Design of Compact and Low Mutual-Coupling Quasi-Yagi Antenna Using Stepped-Width Resonator

Shi-Jie Zeng [1], Yu-Hsiang Tseng [2], #Wen-Hua Tu [2]
[1]Quanta Computer Inc, Kuei Shan,Taoyuan, 333, Taiwan
[2]Dept. of Electrical Engineering, National Central University, Jhongli, Taoyuan, 32001, Taiwan
Email: whtu@ee.ncu.edu.tw

Abstract

A compact microstrip-fed quasi-Yagi antenna using stepped-width resonator is investigated. Analysis for the stepped-width dipole is outlined. In comparison to the conventional one using a uniform-width dipole, the proposed antenna shows a 20% size reduction. Furthermore, the proposed antenna has a lower mutual coupling. The proposed antenna achieves a measured 28% fractional bandwidth with a return loss of greater than 10 dB at the center frequency of 3.3 GHz, a front-to-back ratio of better than 13 dB, and an antenna gain varying from 2.4 dBi to 3.5 dBi.

Keywords : Microstrip-fed quasi-Yagi antenna

1. Introduction

Recently, planar quasi-Yagi antenna is widely used in miniaturized wireless communication system because of its simple structure, low cost, and ease to integrate with other planar devices. Some related papers have been published [1]-[6]. In [1], the authors proposed a modified quasi-Yagi antenna with a bowtie driver, and the new driver configuration was proposed to improve the bandwidth. In [2], the authors proposed a novel broadband planar antenna on a high dielectric constant substrate. For the sake of increasing the fractional bandwidth of the antenna, the authors discussed five factors that would affect the fractional bandwidth of the quasi-Yagi antenna [3]. By adjusting these five factors properly, a broadband antenna was achieved. In order to simplify the design process of the balun, the authors proposed the modified microstrip-fed quasi-Yagi antenna with the two arms of the driving dipole connected separately to two microstrip sections, which are tapered from the feeding microstrip line and its truncated ground plane [4]. Furthermore, it also shows that the end points of the two tapered sections can be properly adjusted to obtain wide bandwidth [4]. On the other hand, coplanar waveguide (CPW) feeding structure is used [5]-[6]. In [5], the authors propose a conductor backed coplanar waveguide (CB-CPW) to achieve a wide bandwidth, a better front-to-back ratio, and a lower cross polarization level. In [6], the authors used the simple structure to achieve wide bandwidth. Furthermore, the proposed antenna also had a high efficiency.

In this paper, we present detailed information on the design and performance of quasi-Yagi antennas. It is clear that in past literatures the mutual coupling issue is less discussed. To this end, the stepped-width resonator is used to replace a uniform-width resonator at the driven dipole as most of the coupling comes from the driven dipole. Section 2 will introduce the basic structure and characteristic of stepped-width resonator at resonance. The detail design process and the measured response of the proposed antenna will be shown in section 3.

2. Analysis of the Stepped-Width Resonator

Fig. 1 shows the two configurations of the dipole resonators. Fig. 1(a) is for the conventional uniform width resonator, and Fig. 1(b) shows the structure of the stepped-width resonator. The dipoles are on a 1-mm FR4 substrate with a relative dielectric constant of 4.4 and a loss tangent 0.02. The uniform resonator has a width W and a length L. The stepped-width resonator has four line sections. The inner two lines have a width of W_1 and a length of L_1. On the other hand, the outer two lines have a width of W_2 and a length of L_2. In order to investigate the proposed resonator, several full-wave simulations are carried out in HFSS [7], where the resonators are fed by a differential port. Fig. 2 shows the curves of frequency ratio versus length ratio at different width ratios, where f_0 is the fundamental frequency of the uniform-width resonator and f_{s0} is the fundamental frequency of the stepped-width resonator. The length ratio and width ratio are defined as $L_1/(L_1+L_2)$ and W_2/W_1, respectively. Six cases of width ratios of 1, 2.9, 4, 5, 6.1 and 7.1 are plotted, where we only vary W_2 and length ratio, and the values of W_1 (= 1.9 mm) and L_1+L_2 (= 16 mm) are fixed. For width ratio = 1, this is the uniform-width dipole case. As the width ratio increases, the fundamental resonant frequency of the stepped-width dipole drops implying that a compact dipole is achievable. This miniaturization property is the key factor resulting in a low mutual coupling.

