Slotted Rectangular Microstrip Antenna for Bandwidth Enhancement

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***Abstract*—With the loading of a pair of right-angle slots and a modified U-shaped slot in a rectangular microstrip patch, novel bandwidth enhancement of microstrip antennas is demonstrated. Required dimensions of the right-angle slots and modified U-shaped slot for bandwidth enhancement with good radiating characteristics have been determined experimentally in this study and the obtained antenna bandwidth can be as large as about 2.4 times that of a corresponding unslotted rectangular microstrip antenna. Details of the antenna design and experimental results are presented and discussed.**

***Index Terms*—Bandwidth enhancement, microstrip antennas.**

I. Introduction

By loading a pair of bent slots having an angle of 15°–30°, close to the nonradiating edges of a rectangular microstrip patch, a new resonant mode denoted as $TM_{\delta 0}(1 < \delta < 2)$ [1] can be excited near the fundamental mode of TM_{10}. These two modes, $TM_{\delta 0}$, and TM_{10}, are of the same polarization planes and similar radiation characteristics and can be excited with good impedance matching for single-feed dual-frequency operation. However, for such a design, good excitation of the $TM_{\delta 0}$ mode becomes difficult when the resonant-frequency ratio $(f_{\delta 0}/f_{10})$ of the $TM_{\delta 0}$ and TM_{10} modes is less than about 1.29 [1]. In this paper, we demonstrate that by using a pair of right-angle slots, in place of the bent-slots in [1], and loading an additional modified U-shaped slot (see Fig. 1), the two resonant modes of $TM_{\delta 0}$ and TM_{10} can be excited at frequencies very close to each other with good impedance matching. This condition makes possible an enhanced operating bandwidth formed by these two resonant modes for the rectangular microstrip antenna. This novel design of bandwidth enhancement is described in detail in this study. The present proposed design is suitable for applications on regular electrically thin microwave substrates and is unlike the related slot-loading designs [2]–[6] that work mainly for thick foam or air substrates. Other techniques for enhancing the bandwidth of a single-layer single-patch microstrip antenna include the designs with a three-dimensional microstrip transition feed [7], a gap-coupled feed [8], a capacitively coupled feed [9], an optimally designed impedance matching network [10], [11], a chip-resistor loading [12], an integrated reactive loading [13], and so on. The proposed design here provides another promising bandwidth-enhancement design for a rectangular microstrip antenna with an electrically thin substrate.

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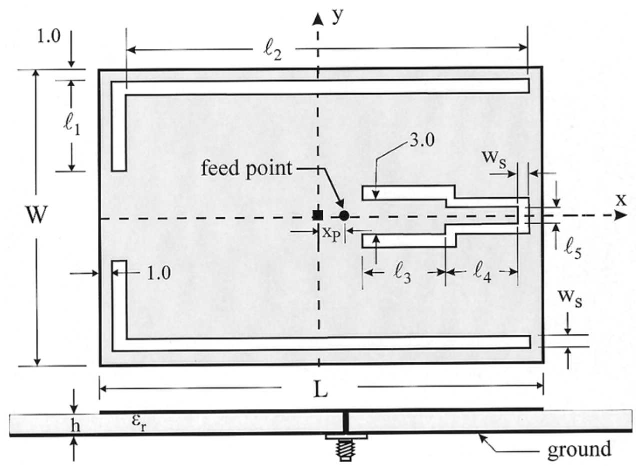


Fig. 1. Geometry of a broad-band rectangular microstrip antenna with a pair of right-angle slots and a modified U-shaped slot. The dimensions given in the figure are in millimeters.

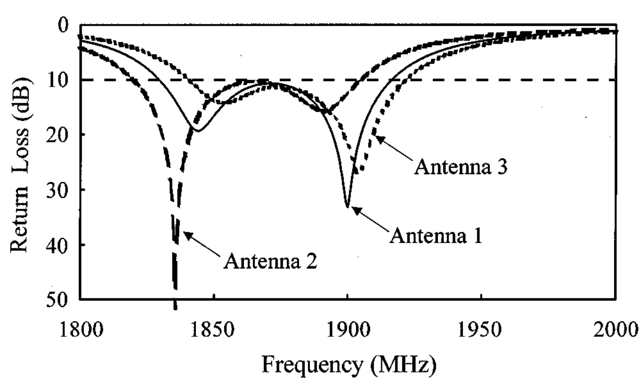


Fig. 2. Measured return loss against frequency for proposed antennas with an FR4 substrate. Parameters for antennas 1–3 are described in Table I.

