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A Broadband Planar Quasi-Yagi Antenna with a Modified Bow-Tie Driver for Multi-Band 3G/4G Applications

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Abstract—This paper presents a broadband and compact planar quasi-Yagi antenna for multi-band 3G/4G applications. The proposed quasi-Yagi antenna consists of a modified bow-tie driver to increase the bandwidth, a passive reflector and two passive directors to enhance the directivity at the lower and higher ends of the operating band, respectively. A microstrip-to-slotline transition feed is used to achieve a good impedance matching. It is confirmed by experiment that general approaches for increasing the bandwidth of bow-tie antennas are also feasible for quasi-Yagi antennas with bow-tie drivers. Furthermore, with the modified bow-tie structure, the directivity of the antenna at higher frequencies of the operating band is enhanced, because the bow-tie shape can form planar horn structures and has strong current distributions at high frequencies. The proposed antenna is fabricated using an FR4 substrate with a dielectric constant of 4.2, and the overall dimension of the antenna is $1.24\lambda_{gc} \times 0.94\lambda_{gc}$. Measurements show that the 10 dB return loss bandwidth is 80.4%, operating from 1.45 to 3.4 GHz. Measured gains are greater than 4 dBi within the entire bandwidth, and the front-to-back ratios are greater than 10 dB. Having a multi-band coverage within the 3G/4G spectra, this antenna is expected to be used for 3G/4G mobile wireless communications.

1. INTRODUCTION

Quasi-Yagi antennas have been widely used for wireless communications for their properties such as low-cost, easy fabrication process, compact size, lightweight and endfire radiation pattern [1]. A conventional Yagi-Uda antenna consists of a dipole driver in the centre, a single reflector on one side, one or more directors on the other side and a feeding structure. There is always a tradeoff between the gain and bandwidth, with the bandwidth narrowing as more elements are used. To obtain a high gain ($\sim$ 6.5 dBi), the typical bandwidth of a conventional quasi-Yagi antenna is relatively narrow (10–20% for VSWR < 2), limiting their applications for broadband wireless communications. A wider bandwidth (40–50% for VSWR < 2) can be achieved at the cost of reduced gain ($\sim$ 4 dBi).

The theory of operation for quasi-Yagi antennas has been well established, and research work has been focused on improving the bandwidth. Instead of using a single radiating element, quasi-Yagi antenna arrays were proposed in [2–4] to obtain wider bandwidths. However, antenna arrays are large in size, and integration into mobile devices would be difficult. In [5–7], the bandwidths of quasi-Yagi antennas were improved by changing the feeding structures. Other driver shapes such as gradient dipoles or bow-tie structures have also been used to replace the conventional dipole drivers of quasi-Yagi antennas to improve the bandwidth [8–10]. However, the central operating frequencies of these antennas are normally higher than 4 GHz and may not be suitable for multi-band 3G/4G applications.

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In this paper, we propose a broadband and compact planar quasi-Yagi antenna with a modified bow-tie driver for multi-band 3G/4G applications. This antenna uses a modified bow-tie shape as the driver and a horn structure as the feeding structure. The modified bow-tie structure can further increase the bandwidth of the quasi-Yagi antenna compared to those with standard bow-tie drivers, while the directors are designed to enhance the directivity at the higher end of the operating bandwidth. The proposed antenna is fabricated on an FR4 substrate with a dielectric constant of 4.2, and the overall size of the antenna is $\sim 80\,\text{mm}$ by $61\,\text{mm}$ $(1.24\lambda_{gc} \times 0.94\lambda_{gc})$. Measurements show that the 10 dB return loss bandwidth is 80.4% at frequencies between 1.45 and 3.4 GHz, and the gains are $> 4\,\text{dBi}$ within the entire bandwidth. It is also interesting to note that at higher frequencies, the bow-tie shape can form a planar horn antenna and can concentrate the electromagnetic energy within the upper half of the horn structure. As a result, more energy will be forwarded to the directors. This characteristic is confirmed by simulated surface current distributions and measured radiation patterns at different frequencies. Covering multi-bands including the widely used B2, B4, B25 and B41 for 3G UMTS/CDMA and 4G LTE/WIMAX technologies, this antenna is expected to find wide applications in modern mobile wireless communications systems.