3. Microstrip-fed Quasi-Yagi Antenna

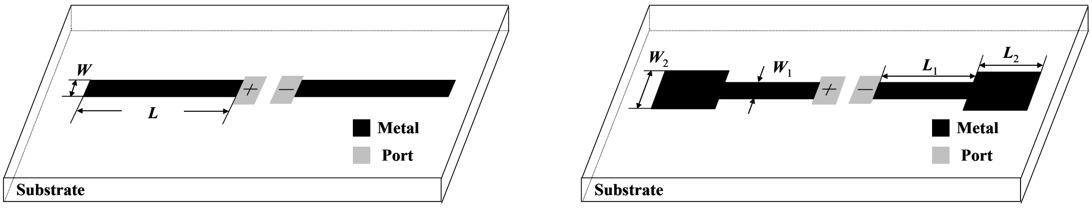
Using the proposed stepped-width resonator in section 2, a microstrip-fed quasi-Yagi antenna is presented as shown in Fig. 3. The microstrip-fed antenna consists of a uniform-width director, a stepped-width driven dipole, a microstrip line-to-coplanar stripline balun, a microstrip quarter-wave impedance transformer, and a truncated ground plane. The dimensions of the proposed antenna are L_3 = 8, L_4 = 8, L_5= 22, L_6 = 11.2, L_7 = 4, L_8 = 14.4, L_9 = 12.2, L_{10} = 8.2, L_{11} = 20, L_{12} = 55, L_{13} = 34.5, L_{14} =8, W_3= 1.9, W_4= 7.5, W_5=1.9, W_6=3.8, W_7=1.9, and G_1=1, all units are in mm. These parameters are optimized using HFSS. In comparison to the driven dipole, typically, the director has a short length and carries less energy on itself. Therefore, we keep it as a uniform-width resonator, and only replace the driven dipole by a stepped-width resonator. The stepped-width resonator has a width ratio of 4 and length ratio of 0.5. This corresponds to a frequency ratio of 0.83 as suggested by Fig. 2., which shows that the proposed resonator achieves a smaller fundamental resonant frequency than that of a uniform-width resonator at the same total resonator length. In other word, the total length of stepped-width resonator is only L_3 + L_4 = 16 mm, and the total length of the uniform-width resonator at the same center frequency is 20 mm, which shows that a 20 % length reduction is obtained. Fig. 3(b) shows the photograph, simulated and measured S parameters of the proposed antenna, the -10 dB fractional bandwidth is 28 % at the center frequency of 3.3 GHz. The simulated results are in a good agreement with the measured results. Fig. 4(a) and Fig. 4(b) show the measured E- and H-plane radiation patterns at 3.3 GHz, respectively. The figures indicate well-defined endfire radiation patterns with a result in a compact dipole as shown in Fig. 2. Fig. 5 shows the measured antenna gain varying from 2.4 dBi to 3.5 dBi. After several antennas with different width ratios were simulated in full-wave simulator; however, there is a trade-off between the fractional bandwidth and the frequency ratio percentage as shown in Fig. 6. It shows that the fractional bandwidth increases as the frequency ratio increases. This is due to the change of the dipole input impedance dipole when the width ratio is varied. To obtain a compact antenna, a small frequency ratio is preferred. However, the input impedance of the stepped-width dipole would be so low making it difficult to match for a broad bandwidth. About the mutual coupling, in array antennas, it is one of the considerable factors, because it will lower the gain and affect the pattern of the antenna. Therefore, one may desire its value as small as possible. The proposed antenna with a compact size is beneficial for reducing the mutual coupling. Fig. 7 shows the mutual coupling of the two antennas at 3 and 3.3 GHz. The distance between the antennas is about $\lambda_g/2$ to λ_g, where λ_g is the guided wavelength at 3.3 GHz. In comparison with the pair of antennas using uniform-width resonator, the proposed antenna achieves a lower mutual coupling.

4. Conclusion

A compact quasi-Yagi antenna using stepped-width resonator structure is presented. The proposed antenna shows a small size and a lower mutual coupling. These features would make the proposed antenna attractive in antenna array design.

Acknowledgments

This work was supported in part by the National Science Council of Taiwan under Contract NSC 97-2221-E-008-035 and NSC 100-2221-E-008-113.



(a) uniform resonator (b) stepped-width resonator

Figure 1: Configuration of the dipoles.