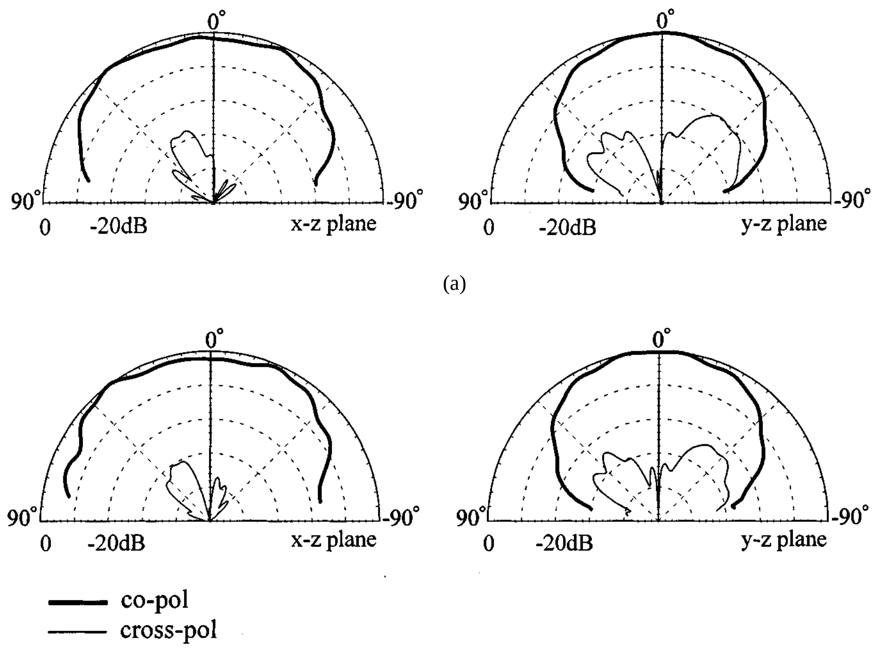
II. Design Considerations of the Proposed Antenna

As shown in Fig. 1, the two right-angle slots are of width w_s and are placed close to the nonradiating edges, with 1 mm away from the edges in this study. The rectangular patch has dimensions of 37.3 mm × 24.87 mm $(L \times W)$ and is printed on a grounded FR4 substrate of thickness (h) 1.6 mm, relative permittivity (ε_r) 4.4, and size 60 mm × 50 mm. In the proposed antenna, the longer arm of the right-angle slots is in parallel to the nonradiating edges and its arm length ℓ_2 needs to

TABLE I

PERFORMANCES OF THE PROPOSED BROAD-BAND ANTENNAS; $\varepsilon_r = 4.4$, $h = 1.6$ mm, $\ell_3 = 11.5$ mm, $\ell_4 = 6.0$ mm, $\ell_5 = 0.5$ mm, $w_s = 1$ mm, PATCH SIZE $= 37.3$ mm $\times 24.87$ mm $(L \times W)$, GROUND-PLANE SIZE $= 60$ mm $\times 50$ mm. OTHER PARAMETERS ARE GIVEN IN FIG. 1. THE CENTER FREQUENCY, f_c, IS DEFINED TO BE $(f_L + f_H)/2$, WHERE f_L AND f_H ARE THE LOWER AND HIGHER FREQUENCIES WITH 10-dB RETURN LOSS IN THE OPERATING BANDWIDTH, AND THE ANTENNA BANDWIDTH IS DETERMINED FROM f_L–f_H

	ℓ_1	ℓ_2	x_p	f_{10}	f_c	$f_{\delta 0}$	Bandwidth
	mm	mm	mm	MHz	MHz	MHz	MHz, %
Antenna 1	10.4	33.5	2.85	1844	1873	1900	86, 4.6
Antenna 2	10.4	33.9	2.85	1836	1864	1891	85, 4.6
Antenna 3	10.4	33.5	3.05	1854	1882	1905	81, 4.3



(a)

(b)

