A High-Gain Filtering Quasi-Yagi Antenna Based on Compressed Third-Order Mode Dipole

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***Abstract*—A high-gain filtering quasi-Yagi antenna based on compressed third-order mode dipole is presented in this paper. The meander line structure is employed on the dipole to realize the compressed dipole. The current distributions on the meander structure are equal amplitude and out-of-phase to cancel the far-field radiation to realize sidelobes suppression. An in-parallel grounded branch consisting of a bandstop filter and a grounded resistor is used to achieve filtering characteristics with four radiation nulls. The reflection coefficients of the bandstop filter are nearly complementary to that of the antenna to generate the radiation nulls. Moreover, directors are set in front of the dipole symmetrically to achieve a stable gain of the passband. To validate the feasibility of proposed antenna, a prototype is fabricated and measured. Good endfire characteristics are obtained with a bandwidth of 2.58 GHz to 2.82 GHz (8.8%), a peak gain of 9 dBi, sidelobe level (SLL) less than −19 dB, and out-of-band suppression larger than 14 dB. The measured results are in good agreement with the simulation.**

***Index Terms*—Compressed dipole, grounded branch, quasi-Yagi antenna, third-order mode.**

I. Introduction

With the rapid development of modern wireless communication systems, the requirement for high-performance antennas is increasing [1], [2]. The quasi-Yagi antenna has been widely used due to its low profile, low cost, lightweight and high directivity [3]. Furthermore, as the main radiator of quasi-Yagi antenna, the dipole plays a key role in the performance of the quasi-Yagi antenna, such as gain and radiation efficiency. If a dipole working in a higher-order mode, which has higher gain and higher radiation efficiency characteristics rather than the fundamental mode dipole, can be introduced, the performance of quasi-Yagi antenna can be significantly improved. However, the higher-order mode of dipole will cause high sidelobe level (SLL) in the radiation pattern, which is unacceptable in practical application. To enhance the directivity of higher-order mode dipole, the concept of compressed dipole is proposed in [4]. Inspired by this, some methods of compressed dipole are reported. In [5], spoof surface plasmon polaritons are used to realize the compression coefficient, but the structure is complex and limited SLL is achieved with only −0.5 dB. In [6], stubs are loaded on the dipole to realize a wider operating band composed of third-order and fifth-order modes, while the SLL is still limited to −6 dB. In [7], the third-order mode of a compressed dipole is obtained by employing a loop resonator, but the gain is 2 dBi, which limits its application. Although these works of compressed dipole can increase the gain and radiation efficiency, there are no reported works of compressed dipole used in quasi-Yagi antennas. Thus, it is important and interesting to study higher-order mode quasi-Yagi antenna with low SLL.

Moreover, with the increase of the electromagnetic environment complexity and the requirement of miniaturization of modern wireless communication systems, filter units are inevitable to suppress the interference. A filtering antenna is one of the good solutions to realize the system integration and filtering performance, and has concentrated extensive attention [8], [9]. Generally, the design methods of filtering quasi-Yagi antenna can be divided into the following three categories. First, cascading the antenna and filter units is a method, but this makes the structure larger and the insertion loss increases. For example, in [10], although the filtering function is implemented by integrating the filter unit in the slot line, which makes the structure complex, and the bandwidth is narrow, as well. The second method is treating the antenna radiator as the last-stage resonator of the filter [11], [12]. However, the large insertion loss and the occupied size of the filtering antennas are unavoidable. To avoid the drawback, the design method of filtering antennas exploits the intrinsic filtering characteristics of antennas. Nonetheless, structure and design complexities are increased, and huge fine-tuning works are required [13], [14], [15]. This design method of filtering antenna requires the applicability restricted by the antenna structure/configuration with the cost of high optimization effort [16].

In this letter, a high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole is proposed. Using the meander line on the dipole to compress the distribution of electricity of the dipole suppresses the SLL of the proposed antenna significantly with the level of −19 dB and improves the directivity simultaneously. To realize the filtering function, a grounded branch is added at the feed microstrip line, which