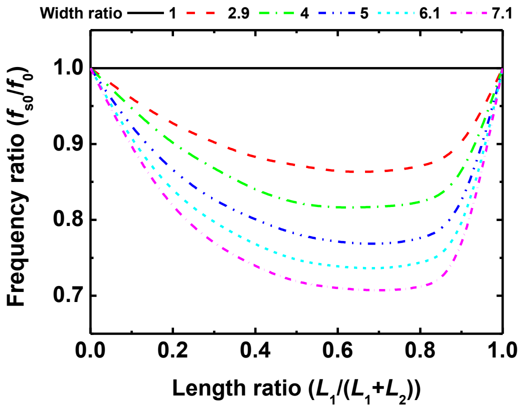
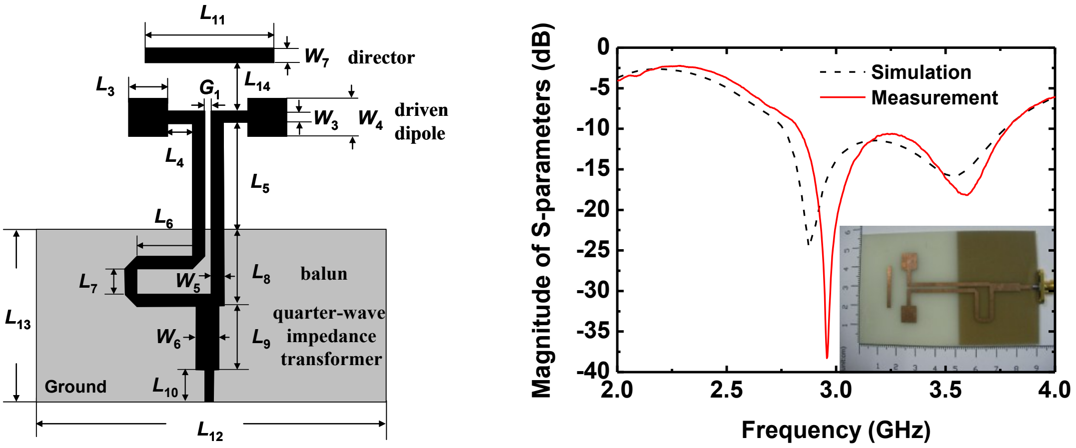
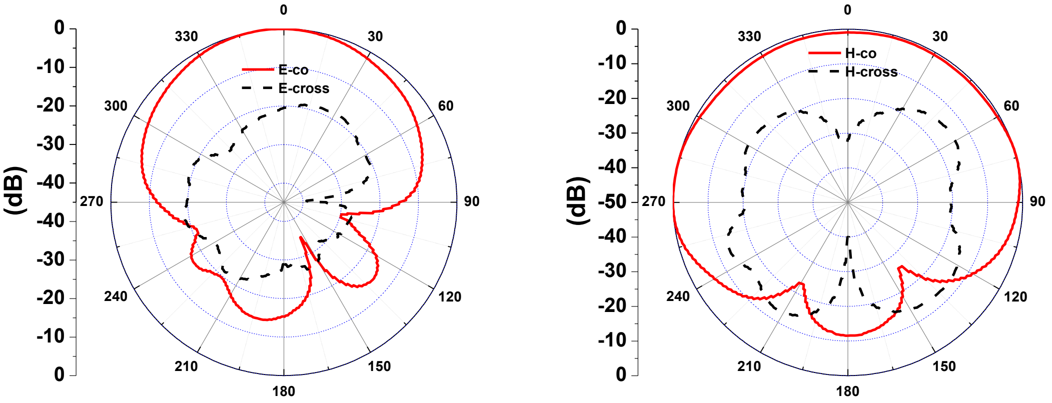


Figure 2: Frequency ratio versus length ratio of stepped-width resonator.



(a) (b)

Figure 3: (a) Schematic of the proposed antenna. (b) Photograph of the proposed antenna and simulated and measured S parameters.



(a) E-plane (b) H-plane

Figure 4: Measured radiation patterns of the proposed antenna at 3.3 GHz.

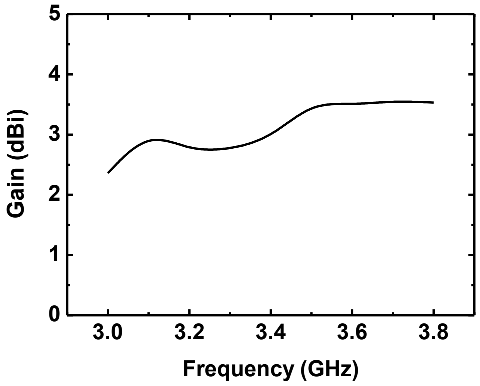


Figure 5: Measured antenna gain.

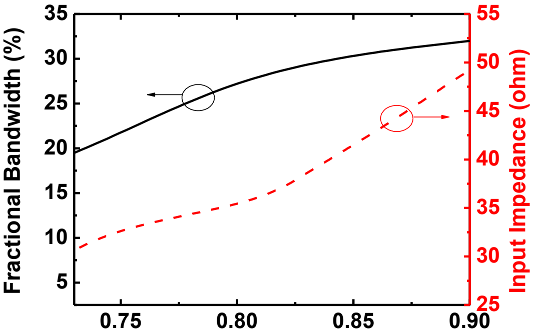


Figure 6: Fractional bandwidth and input impedance versus frequency ratio.

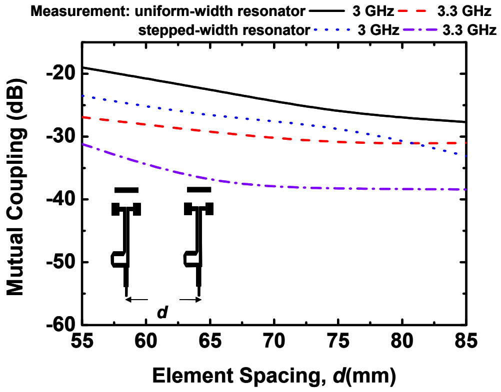


Figure 7: Mutual coupling of the antenna

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