Wang-Shaped Patch Antenna for Wireless Communications

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***Abstract*—A novel Wang-shaped patch antenna with a small aperture is presented in this letter. Stable radiation patterns and cross-polarization levels of -20 dB are achieved at a wide operational bandwidth of 1.7–2.5 GHz. Average gain, return loss, and efficiency are measured as 6.5 dBi, $\geq$ 15 dB, and $> 80\%$, respectively, across the bandwidth. The antenna can serve simultaneously most of the modern wireless communication standards.**

***Index Terms*—Cross polarization, E-shaped patch antenna, *L*-probe feed, U-slotted patch antenna, wideband patch antenna.**

I. Introduction

A SINGLE patch antenna with air substrate has its inherent advantages in obtaining wide impedance bandwidth at low cost. First, air substrate is free of charge and free from dielectric loss. Second, high values of impedance bandwidth and antenna efficiency can be obtained using the lowest dielectric-constant ($\varepsilon_r = 1$) medium–air dielectric. When a single patch with a U-slot [1] or parallel slots [2], [3] is incorporated, additional nearby resonant modes are excited due to the creation of supplementary current paths on the patch. By merging the additional resonant frequencies with the fundamental one while suppressing the reflection coefficient below -10 dB (return losses above 10 dB), wide impedance/return-loss bandwidth can be obtained. Nevertheless, geometries of U-slotted and E-shaped patches are inherently asymmetric. Often, wide impedance bandwidth is accomplished at the cost of high cross-polarization levels and asymmetrical radiation patterns when electrically thick ($\sim 0.1\lambda_o$) dielectric substrate is used [1]–[3], where λ_o is the free-space wavelength at the midband of the working bandwidth. It is well known that impedance bandwidth can be enhanced by using the suspended plate technique [4]. This technique is equivalent to a metallic patch placed on an electrically thick air substrate. However, as the substrate height goes beyond $0.1\lambda_o$, radiation performance of suspended plate antennas will be degraded due to unwanted surface currents generated by higher order modes at the high end of bandwidth [4], [5]. Consequently, copolarization patterns in E-plane are distorted severely, while cross-polarization levels in H-plane are increasing significantly. Unlike the conventional microstrip patch antenna, achievable working bandwidth of a wideband suspended patch antenna with an electrically thick ($> 0.1\lambda_o$) dielectric substrate is limited by the pattern and/or polarization bandwidth rather than its impedance bandwidth.

In this letter, we present a wideband single-patch antenna, the Wang-shaped patch antenna. Two pairs of parallel slots are included on a rectangular patch, which is suspended over a ground plane at a height of $0.2\lambda_o$. The Wang geometry evolved from compensation of the asymmetry of the E-shaped patch: two mirrored E-shaped patches combined into a single (Wang-shaped) patch. The aim is to obtain symmetrical radiation patterns in a wide working bandwidth. In the design process, the limitation of $0.1\lambda_o$ on thickness of the dielectric substrate of microstrip patch antennas has been overcome. The proposed antenna features a working bandwidth of 1.7–2.5 GHz, thus meeting the requirements of multiple wireless communication standards such as GSM1800, PCS1900, 3G/UMTS, WCDMA, WiFi, Hiperlan, WiMAX, etc. Within the bandwidth, stable symmetrical patterns are accomplished with cross-polarization levels of less than -20 dB. Antenna gain and efficiency are also investigated.