2. ANTENNA DESIGN

Standard quasi-Yagi antennas normally use dipole or folded dipole drivers. It is known that bow-tie antennas also have symmetrical structures as dipole-based quasi-Yagi antennas, but have wider bandwidths. Therefore, bow-tie structures can be used to replace conventional dipole drivers to achieve a wide bandwidth [10]. Figure 1 shows the structure of a quasi-Yagi antenna with a standard bow-tie driver. A microstrip-to-slotline transition structure, a bow-tie driver, two directors and a reflector are located on the top layer of the substrate. This standard design has a bow-tie driver that consists of two triangular shapes (as defined by $L5$ and $W2$). Two small passive directors (defined by $W4$, $L6$ and $L7$) are designed to increase the directivity at higher frequencies, while the reflector (defined by $L4$ and $W1$) is used to improve the directivity at lower frequencies. On the bottom layer, a horn-shaped microstrip-to-slotline balun is used to achieve a good impedance matching. The design parameters for the quasi-Yagi antenna with a standard bow-tie driver are shown in Table 1.

To further increase the bandwidth of the quasi-Yagi antenna, we propose an improved design of the quasi-Yagi antenna with a modified bow-tie driver, as shown in Figure 2. In this design, we modify the standard bow-tie shape by extending $L5$, obtaining a square shape that is defined by $W2$ and $L6$. This is a widely used approach to improve the bandwidth of bow-tie antennas. As will be shown later, general methods for increasing the bandwidth of bow-tie antennas are also feasible for increasing the

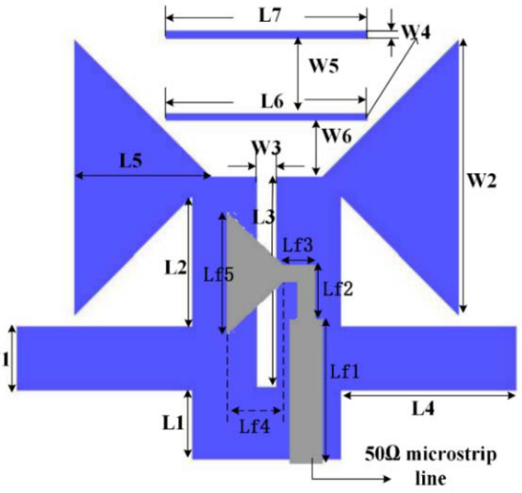


Figure 1. Standard design: quasi-Yagi antenna with a standard bow-tie driver.

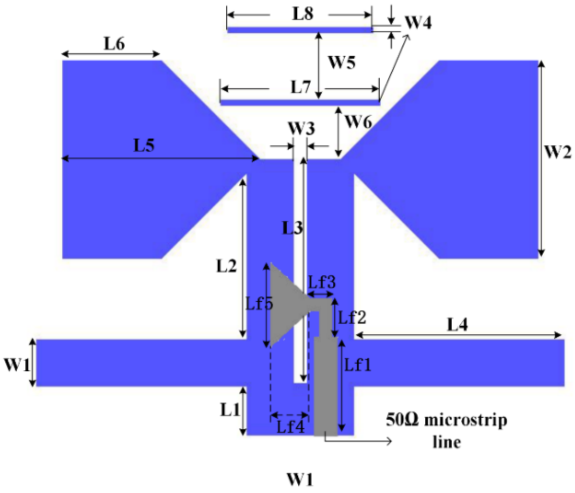


Figure 2. Improved design: quasi-Yagi antenna with a modified bow-tie driver.

