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A Filtering Dipole Antenna Design with Bandwidth Enhancement for 5G

Feza Turgay Çelik*, Sulayman Joof†, Kamil Karaçuha‡,
Department of Microelectronics, Delft University of Technology, Delft, Netherlands, F.T.Celik@tudelft.nl
†Department of Communication Systems, Istanbul Technical University, Istanbul, Türkiye
‡Department of Electrical Engineering, Istanbul Technical University, Istanbul, Türkiye

***Abstract*—The present study proposes a dipole filtering antenna with wide-band characteristics for communication. The filtering is achieved by employing parasitic elements and wide-band characteristic is obtained by reshaping the dipole and using specially designed balun structure. One radiation null is optimized at the higher frequency band limit for sharp transition from pass band to stop band via two half-rectangular ring resonators. The antenna operates between 2.6 and 5 GHz and has maximum realized gain of 8.39 dBi. The $|S_{11}|$ is less than -10 dB in the operating frequency band. The simulation results and evolution of the design procedure are presented.**

***Index Terms*—broadband antenna, enhanced dipole antenna, filtering antenna, telecommunication**

I. Introduction

For the last decades, the wireless communication and its products have been evolving drastically. The connectivity demands on human-to-human and machine-to-human interactions are getting common in humans daily life [1], [2]. For numerous electronic devices and services such as mobile phones, personal computers, global positing system, Wi-Fi and Bluetooth, the antenna and filtering circuit elements are utilized for operational purposes. To have a compact and modular single component, filtering antennas can be used as a replacement for the same operational purpose. Recently, there are huge numbers of studies regarding the design of the filtering antennas [3]–[9]. The studies utilize vast number of approaches in the corresponding designs. In general, the aim is to enhance the bandwidth and to sharpen the frequency response by generating radiation nulls at the limits of the bandwidth. In [3], a coupled line, two square open-loop resonators, and a Γ-shaped antenna elements are employed for filtering and radiating purposes. Secondly, in [4], two radiation nulls were generated by parasitic loops and radiation was achieved by the specifically designed dipole. Apart from the previous studies, common-mode suppression was employed in [5] where tunable bandwidth and sharp filtering were obtained by pin diode and stub loaded resonator, respectively. To enhance the bandwidth of the antenna design, [6] utilizes complementary split ring resonators providing the radiation null at the lower band of the operating bandwidth whereas layered circular patches in the design leads to having another radiation null at the upper bound. In [7], the dual polarized simple two dipoles with U-shaped parasitic element were proposed. The radiation nulls are created by the phenomenon based on the current cancelling for radiation nulls. Finally, [8] proposes a compact wide-band filtering dipole antenna suppressing out-of-band signals in which lumped elements and folded parasitic dipoles are employed. Our approach is differentiated by broadband design of the antenna element and placing the appropriate parasitic element on it. The wideband design of the antenna and the fact that the radiation nulls are achieved with small and efficient parasitic elements make this unit cell suitable for array topologies. However, other studies have generally tried to make wide bandwidth characteristics by incorporating different elements or employing different physical phenomena into the design.

Consecutive sections covers the design and numerical results including the antenna configuration, filtering and balun structures. After that, the conclusion is drawn.

II. Dipole Filtering Antenna Design

In this section, design details and the working principles of the antenna and balun structures are explained.

A. The Antenna Configuration

The present study proposes a printed dipole antenna design by evolving a regular printed dipole antenna structure [10]. The primary printed dipole antenna is selected as the starting point of the design, whose structure can be summarized as one of its arms lying below the substrate while the other arm is located on the upper side of the substrate. This type of design is beneficial as it provides an easy feeding structure since the printed two-wire feeding network for the dipole can be employed as it provides balanced feeding without employing any balun structure [10]. However, this dipole antenna type is improper for several scenarios such as 5G base station applications and medical imaging. Base station antennas employ a large ground plate beneath the antenna layer to provide more significant gain, so the arms of printed dipoles must be located at the same layer. Although both arms of the dipole can be printed on the same layer, the feeding structure becomes more challenging as it requires a balun structure for such case [11]. In our design, we evolved a simple dipole antenna into the filtering dipole antenna. Fig. 1 shows the top view of those antennas.