II. Wang-Shaped Patch Geometry

The antenna geometry of top (xy plane) and side (yz plane) views together with a wideband feed network is shown in Fig. 1. The Wang-shaped patch is designed by merging two E-shaped patches, one mirrored to the other, as a single patch that leads to symmetrical geometry with respect to both axes. The topological shape of the patch resembles the well-known Chinese character "王" (pronounced as *Wang*), hence the name Wang-shaped patch antenna. The 0.5-mm-thick Wang-shaped copper plate is mounted over an aluminum ground plane of size 150×230 mm^2, by means of foam supports as shown in the photograph of Fig. 1(d). Dimensions of the Wang patch, slots, and the probes are $\mathrm{L} = 50$, $\mathrm{W} = 37.5$, $\mathrm{H} = 27$, $\mathrm{L_S} = 12.5$, $\mathrm{W_S} = 2.5$, $\mathrm{W_C} = 5.0$, $\mathrm{L_F} = 7.5$, $\mathrm{F_H} = 13.5$, $\mathrm{F_V} = 21.8$ (unit: mm). A Rogers RO3003 ($\varepsilon_r = 3.0$, $\tan\delta = 0.0013$) dielectric substrate of 1.52 mm thickness is used for fabricating the wideband balun (feed network), which is placed directly on top of the ground plane. To facilitate matching of impedance at the large dielectric height, the *L*-probe feeding technique is used [6] for capacitive coupling. To have overall symmetry and minimize irregular surface currents, a pair of mirrored *L*-probes excited with antiphase currents is used. The 180° phase difference is produced at output ports by using differential length from the 100-Ω microstrip lines of the wideband balun [7]. For this reason, radiation leaking from vertical portions of the *L*-probes and the possible higher order mode currents on the copper patch are eliminated [8], [9]. As a result, stable symmetrical radiation patterns and cross-polarization suppression can be achieved over a wide range of frequency. Throughout the study, the electromagnetic (EM) simulator HFSS was used in design and optimization processes.

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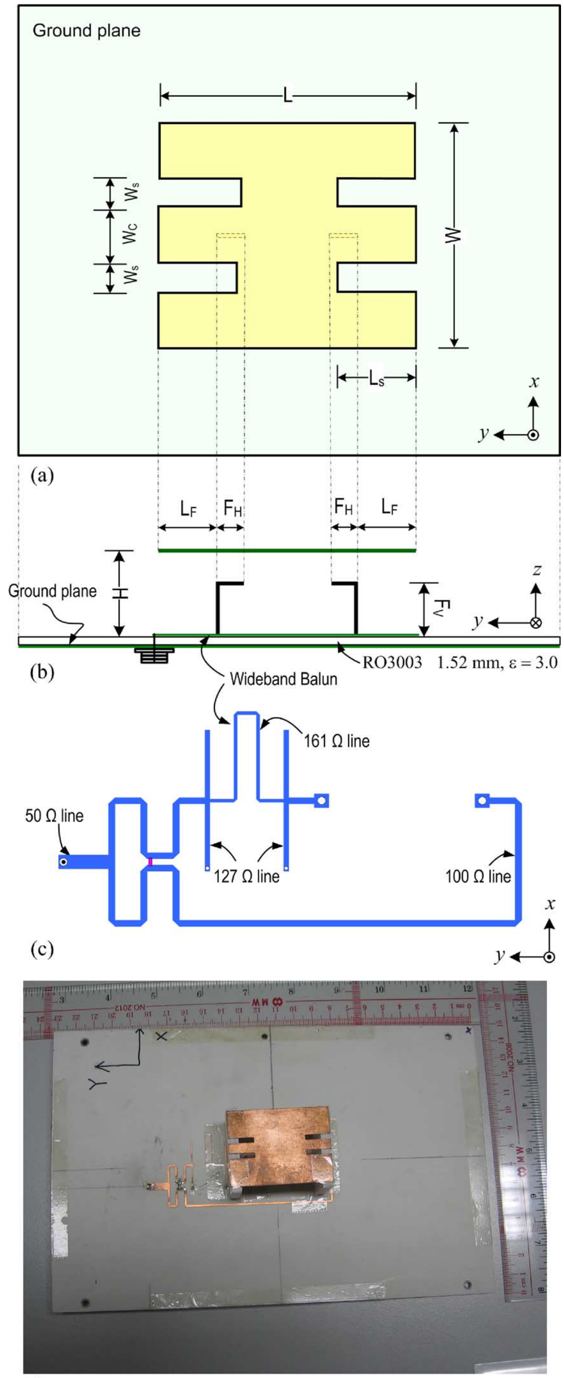

Fig. 1. Geometry of the Wang-shaped patch antenna. (a) Top view. (b) Side view. (c) Wideband feed network. (d) Photograph of the fabricated Wang-shaped patch antenna. Ground plane size: 150×230 mm^2.