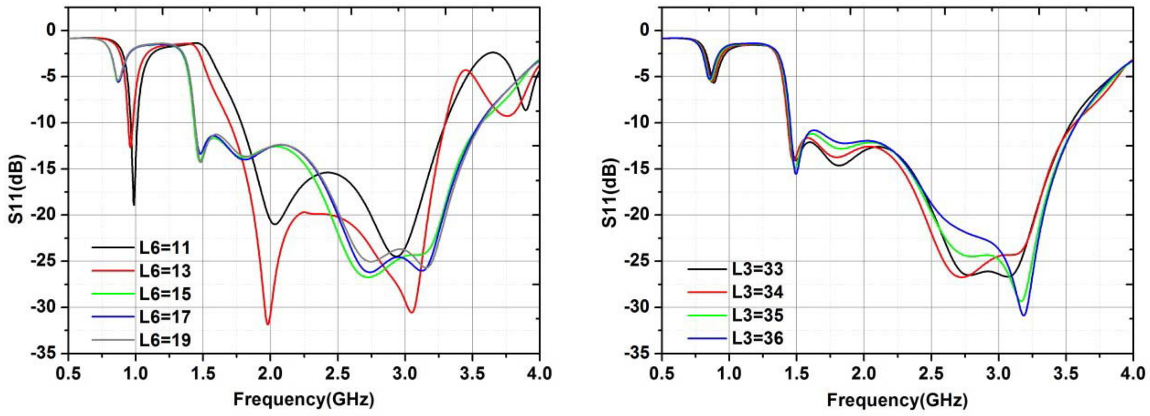
Table 1. Optimized parameters for the quasi-Yagi antenna with a standard bow-tie driver.

Parameter	Value (mm)	Parameter	Value (mm)
L1	7.5	**W3**	2.2
L2	14.3	**W4**	1
L3	23	**W5**	11
L4	19.3	**W6**	9
L5	15	**Lf1**	10
L6	22	**Lf2**	5.75
L7	22	**Lf3**	3.25
W1	7	**Lf4**	6
W2	30	**Lf5**	12.75

bandwidth of quasi-Yagi antennas with bow-tie drivers.

To achieve the optimization, initial values for the parameters have to be determined. According to operation principle of Yagi-Uda antennas, the length ($L5$) and width ($W2$) of the bow-tie structure are chosen to be $0.5\lambda_{gc}$ ($\lambda_{gc} = 64.4$ mm is the wavelength in substrate at the central operating frequency of 2.5 GHz), the arm length of the reflector ($L4$) is selected to be $0.25\lambda_{gl}$ ($\lambda_{gl} = 114.6$ mm is the wavelength at the lowest operating frequency of interest, e.g., 1.45 GHz), and the lengths of the directors ($L7$ and $L8$) are around $0.5\lambda_{gh}$ ($\lambda_{gh} = 48.2$ mm is the wavelength at the highest operating frequency of interest, e.g., 3.4 GHz). The initial values for the spacing between the bow-tie driver and the directors ($W5$ and $W6$) are chosen to be $0.25\lambda_{gh}$. The bandwidth of the antenna is not sensitive to the widths of the reflector ($W1$) and directors ($W4$), as long as they are kept small. In our design, they are assigned the fixed values of 7 mm and 1 mm, respectively. To achieve a 50-Ω characteristic impedance, the microstrip feeding line has a fixed structure that is independent of the operating frequency, and is controlled by parameters $Lf1$–$Lf5$. When comparing Figure 2 to Figure 1, it is found that the length of the square shape in the bow-tie driver ($L6$) will have a significant effect on the bandwidth of the quasi-Yagi antenna. Having $L6 = 0$ mm in Figure 2 will result in a quasi-Yagi antenna with a standard bow-tie driver, as shown in Figure 1. It is expected that with a larger value of $L6$, a wider bandwidth can be obtained. The initial value for $L6$ is set to $0.25\lambda_{gc}$, which is half the length of the bow-tie structure ($L5$).

