaped feed structure with horizontal length $l_1 = p = 0$ mm shown in Fig. 1. For the I-shaped line, l_2 is set at 28 mm, and w is set at 1 mm. The other parameters are set as follows: $L = 54$ mm and $G = 80$ mm. The structure with side $p = 1$ mm is the antenna with a simple L-shaped feed line shown in Fig. 1. The horizontal length $l_1 = 27.5$ mm, and the values of the remaining parameters are identical to those for the simple line to obtain an accurate comparison. In the case of the L-shaped feed line with a square patch (type 2), shown in Fig. 2, the lower edge of the bandwidth decreases as the size of the patch increases, resulting in a larger bandwidth. The bandwidth of the proposed antenna increases from 77% to 102.9% as the patch size p is increased from 8 mm to 16 mm. However, when the patch size grows larger, the reflection coefficient characteristics tend to worsen at 2 GHz and 3 GHz. Thus, there is a limit on how far the patch size can be increased.

The slot antenna with an I-shaped line exhibits dual-band characteristics. As the simulation results of Fig. 4 indicate, when the feed structure is altered from an I-shaped feed line to an L-shaped feed line, f_1 does not change significantly, but f_2 decreases from 4.37 GHz to 3.4 GHz. The lower resonant mode begins to split into two separate resonance modes when p is equal to 8 mm. As p increases, the type 2 structure begins to exhibit three resonance modes.

Fig. 5 shows the simulated reflection coefficients of the proposed antenna in relation to changes in the horizontal length l_1. The other parameter values are as follows: $l_2 = 20.5$ mm, $p = 16$ mm, $w = 1$ mm, $L = 54$ mm, and $G = 80$ mm. As l_1 is increases, both the lower and upper edges of the bandwidth increase. Because the rate of increase is similar at both edges, there is virtually no variation in the antenna bandwidth. As l_1 increases, the matching characteristics worsen at the

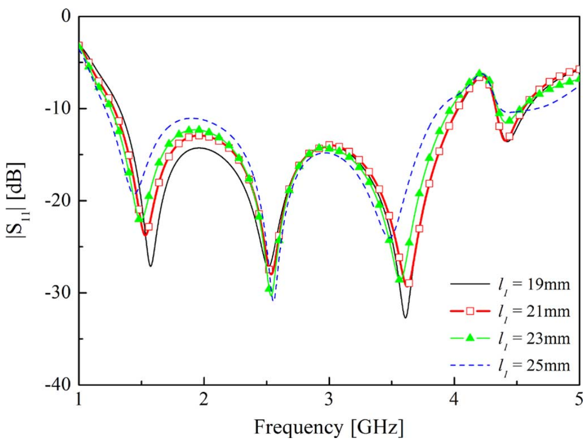

Fig. 5. Simulated reflection coefficients of the proposed antenna with different horizontal lines l_1.

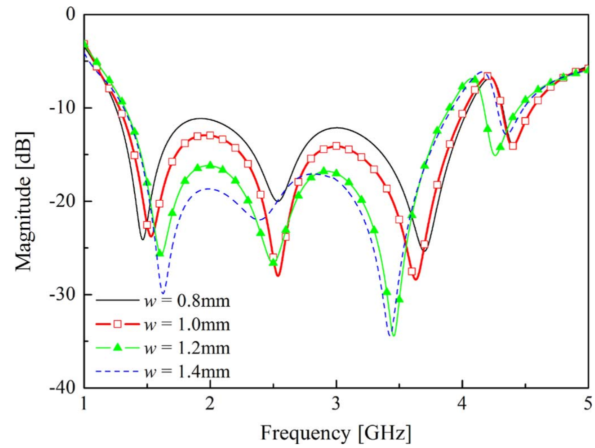

Fig. 7. Simulated reflection coefficients of the proposed antenna with different line widths w.

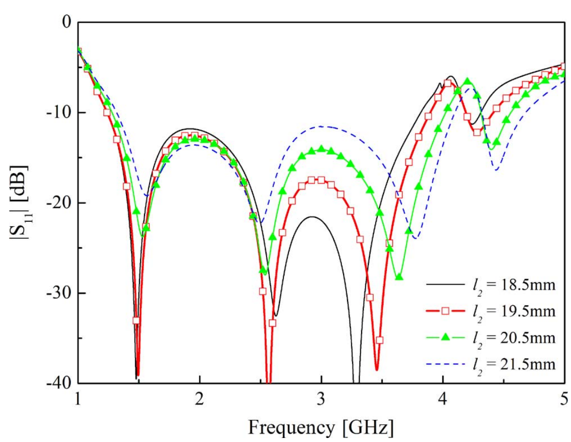

Fig. 6. Simulated reflection coefficients of the proposed antenna with different vertical lines l_2.

