A novel wideband planar quasi-yagi antenna loading with parasitical patches and multiple reflectors

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Abstract: In this paper, a novel wideband microstrip-fed quasi-Yagi antenna is presented. The proposed quasi-Yagi antenna consists of a microstrip-fed monopole, three radiating patches (two square patches and a rectangular patch), and three parasitic strip elements as the function of reflector. In order to achieve wide bandwidth, two parasitical patches are etched on both sides of the substrate. Furthermore, the stepped microstrip feeding line is adopted so as to get a good impedance matching. A fabricated prototype with the dimensions of 40 mm $\times$ 55.5 mm yields a directional far-field radiation pattern with no director, a $-10$ dB bandwidth (2.21–5.4 GHz) of 83.8\% and a peak radiation gain of 4.17 dBi. Finally, the proposed antenna is analyzed, fabricated and measured. Measured and simulated results are in good agreement.

Keywords: wideband, end-fire, gain, parasitic strip, monopole antenna, coupling

Classification: Microwave and millimeter-wave devices, circuits, and modules

References

1 Introduction

Many system applications require an antenna to operate over a large range of frequencies. Furthermore, compact antennas with broadband and directional radiation characteristics are needed. Yagi antennas have attracted great interests in microwave applications because of their properties of simplicity and relatively high gain. The first research done on the Yagi-Uda antenna was performed by S. Uda in 1926 [1]. With the development of technology, microstrip antennas are widely used because of their stable performance, low cost, low profile, and easy to fabricate. Since, the microstrip-fed planar printed quasi-Yagi antenna was first introduced by Huang in 1991 [2], which consists of a reflector, a driven element, and two directors. It utilizes a similar principle as a conventional Yagi-Uda dipole array.

Recently, studies on extend the bandwidth of planar printed quasi-Yagi antennas have been widely investigated [3, 4, 5, 6, 7]. A novel Yagi-like printed dipole array antenna is obtained in [3] to achieve a wide operation bandwidth. The antenna is fed by a microstrip to coplanar strip transition, and uses the truncated ground plane as its reflecting element. The proposed antenna has a measured bandwidth of 17% with $-10$ dB reflection coefficient. More important, a very compact and simple planar antenna based on the modification of the Yagi-like antenna has been
presented. The antenna experimentally demonstrated a bandwidth of 48% for a VSWR < 2, a gain between 3–5 dB in [4]. However, these antennas typically exhibit narrow bandwidths. The reference [5] presents a broadband design of the microstrip-fed modified quasi-Yagi antenna is presented. A measured bandwidth of approximately 51.6% (7.17–12.16 GHz) was obtained. Nevertheless, this design pays the price of a large ground plane, which increases the antenna size. A broadband quasi-Yagi antenna with a simple coplanar stripline-fed provides more flexibility in design [6]. However, the antenna was not suitable for array applications because of the feed structure. Coplanar waveguide feeding is presented to improve the bandwidth in [7]. However, the asymmetric nature of the printed quasi-Yagi antenna deteriorates the unidirectional radiation patterns.

Applying an electromagnetic band-gap structure can increase the bandwidth [8] as well. The simulated and measured results show a relative bandwidth better than 53%, a cross polarization lower than 19 dB in the main lobe. Wideband antennas can be obtained according to multilayered technique. Approximately 27.8% and 70.8% bandwidth are achieved in [9] and [10], respectively. In [11], a top-hat monopole Yagi antenna has been designed with the bandwidth of 20.5%. An octagon microstrip Yagi antenna [12] has the ability to obtain 15.97% bandwidth. Microstrip-fed structure monopole antennas have also been used in quasi-Yagi antenna design [13, 14]. In [14], proper utilization of C-shape reflector has potential to improve impedance bandwidth. The proposed antenna provides a wide impedance bandwidth of about 68.0% (2.04–4.14 GHz) for return loss less than −10 dB. But these design solutions generally require large size or volumes.