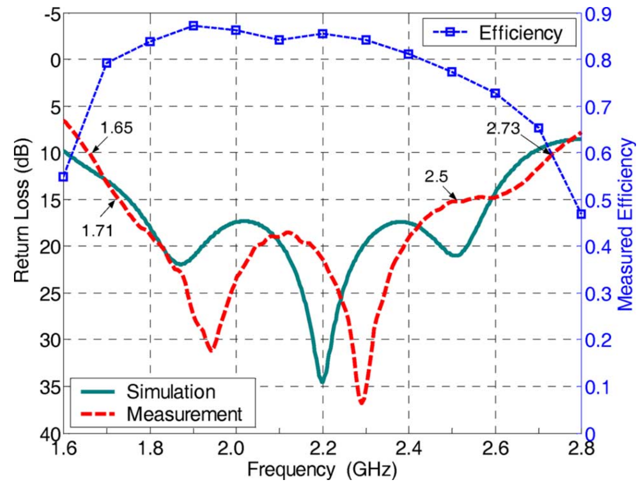

Fig. 2. Simulated and measured return loss and measured antenna efficiency versus frequency.

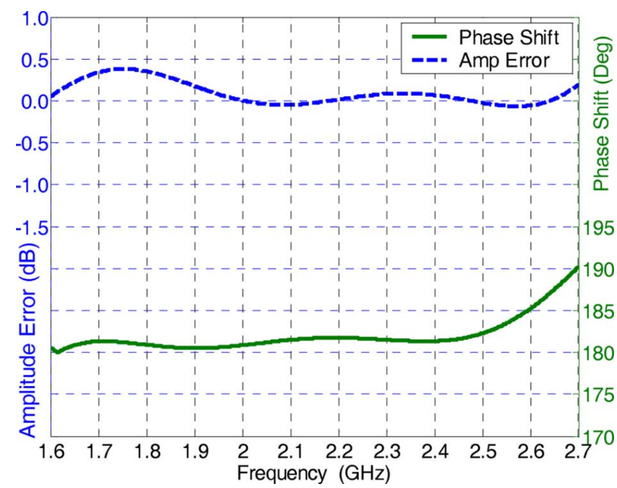

Fig. 3. Calculated amplitude error and phase shift of the wideband balun.

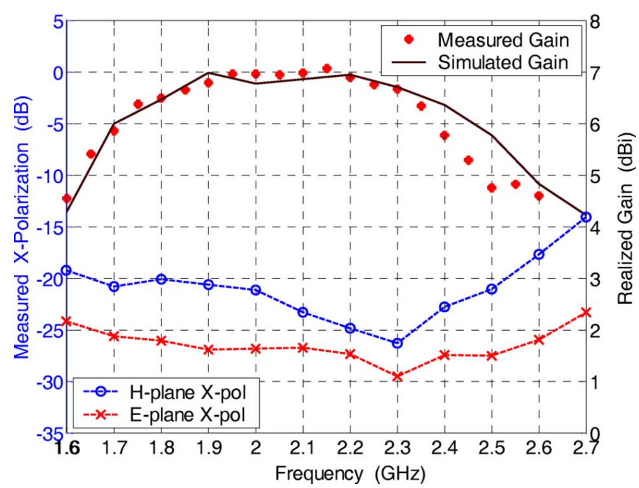

Fig. 4. Simulated and measured (realized) gain and measured cross-polarization levels versus frequency.

III. Results and Discussion

The proposed Wang-shaped antenna features additional resonances due to the dual *L*-probe feed as well as the supplementary inductance and capacitance introduced by the slots. The measured return loss together with the simulated one (Fig. 2) verifies this. For the 10-dB return-loss criteria, the measured bandwidth was achieved as 49.3% at a mean frequency of 2.19 GHz, which is in good agreement with the HFSS simulation. The upper resonant frequency measured at 2.5 GHz becomes less obvious due to fabrication tolerances. However, the dual *L*-probe-fed Wang-shaped patch has excellent impedance matching over a wide frequency range; both measured and simulated results indicated $\geq 37.5\%$ (1.71–2.5 GHz) bandwidth, i.e., 15 dB return-loss bandwidth, had been obtained. Measured antenna efficiency was