After choosing the initial values, the effect of each parameter on the bandwidth will be investigated. The simulated return losses can be obtained by sweeping each parameter over the ±20% range



(a) (b)

Figure 3. Simulated return losses of the quasi-Yagi antenna versus (a) $L6$, and (b) $L3$.

individually. As expected, it is found that $L6$ has the most significant effect on the bandwidth, while the bandwidth is less sensitive to the other parameters (e.g., $L3$). Figures 3(a) and (b) show the simulated return losses by varying $L6$ and $L3$, respectively. It is found that for $L6 \geq 15\,\mathrm{mm}$, its effect on the bandwidth becomes less significant. To keep a compact size of the antenna, $L6$ is chosen to be 15 mm. Having determined all these values, the parameters are used for final optimization, so that the widest bandwidth can be obtained from all possible combinations of these parameters. The optimization is carried out using the three-dimensional EM-simulator Ansoft HFSS 14.0, and the goal of optimization is set to obtain the widest 10 dB return loss bandwidth. Optimized parameters for the proposed quasi-Yagi antenna with a modified bow-tie driver are listed in Table 2.

Table 2. Optimized parameters for the quasi-Yagi antenna with a modified bow-tie driver.

Parameter	Value (mm)	Parameter	Value (mm)
L1	7.5	**W3**	2.2
L2	25.3	**W4**	1
L3	34	**W5**	11
L4	31.9	**W6**	9
L5	30	**Lf1**	15
L6	15	**Lf2**	5.75
L7	24	**Lf3**	3.25
L8	22	**Lf4**	6
W1	7	**Lf5**	12.75
W2	30		

Figure 4 further shows the simulated return losses for standard and improved designs. It is seen that for the quasi-Yagi antenna with a standard bow-tie driver (shown in Figure 1), the simulated 10 dB return loss bandwidth is 44%, operating from 2 to 3.11 GHz. By modifying the bow-tie driver, the bandwidth of the quasi-Yagi antenna increases to 84.4%, and the operating band is from 1.44 to 3.56 GHz. It is therefore confirmed that the quasi-Yagi antenna with a modified bow-tie driver has a wider bandwidth than that with a standard bow-tie driver.

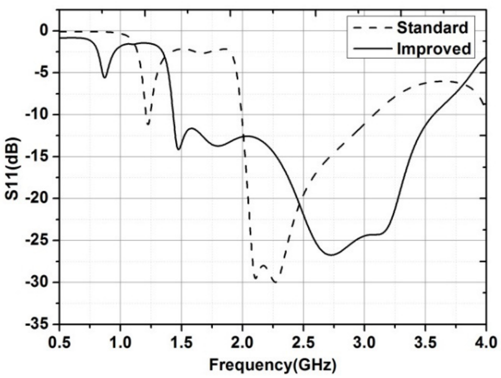


Figure 4. Simulated return losses for the standard and improved designs.

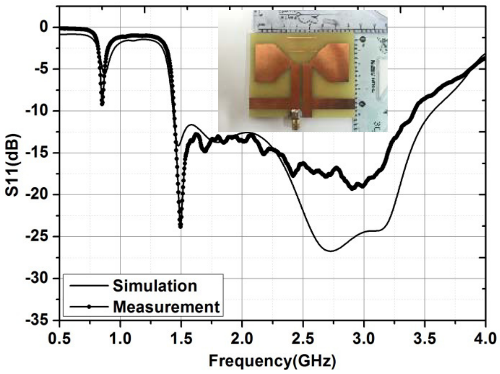


Figure 5. Simulated and measured return losses of the quasi-Yagi antenna with a modified bow-tie driver. Inset: Manufactured antenna (top view).

