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

Daotong Li, Senior Member, IEEE, Chen Yang, Linsong Shi, Ying Liu, Qiang Chen, Senior Member, IEEE and Naoki Shinohara, Senior Member, IEEE

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 end-fire characteristics are obtained with bandwidth of 2.58 to 2.82 GHz (8.8%), peak gain of 9 dBi, Sidelobe level (SLL) less than -19 dB and the out-of-band suppression larger than 14 dB. The measured results are in good agreement with the simulation.

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

I. INTRODUCTION

W ITH the rapid development of modern wireless communication system, 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, light weight and high directivity [3]. Furthermore, as the main radiator of quasi-Yagi antenna, dipole plays the key role in the performance of the quasi-Yagi antenna, such as gain and radiation efficiency. If a dipole working 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 SLL in the radiation pattern, which is unacceptable in practical application. To enhance the

This work was supported in part by the FY2021 JSPS Postdoctoral Fellowship for Research in Japan under Grant P21053, in part by the National Natural Science Foundation of China under Grant 61801059, and in part by the Grant-in-Aid for JSPS Research Fellow under Grant 21F21053, in part by the Basic Research and Frontier Exploration Special of Chongqing Natural Science Foundation under Grant cstc2019jcyj-msxmX0350.

Daotong Li, Chen Yang, Ying Liu and Lisheng Yang are with School of Microelectronics and Communication Engineering, Chongqing University, Chongqing 400044, China (e-mail: dli@cqu.edu.cn).

Daotong Li and Naoki Shinohara are with the Research Institute for Sustainable Humanosphere, Kyoto University, Kyoto 606-8501, Japan.

Daotong Li and Qiang Chen are with the Department of Communications Engineering, Tohoku University, Sendai 980-8579, Japan. 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], third-order mode of compressed dipole is obtained by employing 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.

1

Moreover, as the increase of the electromagnetic environment complexity and the requirement of miniaturization of modern wireless communication system, filter units are inevitable to suppress the interference. 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. Firstly, 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 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 is that exploiting the intrinsic filtering characteristics of antennas. Nonetheless, structure and design complexities are increased, and huge fine tuning works are required [13]-[15]. And 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 paper, a high gain filtering quasi-Yagi antenna with compressed third-order mode dipole is proposed. By using meander line on the dipole to compress the distribution of electricity of the dipole, which suppresses the SLL of the proposed antenna significantly with the level of -19 dB and improve the directivity simultaneously. To realize the filtering function, a grounded branch is added at the feed microstrip line,

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

The arrangement of this paper is as follows. Section II is the mechanism of compressed dipole and the grounded branch of 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, 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 end-fire 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 Proposed structure of high gain filtering quasi-Yagi antenna with compressed third-order mode dipole, (a) top view, and (b) 3D view

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 tan δ of 0.0009 and a thickness of 0.762mm is used. The overall size of the substrate is $105 \times 111.79 \text{ mm}^2$. 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.

2

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).



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, (c)current distribution of proposed antenna



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

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.

This article has been accepted for publication in IEEE Antennas and Wireless Propagation Letters. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/LAWP.2024.3409748

2(a). To better demonstrate the benefits of 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 to 7.46mm, 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 radiation pattern. However, when its value continues increase to 8mm, 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 on the designing filtering antenna can be clarified as Fig. 4.



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

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 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.



3

Fig. 5 Simulation results of S_{11} and realized gain with/without absorptive 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 2.6GHz is generated in the passband, two new radiation nulls of RN1 and RN2 at 1.64 and 2.06 GHz on the lower stopband are generated, and the rejections of two radiation nulls of RN₃ and RN₄ at 3.12 and 3.73 GHz on the upper stopband are improved. The new resonance mode generated by the grounded branch broaden 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 .



Fig. 6 Current distribution of proposed antenna at the frequencies of, (a)RN₁, (b)RN₂, (c)RN₃, (d)RN₄, (d) 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: $L_{sub}=105, W_{sub}=111.79, L_1=14.52, L_2=15.07, L_3=34.43, L_4=35, L_5=30, L_6=7.78, L_7=12, L_8=1.09, L_9=20.5, L_{10}=0.55, L_{11}=30, L_a=7.46, L_b=52.5, W_1=2.01, W_2=2.33, W_3=2.83, W_4=2, W_5=2, W_6=4, W_7=6.5, W_8=3.2, W_9=1.45, W_{10}=1.45, W_{11}=46, W_a=0.3,$

This article has been accepted for publication in IEEE Antennas and Wireless Propagation Letters. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/LAWP.2024.3409748

> REPLACE THIS LINE WITH YOUR PAPER IDENTIFICATION NUMBER (DOUBLE-CLICK HERE TO EDIT) <

*W*_b=0.13, *W*_c=0.6 (Unit: mm).

The photograph of proposed third-order mode filtering quasi-Yagi antenna with 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 S₁₁ is less than -10 dB from 2.58 to 2.82 GHz, i.e., the bandwidth is 8.8%. Moreover, the in-band realized gain is from 8.7 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 proposed antenna in the E (XOY) and H (YOZ) planes at the frequencies of 2.60 and 2.76 GHz, respectively. It can be seen that good end-fire characteristics are obtained and the sidelobes are well suppressed with less than -19 dB. The measured cross-polarization levels are less than -17 and -9 dB in the E-plane and H-plane, respectively, over the whole passband, which means that low cross-polarization is achieved.



(c)

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



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

In order to further illustrate the advantages of the proposed antenna, in Table I, we compare the performance between the proposed antenna and other reported antennas in the 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.