In this letter, we propose a novel structure of microstrip-fed quasi Yagi antenna. The proposed antenna has a simple structure that comprises a monopole antenna, two parasitical patches, and three parasitic strip elements. Bandwidth enhancement of the antenna can be obtained by coupling between the monopole and the parasitical structure. The usable bandwidth of the proposed antenna is 83.8% (2.21–5.4 GHz). Loading three parasitic strip elements, this quasi Yagi antenna presents an upward end-fire radiation pattern within the operating band. It has no additional director comparing with conventional Yagi-Uda antenna. Furthermore, a minimized volume can be obtained (55.5 × 40 mm$^2$).

2 Antenna design and analysis

2.1 Antenna structure

The geometric structure and parameters of the proposed wideband quasi-Yagi antenna are shown in Fig. 1. The antenna is printed on a TLF-35A substrate with a dielectric constant of 3.5, dielectric loss tangent of 0.0022, and thickness of 1.0 mm. The size of the substrate is 55.5 × 40 mm$^2$ (L × W).

The antenna is composed of a microstrip-fed monopole, three radiating patches (two square patches and a rectangular patch), and three parasitic strip elements which function as reflector. A stepped microstrip feeding line is adopted to achieve a good impedance matching. The stepped microstrip feeding line and two square patches are printed on the top layer of the substrate. The truncated microstrip ground, the rectangular parasitic patch, and the reflector are printed on the bottom
layer of the substrate. The microstrip feeding line width of W1 is 2.2 mm to achieve 50 Ω characteristic impedance. The feed line with a length of L1 is connected to the coaxial cable through a 50 Ω SMA connector. The g is the gap between the square conducting patches on the top layer of the substrate. The distance between R1 and R2 is longer than the distance between R2 and R3. The gap between the truncated microstrip ground and the R1 is D1. The D2 is the distance between the rectangular parasitic patch and the R1. The antenna elements is simulated in Ansoft HFSS full wave simulator [15]. The optimized parameters of the antennas are tabulated in Table I.

<table>
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<tr>
<th>Parameter</th>
<th>L</th>
<th>W</th>
<th>D1</th>
<th>D2</th>
<th>L1</th>
<th>W1</th>
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<td>6</td>
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<tr>
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<td>W2</td>
<td>Lg</td>
<td>Wg</td>
<td>Lp</td>
<td>d</td>
</tr>
<tr>
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<td>12.5</td>
<td>12</td>
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</tr>
<tr>
<td>Parameter</td>
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<td>g1</td>
<td>g2</td>
<td>G</td>
<td>Lr</td>
<td>Wr</td>
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<tr>
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<td>0.5</td>
<td>2.5</td>
<td>55</td>
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</tbody>
</table>

Fig. 1. Geometry of the proposed antenna. (a) Top view. (b) Lateral view.

2.2 Driven and reflector elements

It is well known that the basic unit of a Yagi consists of three elements (driven dipole, reflector, and director). The driven element is the most important part to obtain wideband operation. Thus, a novel compact broadband planar microstrip-fed antenna based on the one in [16] is proposed. The antenna design evolution process to achieve broadband operation is shown in Fig. 2. The overall size of the proposed
The antenna is only 12 mm × 39.5 mm. The antenna consists of a microstrip-fed monopole antenna and two parasitic patches. In this communication, we utilize a stepped microstrip-fed structure to improve the impedance matching of the antenna to achieve a wide bandwidth. Furthermore, loading the parasitic patches can significantly improve broadband characteristics.

![Ant. 1](image1)
![Ant. 2](image2)
![Ant. 3](image3)

**Fig. 2.** Design evolution of the proposed antenna.

![Simulated reflection coefficients](image4)