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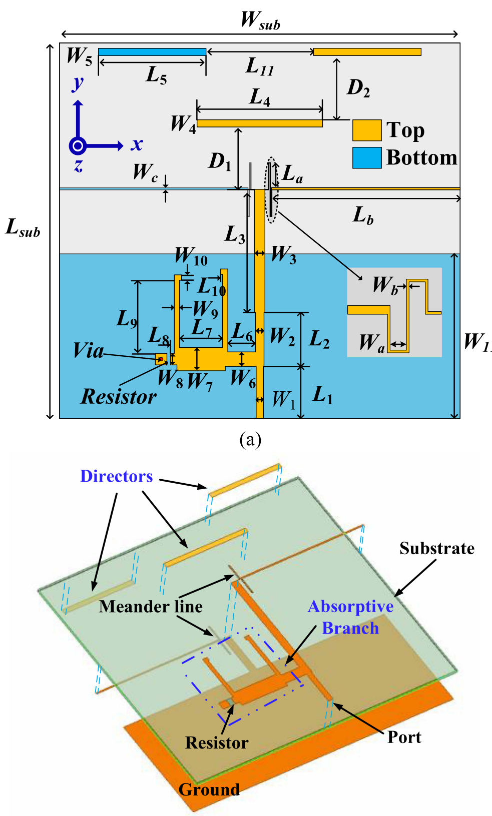

Fig. 1 Proposed structure of high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole, (a) top view, and (b) 3-D view.

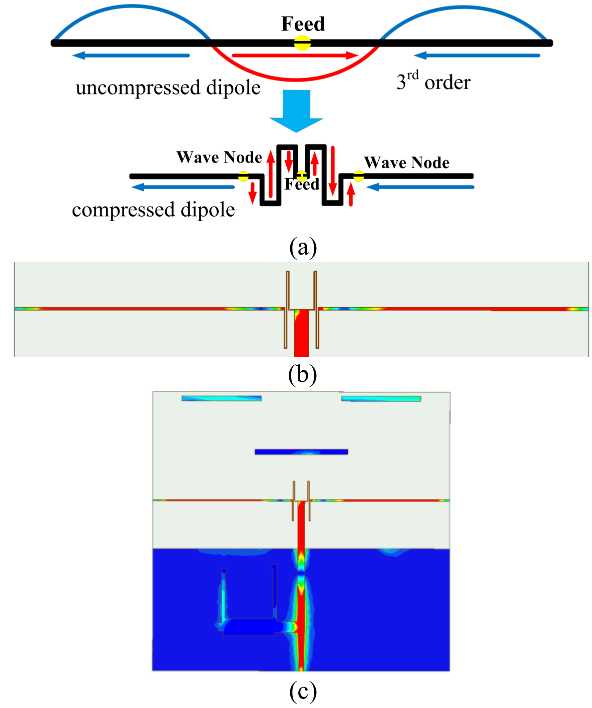

Fig. 2. Current distribution of third-order mode dipole: (a) comparison of current distribution on uncompressed and compressed, (b) current distribution on the dipole of proposed antenna, and (c) current distribution of proposed antenna.

realizes four radiation nulls at lower and upper stopbands and broadens the working bandwidth. Finally, directors are symmetrically added to achieve a higher and flatter gain.

The arrangement of this letter is as follows. Section II is the mechanism of the compressed dipole and the grounded branch of the proposed high gain filtering quasi-Yagi antenna with compressed third-order mode dipole. Section III gives the fabrication and experimental results of the proposed high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole. Finally, a conclusion is drawn in Section IV.

II. Design and Analysis of Filtering Quasi-Yagi Antenna With Compressed Third-Order Mode Dipole

To implement a compact high-gain endfire filtering antenna, a planar printed filtering quasi-Yagi antenna with compressed third-order mode dipole is proposed, which is shown in Fig. 1, and its configuration and operation mechanism are detailed as follows.

A. Antenna Configuration

Fig. 1 shows the configuration of the proposed planar printed high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole, which uses only one layer of Rogers5880 dielectric substrate with a permittivity of 2.2, loss tangent tanδ of 0.0009 and a thickness of 0.762 mm is used. The overall size of the substrate is 105 mm $\times$ 111.79 mm. As can be seen in Fig. 1, the proposed antenna includes the following parts: feed line, directors, driver dipole with meander-line and the grounded branch with bandstop characteristics, and the end of the branches connects a 50 Ω grounded resistor.

B. Mechanism of the Compressed Dipole

For the third-order mode of the dipole, the magnitude of the current along the dipole is cosine distributed, as shown in Fig. 2(a).

For an uncompressed dipole, the current on the middle region is out of phase with the current on either side, causing the large sidelobes of the radiation patterns. To overcome this problem, the meander lines are employed on the middle part of the dipole, which can be seen in Fig. 2(a). The length of the middle part is shorter than half the wavelength, which means that the compressed dipole is realized. On the other hand, the vector current directions on the meander structure are approximately equal amplitude and out of phase, and the radiation on the middle part of the dipole is canceled partially, so the sidelobes are suppressed by the meander-line structure. Fig. 2(b) and (c) is the current distribution of the proposed antenna at the center frequency, which proves the results of Fig. 2(a). To better demonstrate the benefits of a compressed third-order mode dipole compared to the uncompressed third-order dipole, Fig. 3(a) shows the radiation patterns (E-plane) of the proposed antenna with/without meander-line structure at the center frequency. It can be found from Fig. 3(a) that the sidelobes of the antenna are suppressed significantly when the meander-line structure is employed, which proves the advantages of the compressed third-order dipole.