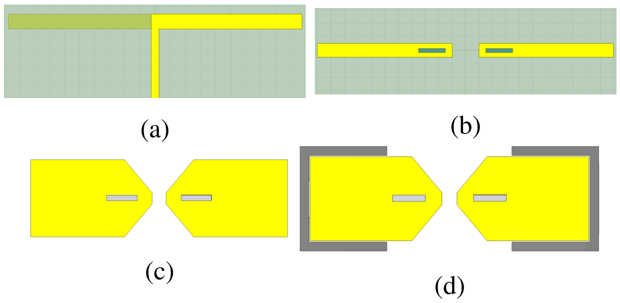

Fig. 1: Top views of the (a) Antenna A, (b) Antenna B, (c)Antenna C and (d) Antenna D.

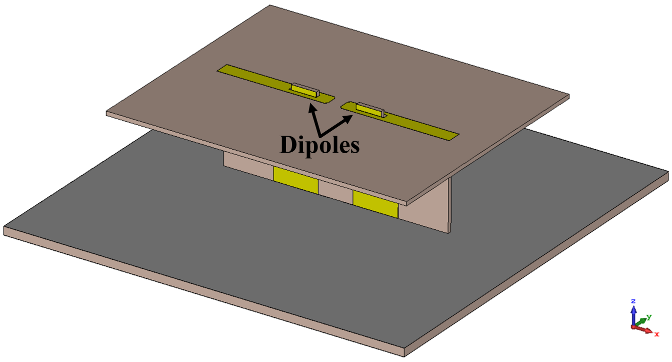

Fig. 2: The geometry of Antenna B.

In this work, Antenna A is considered as the classic printed dipole antenna with impedance bandwidth of 15% given in [10]. In order to have a dipole antenna printed on one layer, we initially begin with a single layer design as depicted in Fig. 2 named Antenna B. Antenna B has an impedance bandwidth of 15.65%. Since one of the aim of this study is to improve the impedance of the antenna, the shape of the dipole is altered as shown in Fig. 1(c) and Fig. 3(a) termed as Antenna C. The bandwidth enhancement is provided by defining alternative surface current paths on the antenna [9]. The currents on the dipole originate from the feeding point and flow till the end of the antenna. By increasing the width of the antenna, alternative current paths are created. This current paths can be observed in Fig. 3(b).

The ultimate goal is to introduce a filtering property to the characteristics of Antenna C, which is achieved by using parasitic elements. The comprehensive view of the final proposed antenna named Antenna D and the configuration of its top view are depicted in Fig. 4 and Fig. 5(a), respectively. The antenna configuration also composed of a ground reflector and a balun structure (see Fig. 5(b) and 5(c)) to feed the dipoles. The working principle of the balun is similar to one described in [12]. It consists of a Γ-shaped microstrip line which is printed on the feed side, a shorted stub and a slot line which is created by the two patches printed on the ground side of the balun substrate. The dipole is excited by the slot line which is coupled by the Γ-shaped microstrip line at the feed

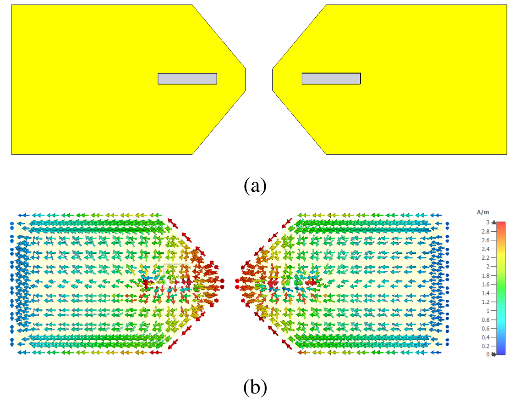

Fig. 3: Top-view and Surface current of dipoles (Antenna C) without passive elements. (a) Top-view of dipole. (b Surface current of dipoles without the passive elements at 3.6 GHz.