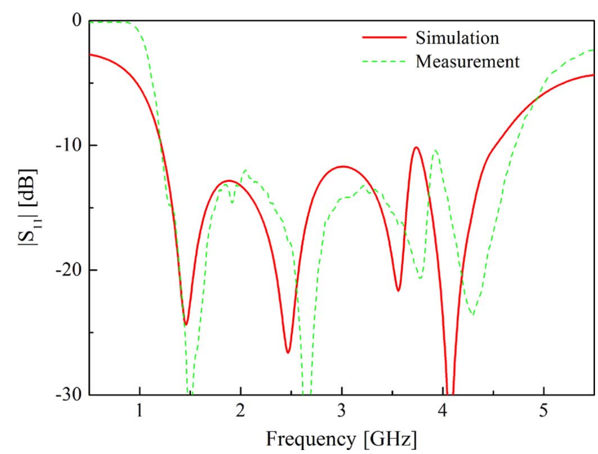

Fig. 8. Simulated and measured reflection coefficients of the proposed antenna with $p = 18$ mm.

first peak of the reflection coefficient, but improve somewhat at the second peak.

Fig. 6 shows the simulated reflection coefficients of the proposed antenna in relation to changes in the vertical length l_2. The other parameter values are as follows: $l_1 = 19$ mm, $p = 16$ mm, $w = 1$ mm, $L = 54$ mm, and $G = 80$ mm. As l_2 is increased, The other parameter values are as follows: $l_1 = 19$ mm, $p = 16$ mm, $w = 1$ mm, $L = 54$ mm, and $G = 80$ mm. As l_2 is increased, the lower and upper edges of the bandwidth also increase. As with l_1, the rate of increase is similar at both edges, and the antenna bandwidth remains virtually constant at 103%. As l_2 is increased, the matching characteristics improve gradually at the first peak of the reflection coefficient, but deteriorate rapidly at the second peak.

Fig. 7 shows the simulated reflection coefficients of antennas with different line widths w. The dimensions of the simulated structure are as follows: $l_1 = 19$ mm, $l_2 = 20.5$ mm, $p = 16$ mm, $L = 54$ mm, and $G = 80$ mm. As w is increased, the lower edge of the bandwidth tends to increase, whereas the upper edge of the bandwidth tends to decrease. Consequently, wider lines result in reduced antenna bandwidth. When w is increased, the matching characteristics tend to improve over the entire band.

IV. Simulated and Measured Results

A prototype of the proposed antenna (shown in Fig. 2) with optimized geometrical parameters was constructed and measured. Fig. 8 compares the simulated and measured frequency responses of the reflection coefficient. The antenna was fabricated on a commercially available FR4 substrate with $h = 1.6$ mm and $\varepsilon_r = 4.4$. The dimensions of the antenna are as follows: $l_1 = 19$ mm, $l_2 = 20$ mm, $w = 1$ mm, $L = 54$ mm, and $G = 80$ mm. As can be seen from the graph, simulation and measurement were in close agreement. The antenna with $p = 12$ mm exhibits a very wide 10-dB bandwidth of about 2.45 GHz (89%). For the antenna with $p = 18$ mm, the measured impedance bandwidth (with a 10-dB reflection coefficient) is as large as 3510 MHz (1210–4720 MHz), or about 118.4% with respect to the center frequency of 2965 MHz.

Figs. 9–11 show plots of the measured radiation patterns of the antenna with $p = 18$ mm. The radiation patterns were measured at four resonant frequencies, and the parameter values were the same as those given above. Note that a printed slot antenna without a reflecting plate is a bi-directional radiator, and the radiation patterns on both sides of the antenna are similar. The proposed antenna exhibits the same characteristics.

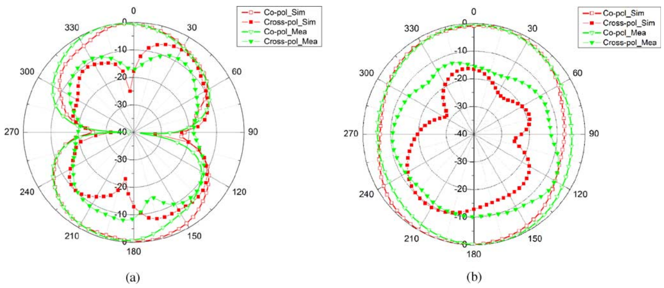

Fig. 9. Simulated and measured radiation patterns at 1.5 GHz. (a) x-z plane (b) y-z plane.