Fig. 3(b) shows the effect of L_a on the radiation pattern of the proposed antenna at the frequency of f_0. It can be found that as the value of L_a increases from 7 mm to 7.46 mm, the SLL of the radiation pattern decreases from -18.7 dB to -25 dB, which means that the compressed dipole can suppress the SLL of the

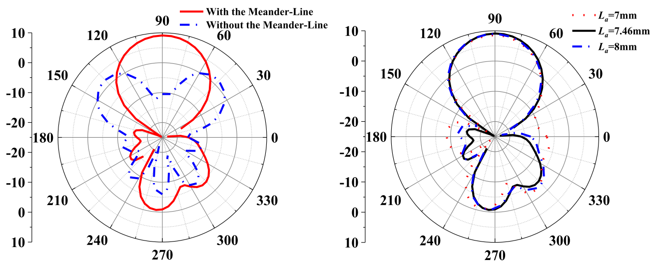

Fig. 3. Effects of the meander-line structure on the radiation patterns (E plane): (a) with/without the meander-line and (b) parameter L_a.

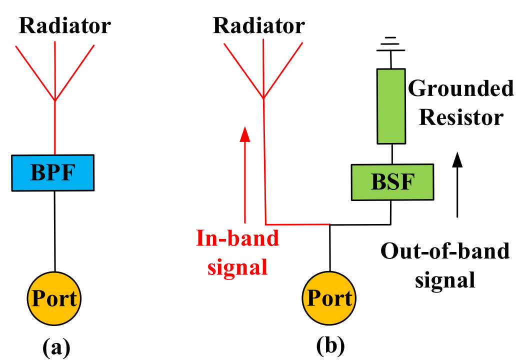

Fig. 4. Principle of designing filtering antenna: (a) traditional method and (b) proposed filtering antenna principle.

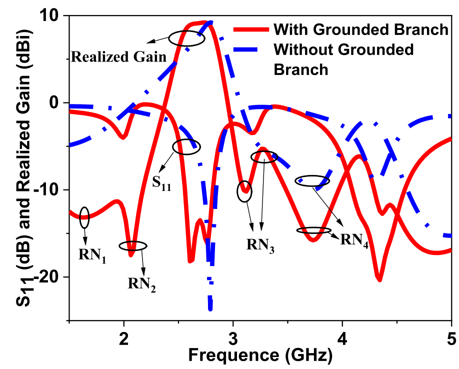

Fig. 5. Simulation results of S_{11} and realized gain with/without absorptive branch.

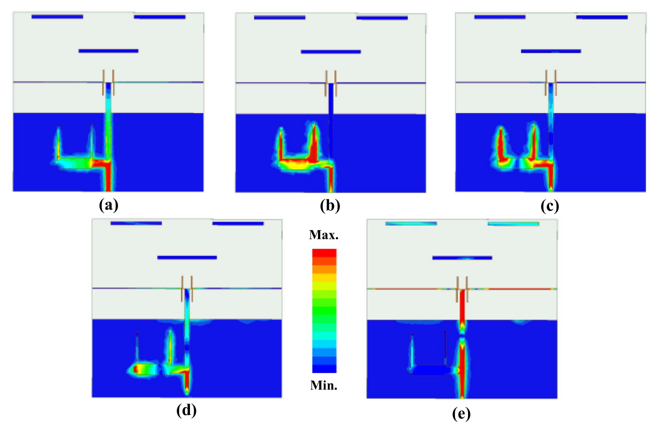

Fig. 6. Current distribution of proposed antenna at the frequencies of (a) RN_1, (b) RN_2, (c) RN_3, (d) RN_4, and (d) f_0.

radiation pattern. However, when its value continues to increase to 8 mm, the SLL increases to −21.6 dB. Therefore, the value of L_a can be used to guarantee low SLL.

C. Mechanism of the Radiation Nulls

To enhance the working bandwidth and realize the filtering response with multiple radiation nulls, a grounded branch with bandstop performance is employed, and its mechanism for designing the filtering antenna can be clarified in Fig. 4.