4



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

COMPARISON OF THE I ROPOSED ANTENNA WITH SOME EXISTING WORKS							
Ref.	Туре	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

Ref.: References, Omn.: Omnidirectional, E.F.: End-fire, P.G.: Peak Gain, SLL: Sidelobe Level, Sup.: Suppression, R.O.R.: Roll-off Rate, equal to the gain difference between passband edge and nearest radiation null divided by the frequency difference, $|(G_{edge}-G_{null})/(f_{edge}-f_{null})$, N.A.: Not Available

IV. CONCLUSION

In this paper, 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 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.

5

References

- D. Li, L. Shi, J. Wang, Y. Liu and Q. Chen, "High-Gain Wideband Dielectric Resonator Antenna Based on Semi-Cylindrical Grooved Structure," *IEEE Transactions on Circuits and Systems II: Express Briefs*, Early Access.
- [2] N. -W. Liu, L. Zhu, Z. -X. Liu and Y. Liu, "Dual-Band Single-Layer Microstrip Patch Antenna With Enhanced Bandwidth and Beamwidth Based on Reshaped Multiresonant Modes," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 11, pp. 7127-7132, Nov. 2019
- [3] D. Li, C. Yang, Y. Liu, L. Yang and Q. Chen, "Planar Printed Wideband Filtering Quasi-Yagi Antenna and Its Notch-Band Design Using Parasitic Elements for Vehicular Communication," *IEEE Transactions on Vehicular Technology*, Early Access.
- [4] Y. Luo and Z. N. Chen, "Compressed Dipoles Resonating at Higher Order Modes With Enhanced Directivity," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 11, pp. 5697-5701, Nov. 2017.
- [5] Y. Yang, Z. Li, S. Wang, X. Chen, J. Wang and Y. J. Guo, "Miniaturized High-Order-Mode Dipole Antennas Based on Spoof Surface Plasmon Polaritons," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 12, pp. 2409-2413, Dec. 2018.
- [6] Y. Luo, Z. N. Chen and K. Ma, "Enhanced Bandwidth and Directivity of a Dual-Mode Compressed High-Order Mode Stub-Loaded Dipole Using Characteristic Mode Analysis," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 1922-1925, March 2019.
- [7] W. Zhang, Y. Li, Z. Zhou and Z. Zhang, "Dual-Mode Compression of Dipole Antenna by Loading Electrically Small Loop Resonator," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 4, pp. 3243-3247, April 2020.
- [8] W. Wang, C. Chen, S. Wang and W. Wu, "Circularly Polarized Patch Antenna With Filtering Performance Using Polarization Isolation and Dispersive Delay Line," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 8, pp. 1457-1461, Aug. 2020.
- [9] C. Chen, "A Compact Wideband Endfire Filtering Antenna Inspired by a Uniplanar Microstrip Antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 21, no. 4, pp. 853-857, April 2022.
- [10] F. Wei, X. -B. Zhao and X. W. Shi, "A Balanced Filtering Quasi-Yagi Antenna With Low Cross-Polarization Levels and High Common-Mode Suppression," *IEEE Access*, vol. 7, pp. 100113-100119, 2019.
- [11] J. Shi, X. Wu, Z. N. Chen, X. Qing, L. Lin, J. Chen, Z. H. Bao, "A Compact Differential Filtering Quasi-Yagi Antenna With High Frequency Selectivity and Low Cross-Polarization Levels," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1573-1576, 2015.
- [12] J. Zang, X. Wang, A. Alvarez-Melcon and J. S. Gomez-Diaz, "Nonreciprocal Yagi–Uda Filtering Antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 12, pp. 2661-2665, Dec. 2019.
- [13] S. Wang, F. Fan, R. G. García, L. Yang, Y. Li, S. W. Wong, G. Zhang, "A Planar Absorptive-Branch-Loaded Quasi-Yagi Antenna With Filtering Capability and Flat Gain," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 9, pp. 1626-1630, Sept. 2021.
- [14] Y.-H. Ke, L. -L. Yang, Y.-Y. Zhu, J. Wang and J. -X. Chen, "Filtering Quasi-Yagi Strip-Loaded DRR Antenna With Enhanced Gain and Selectivity by Metamaterial," *IEEE Access*, vol. 9, pp. 31755-31761, 2021.
- [15] H. U. Bong, M. Jeong, N. Hussain, S. Y. Rhee, S. K. Gil, and N. Kim, "Design of an UWB antenna with two slits for 5G/wlan-notched bands," *Microwave and Optical Technology Letters*, vol. 61, no. 5, pp. 1295– 1300, 2019.
- [16] G. Liu, Y. M. Pan, T. L. Wu and P. F. Hu, "A Compact Planar Quasi-Yagi Antenna With Bandpass Filtering Response," *IEEE Access*, vol. 7, pp. 67856-67862, 2019.
- [17] Y. Luo, N. Zhang, Z. N. Chen, W. An, K. Ma and Q. -X. Chu, "A Nonuniform Compressed High-Order Mode Dipole With Sidelobe Suppression," *IEEE Antennas and Wireless Propagation Letters*, vol. 21, no. 12, pp. 2372-2376, Dec. 2022.
- [18] Y. Luo, X. Ma, N. Yan, W. An and K. Ma, "Sidelobe Suppression of Dual-Mode Compressed High-Order-Mode Dipole by Loading Bent Stubs," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 6, pp. 898-902, June 2021.