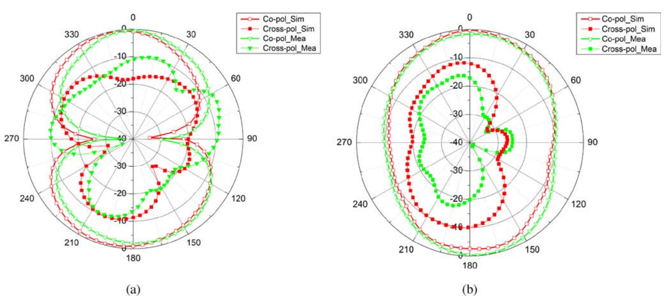

Fig. 10. Simulated and measured radiation patterns at 2.6 GHz. (a) x-z plane (b) y-z plane.

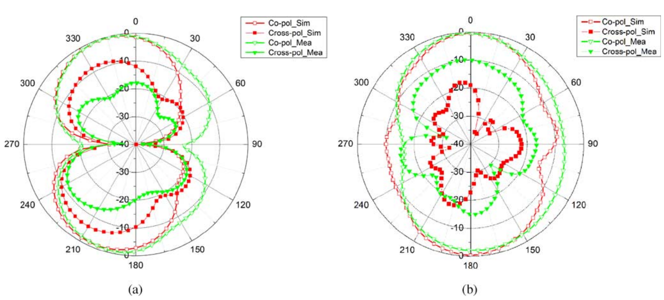

Fig. 11. Simulated and measured radiation patterns at 4.3 GHz. (a) $x-z$ plane (b) $y-z$ plane.

The measured results indicate that the proposed antenna has the polarization planes expected for a wideband antenna, and similar broadside radiation patterns. It can also be seen that the radiation patterns in the two planes (x-z and y-z planes) are symmetric with respect to the antenna axis ($\theta = 0^\circ$), also as expected. Fig. 12 shows measured antenna gain. The peak gain of the proposed antenna is 4.1 dBi. The gain variation is <1.7 dB within the entire operating bandwidth. Fig. 13 shows a photograph of the fabricated antenna.

V. Conclusion

By introducing a square patch into a conventional L-shaped feed line, broadband characteristics can easily be achieved. When the antenna geometry is optimized, the measured impedance bandwidth determined by the 10-dB reflection coefficient reaches nearly three times that of a conventional square-slot antenna with a simple L-shaped line. The proposed antenna exhibits stable far-field radiation characteristics over the entire operating bandwidth. The gain variation is less than 2.3 dBi. Therefore, the proposed antenna is feasible for use as a low-profile, low-cost wideband antenna for various wireless communication services.

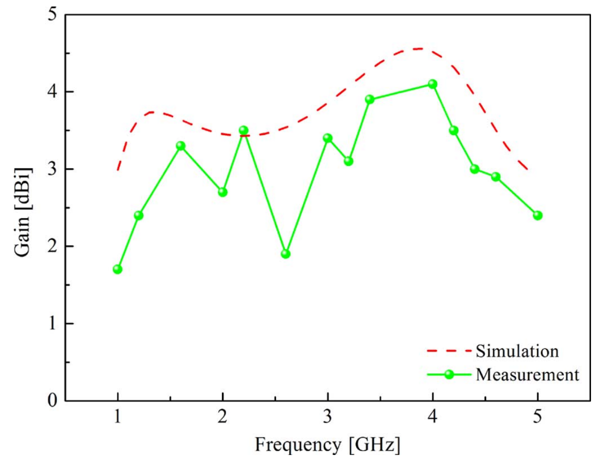

Fig. 12. Measured antenna gain.

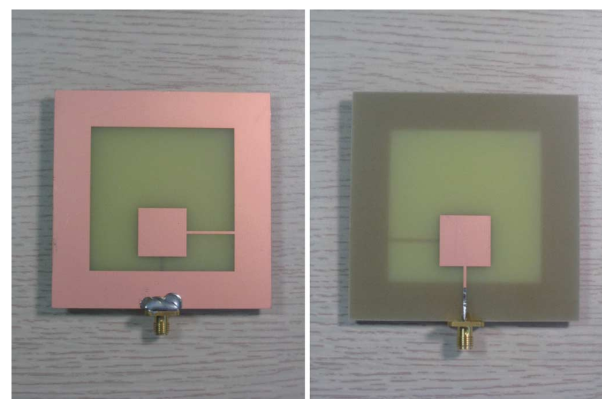

Fig. 13. Photograph of the fabricated antenna with $p = 18$ mm. (a) Top view. (b) Bottom view.