TABLE I: Dimensions of the proposed antenna

Parameter	Value(mm)	Parameter	Value(mm)
G1	2.5	W2	5
G2	0.2	W3	13
L1	14	W4	4
L2	1.5	W5	8
L3	2	W6	4
L4	17	W7	7
L5	3	W8	14
L6	4	W9	6.5
L7	5	W10	8
L8	5	W11	5
L9	3.5	W12	3.9
L10	1.81	W13	45
L11	12.40	W14	10
L12	2	W15	12
L13	1.3	W16	0.2
L14	0.3	W17	1.2
Rw	80	W18	1
Ws	60	θ(deg)	45
W1	16.97		

point. In order to ensure the machining accuracy and structure stability, two bumps are created on the edges of the balun to be inserted into the substrate of the dipole. Moreover, a 50Ω SMA connector is connected to feed line to obtain a more realistic simulation. By selecting appropriate geometric parameters, the antenna element is able to exhibit good wideband performance. Optimized values for the geometric parameters of the final antenna configuration are tabulated in Table I. Note that the both the dipole and Balun where printed on a Rogers 4003 substrate, with relative permittivity and thickness of 3.55 and 0.8 mm, respectively. While the ground reflector is printed on a double sided FR-4 material with relative permittivity 4.6 and thickness of 1.6 mm. The simulations were performed with CST Microwave Studio. More information on the evolution of the antenna are provided in the following paragraphs.

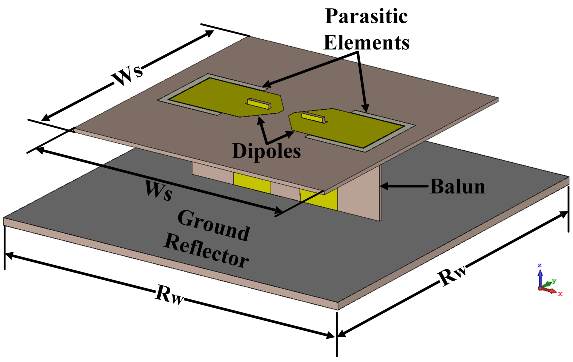

Fig. 4: Final configuration of the proposed dipole filtering antenna (Antenna D).

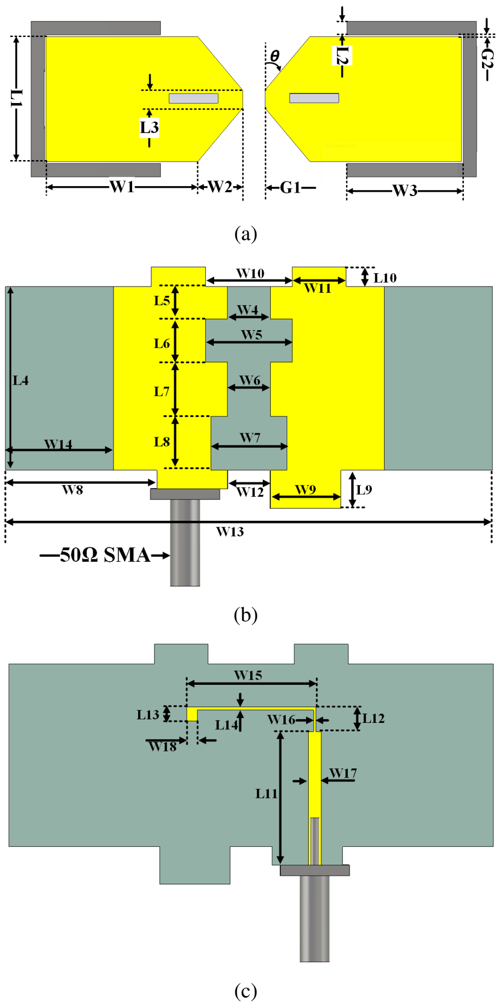

Fig. 5: Configuration of the dipole and balun. (a) Dipole with passive elements (b) Ground side of balun (c) feed side of balun.

B. Effect of the Parameters (L1, G1, and θ) on the Performance of the Antenna

The broadband dipole antenna has several essential parameters that determine the impedance bandwidth of the design.

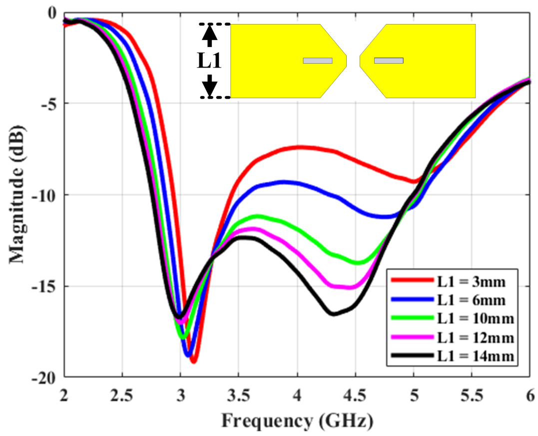

Fig. 6: Effect of L1 on the $|S_{11}|$ parameter of the dipole antenna (L = 14mm bandwidth = %57.73).