3. RESULTS AND DISCUSSIONS

The quasi-Yagi antenna with a modified bow-tie driver was manufactured in order to experimentally investigate its relative bandwidth and radiation characteristics. It was fabricated on an FR4 substrate with a size of $\sim 80\,\text{mm} \times 65\,\text{mm}$ ($W \times L$) and a thickness of 1.6 mm. The dielectric constant of the substrate is 4.2. An SMA connector was soldered onto the edge of the substrate. The manufactured antenna has an overall dimension of $80\,\text{mm} \times 61\,\text{mm}$ ($1.24\lambda_{gc} \times 0.94\lambda_{gc}$) and is shown as the inset of Figure 5. Measured return losses are also illustrated in Figure 5, demonstrating a measured 10 dB return loss bandwidth of 80.4% between 1.45 and 3.4 GHz. A good agreement is obtained between the simulation and measurement.

Figure 6 further shows that the measured gains of the proposed antenna are > 4 dBi within the entire operating band. The discrepancies between the measurement and simulation, especially at the lower end of the operating band, are mainly due to manufacturing error and the quality of the FR4 substrate. As expected, as the frequency increases, the gain also increases as the directors are designed to work at higher frequencies. By changing the length of directors (e.g., $L7$ and $L8$), the gain can also be adjusted to meet other specific requirements. Nevertheless, it is confirmed that the designed broadband quasi-Yagi antenna with a modified bow-tie shape can cover multi bands in 3G/4G wireless communications systems.

Figures 7(a)–(c) illustrate the measured normalized radiation patterns of the quasi-Yagi antenna with a modified bow-tie driver, at 2 GHz, 3 GHz, 3.4 GHz and for E-plane and H-plane, respectively. End fire radiation patterns ($+y$-axis direction) are observed at all evaluated frequencies. The front to back ratio is 12.5 dB, 14.5 dB, 18.5 dB at each operating frequency, and the corresponding 3 dB beamwidth in H-plane is around 175°, 135°, 109°. As indicated by the measured gains, the proposed antenna has a higher front to back ratio and a smaller 3 dB beamwidth at higher frequencies.

According to the measured gains and radiation patterns, the proposed antenna has higher directivities at higher frequencies within its operating bandwidth. In order to investigate this characteristic, simulations of surface current distributions at different frequencies are performed. Figures 8(a)–(c) show the surface current distribution at 2 GHz, 3 GHz, 3.4 GHz, respectively. A high surface current density is observed within the reflector at 2 GHz, and it is weak within the bow-tie driver and directors. As the operating frequency increases, the surface current densities within both the directors and the bow-tie driver become stronger, indicating higher directivities in the forward direction. On one hand, it is because that the directors are designed according to the highest frequency of interest (e.g., 3.4 GHz), and will work effectively at this frequency. On the other hand, this is due to the fact that the angle of bow-tie driver can form a planar horn structure. According to the theory of Vivaldi antennas [11, 12] and planar horn antennas [13, 14], this structure can concentrate the electromagnetic energy around the corner of the bow-tie shape at high frequencies, and more energy can be directed to the directors. Therefore, our proposed bow-tie quasi-Yagi antenna has a better high-frequency directivity because of the two directors the as well as the planar horn structure.