References

[1] M. Kahrizi, T. K. Sarkar, and Z. A. Maricevic, "Analysis of a wide radiating slot in the ground plane of a microstrip line," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 29–37, 1993.

[2] Y. W. Jang, "Experimental study of large bandwidth three-offset microstrip line-fed slot antenna," *IEEE Microw. Wireless Comp. Lett.*, vol. 11, pp. 425–426, 2001.

[3] M. K. Kim, Y. H. Suh, and I. Park, "A T-shaped microstrip line-fed wide-slot antenna," in *Proc. IEEE AP-S Int. Symp.*, 2000, pp. 1500–1503.

[4] S.-W. Qu, J.-L. Li, J.-X. Chen, and Q. Xue, "Ultrawideband strip-loaded circular slot antenna with improved radiation patterns," *IEEE Trans. Antennas Propag.*, vol. 55, no. 11, pp. 3348–3353, Nov. 2007.

[5] P. Li, J. Liang, and X. Chen, "Study of printed elliptical/circular slot antennas for ultrawideband applications," *IEEE Trans. Antennas Propag.*., vol. 54, no. 6, pp. 1670–1675, Jun. 2006.

[6] W.-S. Chen and F.-M. Hsieh, "A broadband design for a printed isosceles triangular slot antenna for wireless communications," *Micro. J.*, vol. 48, no. 7, pp. 98–112, Jul. 2007.

[7] J.-Y. Jan and J.-W. Su, "Bandwidth enhancement of a printed wide-slot antenna with a rotated slot," *IEEE Trans. Antennas Propag.*, vol. 53, no. 6, pp. 2111–2114, Jun. 2005.

[8] W.-L. Chen, G.-M. Wang, and C. X. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," *IEEE Trans. Antennas Propag.*, vol. 57, no. 7, pp. 2176–2179, Jul. 2009.

[9] D. D. Krishna, M. Gopikrihna, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Compact wideband Koch fractal printed slot antenna," *IET Microw. Antennas Propag.*, vol. 3, no. 5, pp. 782–789, Aug. 2009.

[10] J. Y. Sze and K. L. Wong, "Bandwidth enhancement of a microstrip line-fed printed wide-slot antenna," *IEEE Trans. Antennas Propag.*, vol. 49, no. 7, pp. 1020–1024, Jul. 2001.

[11] T. Dissanayake and K. P. Esselle, "UWB performance of compact L-shaped wide slot antennas," *IEEE Trans. Antennas Propag.*, vol. 56, no. 4, pp. 1183–1187, Apr. 2008.
[12] S. Chen, P. Hallbjorner, and A. Rydberg, "Printed slot planar inverted cone antenna for ultrawideband applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 7, pp. 18–21, 2008.
[13] S.-W. Qu, C. Ruan, and B.-Z. Wang, "Bandwidth enhancement of wide-slot antenna fed by CPW ad microstrip line," *IEEE Antennas Wireless Propag. Lett.*, vol. 5, pp. 15–17, 2006.
[14] J.-Y. Jan and L.-C. Wang, "Printed wideband rhombus slot antenna with a pair of parasitic strips for multiband applications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 4, pp. 1267–1270, Apr. 2009.
[15] S.-L. Yang, A. M. Kishk, and K.-F. Lee, "Wideband circularly polarized antenna with L-shaped slot," *IEEE Trans. Antennas Propag.*, vol. 56, no. 6, pp. 1780–1783, Jun. 2008.

Miniaturization of Slot Antennas Using Slit and Strip Loading

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***Abstract*—The design of a miniaturized slot antenna with slit loading fed by the CPW line is proposed. It is seen that the loading slits can be located only on the feed side without degradation in cross-pol performance, unlike the microstrip-fed case. This releases the ground plane area above the slot for accommodating electronic circuitry and effectively reduces the antenna size. In addition, the resonant frequency in this case is reduced by a further 4.60%, compared to the slits on both sides. Another topology of the miniaturized antenna is investigated with the slits replaced by strips of metallization on the reverse side of the substrate, which leaves the ground plane area completely free. A high reduction in the slot resonant frequency is also observed in this case, with a reflector being used to increase the forward radiation.**

***Index Terms*—CPW, miniaturized, reflector, slit, slot antenna, strip.**

I. Introduction

There has been a significant emphasis in current research on realization of compact wireless systems. As a result, it has been imperative to focus on reducing the physical size of the individual system components and building blocks of a modern wireless system.