In the traditional design, a bandpass unit is cascaded with the antenna to realize the filtering function, as shown in Fig. 4(a). However, the structure of cascading a bandpass filter is large, and the insertion loss is also introduced to affect the performance of the antenna. To avoid the potential drawback, the topology of the proposed filtering method is proposed, as shown in Fig. 4(b). Compared with the traditional method in Fig. 4(a), a grounded branch, which consists of a bandstop filtering network and a grounded resistor, is parallel employed at the microstrip feedline. The reflection coefficients between the antenna and the bandstop filter are complementary, which means that the frequency range of the passband of the antenna is that of the stopband of the bandstop filter. Therefore, the out-of-band energy will be bypassed to the grounded branch to realize radiation nulls on the lower and upper stopband of the antenna to introduce filtering characteristics, while the in-band energy flows directly to the dipole without the influence of the branch. By this means, the insertion loss is not introduced because the bandstop filter works outside of the passband of the antenna. It is worth mentioning that the size of the antenna does not get larger when employing the grounded branch.

Fig. 5 depicts the simulated results of the proposed high gain filtering quasi-Yagi antenna with compressed third-order dipole with/without the grounded branch. Due to the grounded branch, a new resonance mode at 2.6 GHz is generated in the passband, two new radiation nulls of RN_1 and RN_2 at 1.64 GHz and 2.06 GHz on the lower stopband are generated, and the rejections of two radiation nulls of RN_3 and RN_4 at 3.12 GHz and 3.73 GHz on the upper stopband are improved. The new resonance mode generated by the grounded branch broadens the bandwidth of the proposed antenna. Excellent out-of-band suppression of more than 14.5 dB is obtained due to the four radiation nulls realized by the grounded branch. To gain further insight into the mechanism of the grounded branch, Fig. 6 shows the simulated current distribution of the proposed antenna at the frequencies of RN_1, RN_2, RN_3, RN_4, and f_0. It can be seen that the current distribution of the grounded branch is strong at the frequencies of radiation nulls while it is weak at f_0.

III. Fabrication and Measurement Results

In order to validate the feasibility of the design, the proposed high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole is fabricated and measured, and the final parameters of proposed third-order mode filtering quasi-Yagi antenna with compressed dipole are as follows: $L_{sub} = 105$, $W_{sub} = 111.79$, $L_1 = 14.52$, $L_2 = 15.07$, $L_3 = 34.43$, $L_4 = 35$, $L_5 = 30$, $L_6 = 7.78$, $L_7 = 12$, $L_8 = 1.09$, $L_9 = 20.5$, $L_{10} = 0.55$, $L_{11} = 30$, $L_a = 7.46$, $L_b = 52.5$, $W_1 = 2.01$, $W_2 = 2.33$, W_3

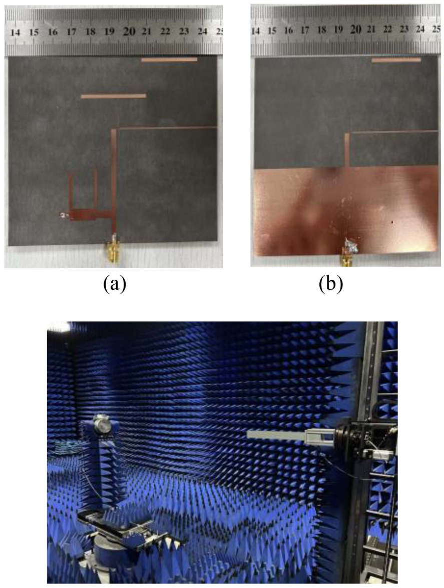

Fig. 7. Photograph of (a) top view and (b) bottom view of fabricated third-order mode filtering quasi-Yagi antenna with a compressed dipole and (c) measurement.

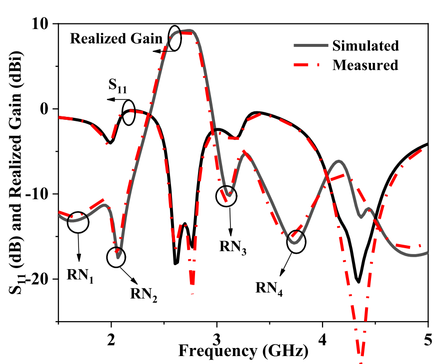

Fig. 8. Measured and simulated S_{11} and realized gain of proposed third-order mode filtering quasi-Yagi antenna.

$= 2.83$, $W_4 = 2$, $W_5 = 2$, $W_6 = 4$, $W_7 = 6.5$, $W_8 = 3.2$, $W_9 = 1.45$, $W_{10} = 1.45$, $W_{11} = 46$, $W_a = 0.3$, $W_b = 0.13$, $W_c = 0.6$ (Unit: mm).