Fig. 3. Measured E-plane (x–z plane) and H-plane (y–z plane) radiation patterns for the proposed antenna (antenna 1). (a) $f = 1844$ MHz. (b) $f = 1900$ MHz.

be about 90% of the patch length; the shorter arm is perpendicular to the nonradiating edges and its arm length ℓ_1 should be greater than 40% of the patch width. The dimensions of ℓ_1 and ℓ_2 of the right-angle slots are obtained from experiments. When there are only right-angle slots presence, the two modes of $TM_{\delta 0}$ and TM_{10} can be excited at frequencies with a ratio $(f_{\delta 0}/f_{10})$ about 1.07 in this study. Although this frequency ratio is much lower than that (1.29) shown in [1], it is still not low enough to form a single wide operating bandwidth. Also, good impedance matching of the two resonant modes is difficult to be achieved. However, it is found that by further embedding a modified U-shaped slot along the center line of the patch in the resonant direction (see Fig. 1), the resonant frequency $f_{\delta 0}$ can again be lowered and the frequency f_{10} is, however, very slightly affected, which leads to an even lower frequency ratio of about 1.03 and a wide operating bandwidth is thus possible. The modified U-shaped slot is also of width w_s and its lower section of length ℓ_4 is with a width of ℓ_5, while its upper section of length ℓ_3 is with a width of 3 mm. This modified U-shaped slot is designed to mainly perturb the excited patch surface current path of the $TM_{\delta 0}$ mode to further decrease the frequency ratio of $f_{\delta 0}/f_{10}$. And most important, with the presence of the modified U-shaped slot, good impedance matching of both the $TM_{\delta 0}$ and TM_{10} modes is found to be obtained easily by using a probe feed at a position x_p away from the patch center.

III. EXPERIMENTAL RESULTS AND CONCLUSIONS

The proposed antennas have been successfully implemented. The proper dimensions of the modified U-shaped slot in the proposed antennas are obtained from experiments. Fig. 2 shows the measured return loss for the proposed antennas of different parameters (denoted as antennas 1–3, here). The corresponding results are also given in Table I. From the IE3D^{TM} simulation results, the lower and higher resonant modes are, respectively, found to be the TM_{10} and $TM_{\delta 0}$ modes, the same as those studied in [1]. Also note that the fundamental resonant frequency of the unslotted rectangular patch antenna is at about 1.9

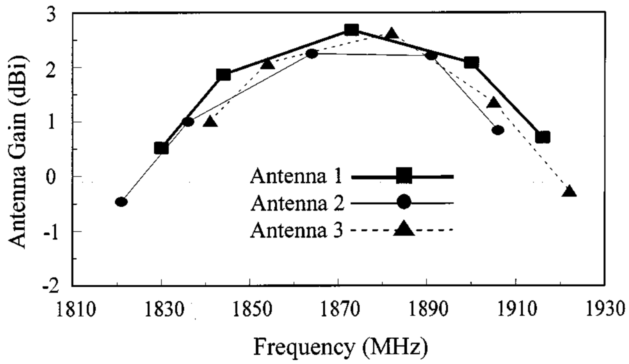


Fig. 4. Measured peak antenna gain against frequency within operating bandwidth for antennas 1–3.

GHz, with an operating bandwidth of 1.9%. Since the obtained antenna bandwidths are as large as 4.3–4.6%, the proposed antennas show a much greater operating bandwidth, more than 2.2 times that of an unslotted rectangular patch antenna. Typical radiation patterns in two orthogonal planes of antenna 1 are also shown in Fig. 3 in which the two resonant modes are seen to have same polarization planes and similar radiation patterns. Fig. 4 presents the measured peak antenna gains for antennas 1–3. The obtained results indicate that the proposed antennas have an antenna-gain variation less than 2.3 dB (antenna 1) or 2.9 dB (antennas 2 and 3) for frequencies within the operating bandwidth and the peak antenna gains are about 2.2–2.7 dBi. The obtained relatively lower antenna gains are mainly due to the large loss tangent (typically 0.025) associated with the FR4 substrates used.