In view of this, there has been considerable efforts to reduce the size of the radiating element, particularly more so since antennas occupy the largest real estate out of all wireless system components. However reduction in antenna size in general impacts adversely on the return loss and the radiation characteristics of the antenna.

The slot antenna has been investigated by many researchers in this regard because of its easy integration with planar elements. A quarter-wavelength slot was realized in [1] by terminating the slot by a quarter-wave spiral. The implementation of a size-reduced slot antenna using reactive terminations at the ends of the slot was presented in [2] for a microstrip feed and in [3] for a CPW feed. Broadband and miniaturized antennas were also presented in [4], [5]. The size reduction of the antenna in [4] was achieved by loading the slot using series inductive slits while proximity coupling between slots was used for bandwidth enhancement. The realization of compact cavity-backed slot antennas was addressed in [6], [7] and [8]. Size reduction of a dual-band triangular slot antenna was proposed in [9]. Folded slot antennas and a reduced size folded slot antenna fed by the CPW line were addressed in [10] and [11] respectively. Broadband and size reduced slot antennas using different slot shapes fed by the microstrip line was proposed in [12].

The miniaturized structure in [4] requires that the loading slits used to miniaturize the antenna be located on either side of the slot for acceptable cross-pol performance. In the following, it is shown that a CPW feed can be used to effectively address this problem in addition to offering a uniplanar configuration. As a result, the loading slits can be located only on one side of the slot and also on the same side of the slot as the CPW feed line without degradation of cross-pol performance. This leaves the ground plane on the other side of the slot free for active integration or housing electronic circuitry and effectively reduces the antenna real-estate. Also, a larger reduction in resonant frequency is obtained with the loading slits only on one side of the slot compared with the slits located on either sides of the slot. A second design is proposed with the slits replaced by strips of metallization on the reverse side of the substrate. A high reduction in the slot resonant frequency is also obtained for this structure, with the loading elements concealed beneath the ground plane, thus leaving the ground plane area totally free in this case. A reflector plate placed below the substrate [13] is used to improve the radiation in the upper hemisphere in this case.

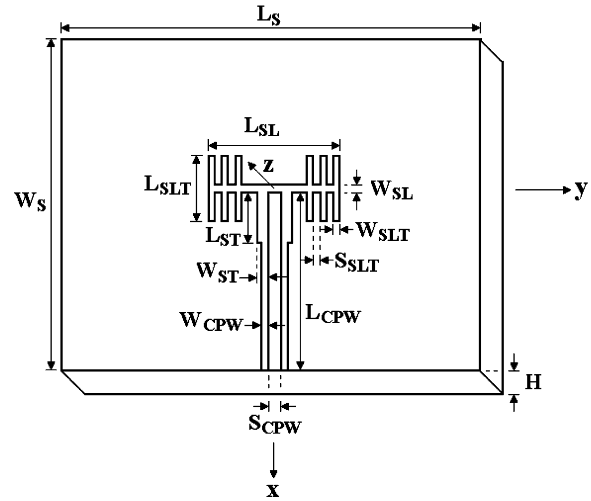

Fig. 1. Slot antenna loaded with slits on either side of the slot.

II. Reduction in Resonant Frequency for Slot Antenna With Slits on Either Side

The antenna structure is shown in Fig. 1. The slot antenna is loaded with inductive slits on either side to reduce the resonant slot length [4]. The dimensions in Fig. 1 are as follows: slot length $(L_{SL}) = 20$ mm, slot width $(W_{SL}) = 1.20$ mm, length of CPW line $(L_{CPW}) = 74.40$ mm, CPW trace width $(S_{CPW}) = 1.80$ mm, gap between the CPW trace and ground $(W_{CPW}) = 0.76$ mm (for a characteristic impedance of 50 ohms), slit length $(L_{SLT}) = 10.00$ mm, slit width $(W_{SLT}) = 1.00$ mm and gap between slits $(S_{SLT}) = 1.00$ mm. The substrate used is RT6010LM with length $(L_s) = \mathrm{width}(W_s) = 150$ mm, height $H = 2.54$ mm. and a permittivity of 10.20 to decrease

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