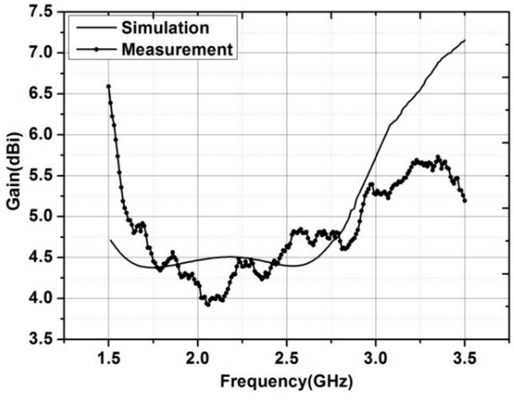
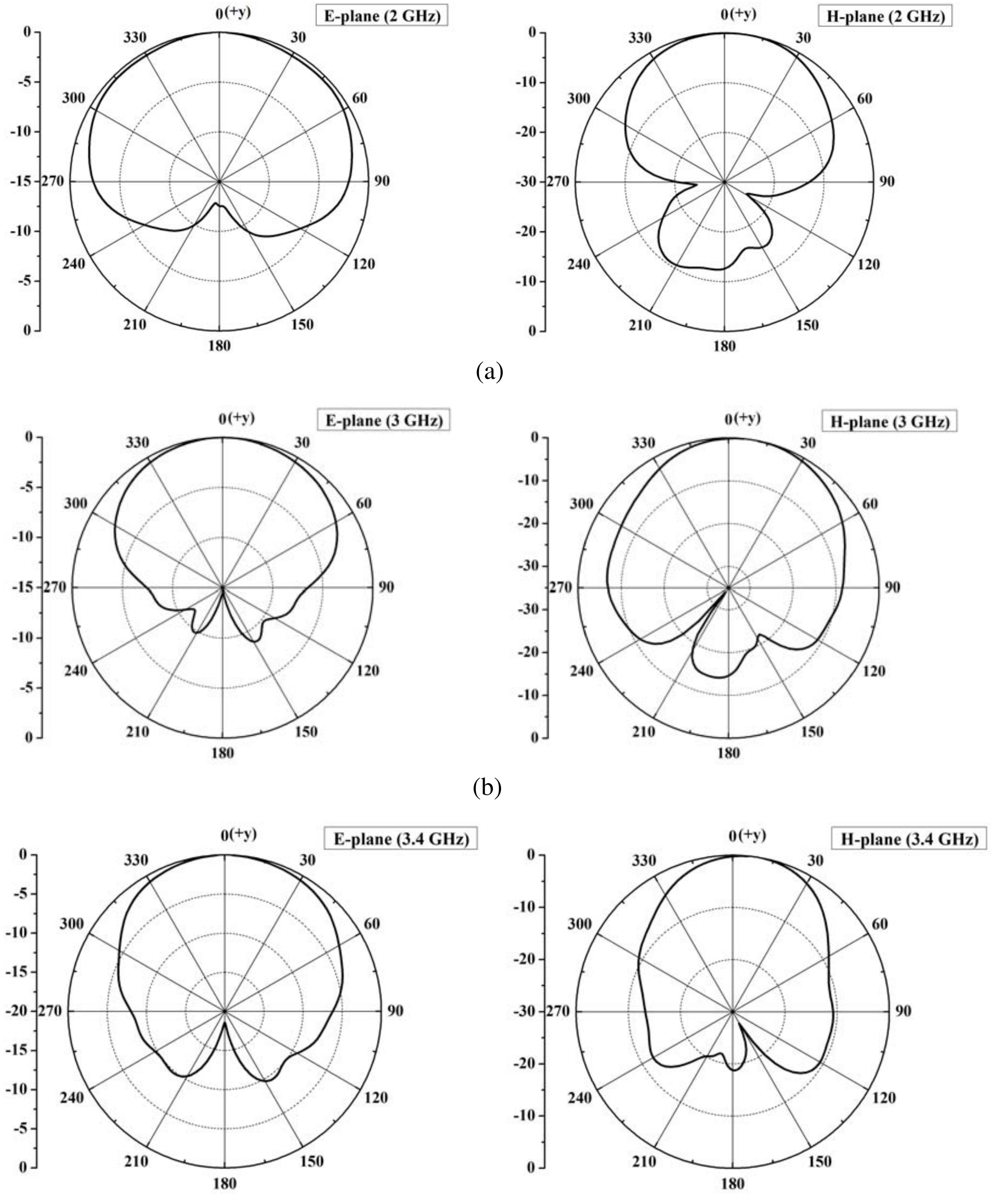


Figure 6. Simulated and measured gains of the quasi-Yagi antenna with a modified bow-tie driver.