The photograph of the proposed third-order mode filtering quasi-Yagi antenna with a compressed dipole is shown in Fig. 7; the measured and simulated results are plotted in Fig. 8. As can be seen in Fig. 8, the measured results show that the reflection coefficient S_{11} is less than -10 dB from 2.58 GHz to 2.82 GHz, i.e., the bandwidth is 8.8%. Moreover, the in-band realized gain is from 8.7 dBi to 9 dBi. Additionally, a good out-of-band suppression with more than 14 dB is also achieved. Fig. 9 shows the radiation patterns of the proposed antenna in the E-(*XOY*) and H-(*YOZ*) planes at the frequencies of 2.60 GHz and 2.76 GHz, respectively. It can be seen that good endfire characteristics are obtained, and the sidelobes are well suppressed with less than -19 dB. The measured cross-polarization levels are less than -17 dB and -9 dB in the E-plane and H-plane, respectively, over the whole passband, which means that low cross-polarization is achieved.

In order to further illustrate the advantages of the proposed antenna, in Table I, we compare the performance of the proposed antenna and other reported antennas in terms of gain, out-of-band suppression, SLL, etc. It can be found that the proposed filtering quasi-Yagi antenna with compressed third-order mode dipole has excellent sidelobes suppression ability with good out-of-band suppression, and high gain.

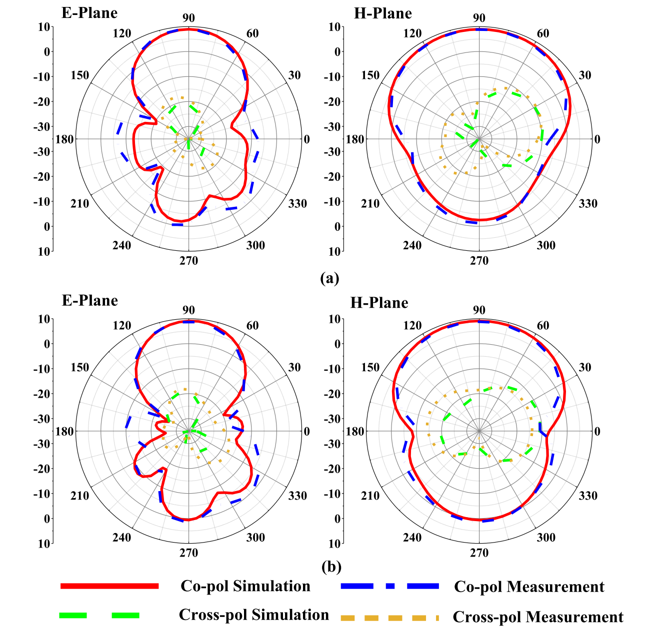

Fig. 9. Radiation patterns at the frequencies of (a) 2.60 GHz and (b) 2.76 GHz.

TABLE I
COMPARISON OF THE PROPOSED ANTENNA WITH SOME EXISTING WORKS

Ref.	Type	P. G. (dBi)	SLL (dB)	Sup. (dB)	Nulls	R.O.R (dB/GHz)	Size (λ_0^2)
[6]	Omn.	4	-8	N.A.	N.A.	N.A.	0.83×1.03
[17]	Omn.	4.7	-15.4	N.A.	N.A.	N.A.	1.02×1.1
[18]	Omn.	3.7	-11	N.A.	N.A.	N.A.	1.1×1.1
[9]	E. F.	7.3	N.A.	15	4	72/60	0.99×0.85
[11]	E. F.	5.8	N.A.	12	0	N.A.	0.76×0.44
[13]	E. F.	4.7	N.A.	9	2	60/44	1.3×0.65
This work	E. F.	9	-19	14	4	51/89	0.99×1.17

IV. CONCLUSION

In this letter, a high-gain filtering quasi-Yagi antenna with compressed third-order mode dipole is proposed. By placing the middle part of the third-order mode dipole using the meander-line structure, the compressed dipole is realized. The current distributions on the meander structure are equal in amplitude and out-of-phase to cancel the far-field radiation partially to realize sidelobes suppression. By employing a grounded branch composed of a bandstop filter and a grounded resistor in parallel, excellent filtering characteristics with four radiation nulls are obtained. The in-band and out-of-band energy can be divided by the bandstop filter, whose reflection coefficients are complementary to the antenna, and four radiation nulls can be generated to improve the out-of-band suppression of the proposed antenna. Unlike the traditional method of cascading bandpass filters, the insertion loss is not introduced in the proposed method. The proposed antenna is fabricated and measured, and the measured and simulated results agree well.

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