By comparing antenna 2 to antenna 1, it is also found that when the length ℓ_2 is increased by about 1% with other parameters unchanged, good bandwidth-enhancement performance is also observed with the center frequency slightly decreased. Also, by comparing antenna 3 to antenna 1, good bandwidth-enhancement characteristics are still obtained for a small variation of the feed position. These results suggest that a small manufacturing error can be tolerated for the proposed design, which is important for practical applications.

Another design with a Rogers RO3003 microwave substrate ($\varepsilon_r, = 3.0$, $h = 1.524$ mm) has also been studied. The patch dimensions of 37.3 mm × 24.87 mm $(L \times W)$ are also selected. The modified U-shaped slot is of width 0.5 mm (w_s) and its upper and lower sections are of lengths 11 mm (ℓ_3) and 7 mm (ℓ_4), respectively; the width of the lower section is 8 mm (ℓ_5). Note that, different from the designs of antennas 1 to 3, the lower section in this case has a larger width than that (3 mm) of the upper section of the modified U-shaped slot. The dimensions of the right-angle slots are the same as those of antenna 2. Fig. 5(a) and (b) show, respectively, the measured return loss and peak antenna gain against frequency. Similar bandwidth-enhancement results as obtained for antennas 1–3 are also observed and the antenna bandwidth is 53 MHz (2197–2250 MHz) or about 2.4% referenced to the center frequency at 2224 MHz, which is about 2.2 times that (about 1.1%) of a corresponding unslotted microstrip antenna with a same substrate [see the dashed curve in Fig. 5(a)]. The peak antenna gain is about 5.3 dBi, which is greater than those of antennas 1–3 and is mainly because the RO3003$^{\text{TM}}$ substrate has a lower loss tangent (typically 0.0013). The lower loss tangent also results in a smaller bandwidth obtained in Fig. 4 by comparing to those of antennas 1–3 with an FR4 substrate. Also, the measured radiation patterns over the obtained impedance bandwidth are similar to those shown in Fig. 3, and are not plotted for brevity. Finally, it should be noted that the design parameters in this study are not optimized and it can be expected that better bandwidth-enhancement performances such as wider antenna bandwidth and smaller antenna-gain variation than those obtained in this study are possible.

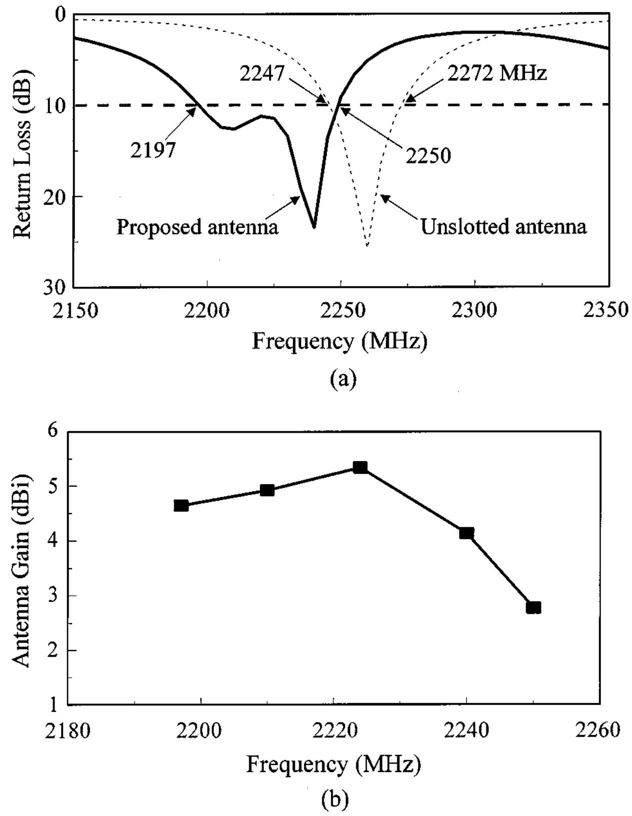


Fig. 5. (a) Measured return loss and (b) peak antenna gain against frequency for proposed antenna with a Rogers RO3003$^{\text{TM}}$ substrate; $\varepsilon_r = 3.0$, $h = 1.524$ mm, $\ell_3 = 11$ mm, $\ell_4 = 7$ mm, $\ell_5 = 8$ mm, $w_s = 0.5$ mm, $x_p = -9.4$ mm. Other parameters are the same as antenna 2.

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