(a)

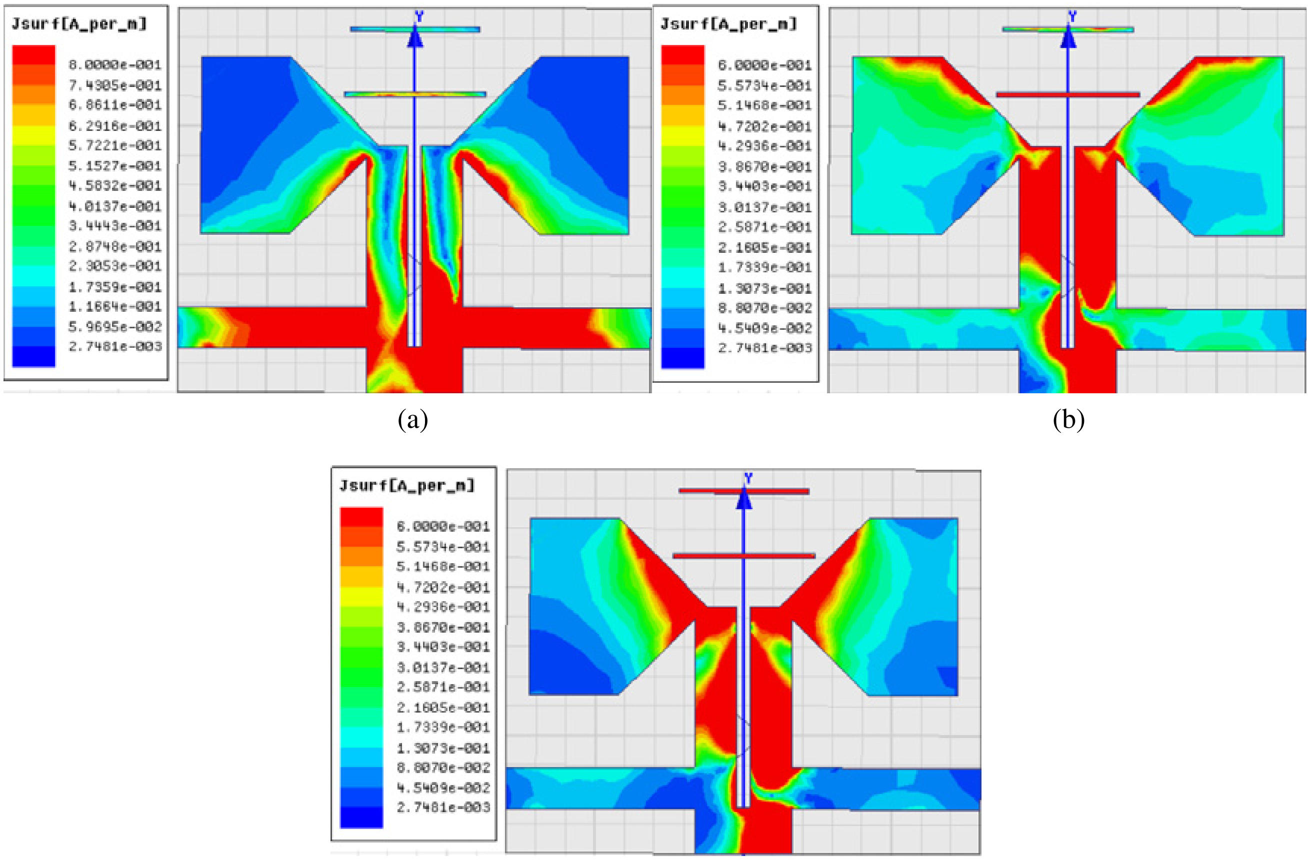
(b)

(c)

Figure 7. Measured normalized radiation patterns at (a) 2 GHz, (b) 3 GHz, and (c) 3.4 GHz.