**Fig. 3.** Simulated reflection coefficients of the different antennas.

The simulated reflection coefficients in Fig. 3 display this effect of becoming wideband gradually. The Ant. 1 did not produce perfect resonance in low frequency (less than 5.75 GHz). However, the Ant. 2 with a rectangular conductor-backed plane for broadband operation has been presented. The −10 dB return loss is ranged from 4.43 to 5.71 GHz (25.2%). But the bandwidth of the Ant. 2 is still narrow but still has potential to own larger bandwidth. The Ant. 3 is designed to achieve wide bandwidth adding a parasitic patch based on Ant. 2. It can be seen in Fig. 3 that by loading two parasitic patches (Ant. 3), a wide operating frequency band is occurred. It has a wide impedance bandwidth (return loss < −10 dB) of 63.4% from 2.78 to 5.36 GHz. In comparing the three designs, it seems that the bandwidth tends to increasing as more parasitical patches are added to the monopole antenna.
To further understand the design of the proposed antenna, the smith chart is shown in Fig. 4. It can be seen that when the parasitic patches loaded to the monopole antenna, the impedance matching get better in operating frequency band. The simulated two-dimensional radiation patterns comparing the quasi Yagi with different number of reflectors at 2.8 GHz are presented in Fig. 5. From the results given in Fig. 5, the stable endfire radiation could be maintained when the antenna owns one reflector to three reflectors. Additionally, there are a little bit enhanced front-to-back ratio with three reflector elements.

3 Simulation and experimental results

To verify the results of the simulated design, the quasi Yagi antenna is fabricated on a 1-mm-thick TLF-35A substrate with a dielectric constant of 3.5 and loss tangent of 0.0022 as shown in Fig. 6. The measured and simulated reflection coefficients are presented in Fig. 7. The measured results is obtained by ROHDE & SCHWARZ ZVA8 vector network analyzer. The −10 dB return loss is range from 2.21 to 5.4 GHz, which means a fractional bandwidth of 83.8%. Compatible with
the fabrication tolerance, the operating frequency band has a slight shift as shown in Fig. 7.

The proposed antenna is measured in the anechoic chamber (SATIMO-SG24). Fig. 8 depicts the measured co- and cross-polarized radiation patterns at 2.8, 3.35, and 4.55 GHz, respectively, in the H plane (x-o-z plane) and E plane (x-o-y plane). It can be concluded that from the results that the radiation patterns are not sensitive to the operation frequency and the broadside radiation patterns are stable over the operating frequency band. Meanwhile, the measured normalized cross-polarization is less than $-20$ dB in the H plane.

The simulated and measured peak gain of the proposed antenna are plotted in Fig. 9 along with measured radiation efficiency of the proposed antenna. The measured radiation efficiency is greater than 32% over the operation bandwidth. The simulated gain varies between 4.3 and 6.4 dBi within the operating frequency ranging from 2.6 to 5.2 GHz. The measured peak gain of the proposed antenna varies from 0.96 to 4.17 dBi within the effective bandwidth (2.4–5.4 GHz) due to the fabricated error and connector effect. Comparisons between the proposed quasi Yagi antenna and other Yagi–Uda antennas in bandwidth, director, dimension, and
Fig. 8. Measured radiation patterns of the proposed antenna at (a) 2.8, (b) 3.35, and (c) 4.55 GHz. Left: XOZ-plane; right: XOY-plane.

Fig. 9. Measured and simulated peak gain and radiation efficiency of the proposed antenna.
antenna structure have been shown in Table II. It is shown that the effective bandwidth is enhanced when compared with other Yagi-Uda antennas. Besides, the single layer structure with no director of the proposed antenna is compact, simple, and easy to fabricate.

4 Conclusion

In this letter, a novel wideband microstrip-fed quasi Yagi antenna is presented. The antenna consisting of one monopole antenna, two parasitical patches, and three parasitic strip elements has been designed to achieve an end-fire radiation with a low profile. The structure of the proposed antenna is simple and easy to fabricate. The bandwidth has been largely improved due to the strong electromagnetic coupling between the monopole and the parasitical structure. The measured antenna has the ability to obtain 83.8% bandwidth. This antenna, having no director, could present a very good end-fire radiation pattern at the same time. The antenna achieves more than 32% radiation efficiency within the operating band, and about 68% peak efficiency at 5 GHz. Hence, the proposed antenna is quite suitable for the modern wireless communication systems.

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