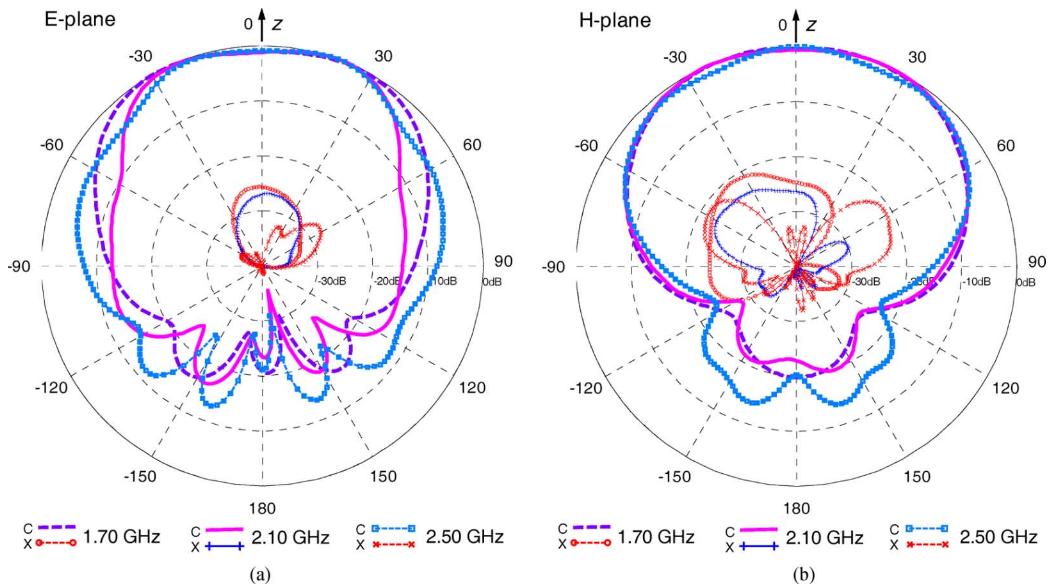

Fig. 5. The measured far-field radiation patterns at 1.70, 2.10, and 2.50 GHz. (a) E-plane (yz plane). (b) H-plane (xz plane). C: copolarization; X: cross polarization.

about 80% across the bandwidth, as shown in Fig. 2. The key part of this Wang-shaped patch antenna is the design of wideband balun in its feed network. Fig. 3 shows the calculated amplitude error and the required phase shift between output ports of the wideband balun over a frequency range of 1.6–2.7 GHz. Over this range, a maximum amplitude error of 0.38 dB occurs at around 1.75 GHz, while phase error is increasing with frequency at the higher end of the frequency range. However, for a criterion of phase error of $\pm 5^{\circ}$, this E-plane oriented balun can be operated at up to 2.6 GHz as shown in Fig. 3.

The simulated and measured (realized) gains together with the measured cross polarization in both the principle planes are plotted in Fig. 4, whereas the measured radiation patterns at frequencies of 1.70, 2.10, and 2.50 GHz are shown in Fig. 5. It can be seen that radiation patterns remain symmetrical with respect to the z-axis in both the principle planes. Cross-polarization levels remain below -25 dB in E-plane (yz plane) and -20 dB in H-plane (xz plane), respectively, over the 15-dB return-loss bandwidth. The measured average realized gain is 6.5 dBi. A maximum gain of 7.0 dBi and a maximum efficiency of 87.3% occur at 1.9 GHz. The boresight gain goes lower, while the H-plane cross polarization becomes stronger as the phase error (Fig. 3) increases with frequency increase. We can find from detailed observations in Figs. 3 and 4 that the H-plane cross polarization is mostly affected by the phase error of the wideband balun. Nevertheless, a large return-loss bandwidth is achieved, which is attributed to the reduction of Q-factor by using a cavity height of 27 mm ($\sim 0.2\lambda_o$). However, effects of higher order modes and cross polarizations are suppressed to the minimum by using the wideband feed network.

IV. Conclusion

A wideband Wang-shaped patch antenna with low cross polarization is presented in this letter. It features a small patch of $0.25\lambda_o \times 0.33\lambda_o$ with a large air-substrate height of $0.2\lambda_o$, whereas the ground plane size used for this prototype is about $1\lambda_o \times 1.5\lambda_o$. The design has overcome the limit of $0.1\lambda_o$ for thickness of the dielectric substrate in the microstrip patch antenna, where higher order mode currents destroy the radiation patterns with very high cross polarization. In the present design, the antiphased currents are provoked by a dual L-probe fed by a wideband balun. A 37.5% return-loss bandwidth of 15 dB was achieved, at which the measured cross polarization is suppressed below -20 dB. An average gain of 6.5 dBi and efficiency of $> 80\%$ are obtained over this working bandwidth. This wideband antenna is a good candidate for multistandard wireless communications.

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