Based on the measured results, it can be seen that the proposed quasi-Yagi antenna with a modified bow-tie driver can cover multi-bands for modern 3G/4G wireless communications. The advantages of the proposed antenna include:

(1) **Wide bandwidth**: The proposed antenna has a measured relative bandwidth of 80.4%, which is similar or wider when compared to other quasi-Yagi antennas. Table 3 lists the operating bands and relative bandwidths of some other quasi-Yagi antennas for comparison. It is also confirmed that general approaches for improving the bandwidth of bow-tie antennas are also feasible for quasi-Yagi antennas with bow-tie drivers, providing a new paradigm for designing wideband quasi-Yagi



(a) (b)

(c)

Figure 8. Simulated surface current distribution at (a) 2 GHz, (b) 3 GHz, and (c) 3.4 GHz.

Table 3. A comparison between this work and other quasi-Yagi antennas.

Antenna	**Operating Band (GHz)**	**Relative Bandwidth (%)**	**Dimension ($\lambda_{gc} \times \lambda_{gc}$)**
[4]	7.6–12	54	N/A (array)
[7]	6.2–18	98	N/A
[9]	3–4.8	46	1.51×1.46
(dual band)	6.1–10.8	58	
[10]	4.75–10.45	75	1.85×1.50
[15]	4.64–7.42	46	2.63×3.16
[16]	1.84–4.59	85.5	1.88×1.00
This work	1.45–3.4	80.4	1.24×0.94

antennas.

(2) **Suitable for 3G/4G applications:** The 10 dB return loss bandwidth of the proposed antenna is between 1.45 and 3.4 GHz, covering multi bands including the popular B2, B4, B25 and B41 for 3G UMTS/CDMA and 4G LTE/WIMAX technologies. In comparison, most of the antennas listed in Table 3 have their lowest operating frequencies > 3 GHz. The antenna in [16] has an operating band from 1.84 to 4.59 GHz and the relative bandwidth is 85.5%, but with a larger dimension.

(3) **Compact size**: The antenna was fabricated on the FR4 substrate with a dielectric constant of 4.2 and a size of $\sim 80\,\mathrm{mm} \times 65\,\mathrm{mm}$ ($W \times L$). The horn-shaped microstrip-to-slotline balun also reduces the size of the feeding structure when compared to other quasi-Yagi antennas [5]. The overall electrical size of the antenna is only $1.24\lambda_{gc} \times 0.94\lambda_{gc}$.

4. CONCLUSIONS

In this paper, a broadband and compact planar quasi-Yagi antenna is designed and verified experimentally. The proposed quasi-Yagi antenna uses a modified bow-tie shape as the driver to obtain a wider bandwidth. This antenna is fabricated on an FR4 substrate with a dielectric constant of 4.2 and has a final dimension of $80 \times 61\,\mathrm{mm}^2$. The measured 10 dB return loss bandwidth is about 80.4%, and the measured gains are greater than 4 dBi within the operating band between 1.45 and 3.4 GHz. High front-back ratios ($> 10\,\mathrm{dB}$) are also obtained. It is further confirmed that general approaches for improving the bandwidth of conventional bow-tie antennas are also feasible for quasi-Yagi antennas with bow-tie drivers.

Furthermore, the proposed antenna shows higher directivities and narrower 3 dB beamwidths as the operating frequency increases. As confirmed by the simulations of surface current distributions, this is in part because the bow-tie driver can form horn antenna structures, concentrating the electromagnetic energy within the bow-tie driver structure at high frequencies. Finally, the proposed antenna shows a similar or wider bandwidth compared to previous research work, and a compact size of only $1.24\lambda_{gc} \times 0.94\lambda_{gc}$. As this antenna can cover multi-bands for 3G UMTS/CDMA and 4G LTE/WIMAX technologies, it is expected to be used for 3G/4G mobile wireless communications.

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