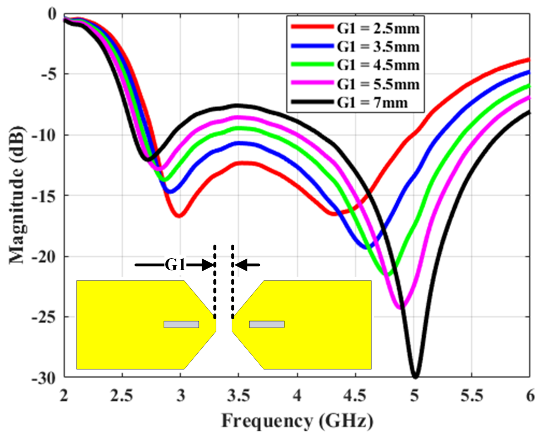

Fig. 7: Effect of G1 on the $|S_{11}|$ parameter of the dipole antenna.

These parameters are the width of the element (L1), the gap between antenna arms (G1), and the flare angle of the antenna element (θ). These essential parameters are studied parametrically, and observations are drawn in the present subsection. The parametric studies of the related variables are provided in Figs. 6, 7, 8.

As stated previously, the width of the antenna has a significant effect on the antenna's bandwidth. Fig. 6 illustrates the S parameters of the antenna with different L1 values. When the width increases, the S parameters of the antenna perform better. However, there is a limit on the width of the antenna. Although the S parameters decrease when the antenna is enlarged after some length, two resonance points seen in Figure 6 starts to yield different radiation pattern. Therefore, the value of the L1 is determined by observing the radiation pattern shape within the band.

The dipole antenna is very special as it excites half the period of sinusoidal current on it. This specific current distribution requires a current maximum at the middle point of the

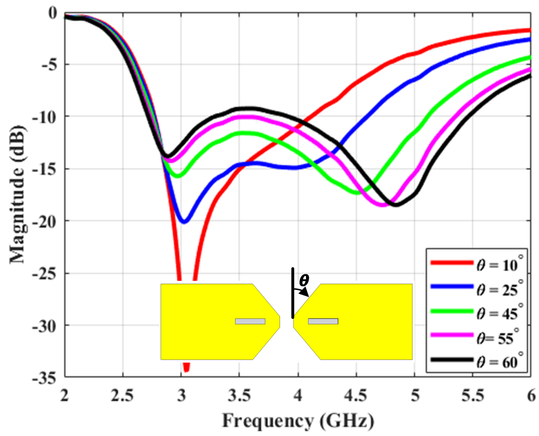

Fig. 8: Effect of θ on the $|S_{11}|$ parameter of the dipole antenna.

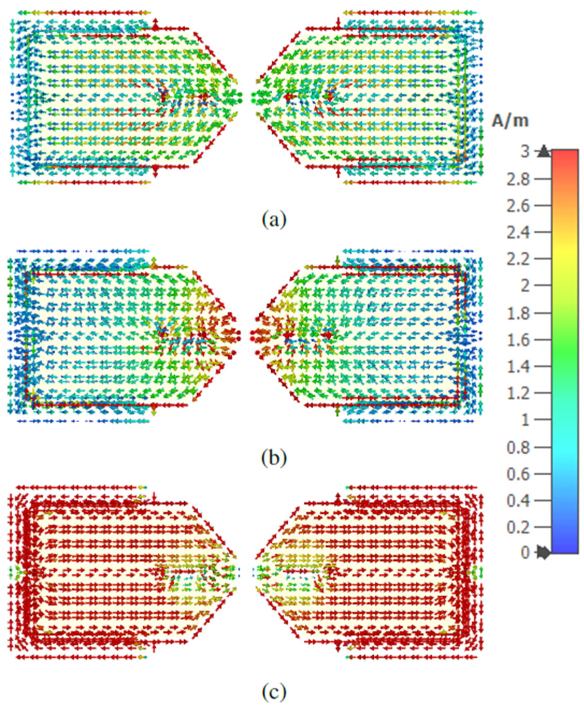

Fig. 9: Surface current of dipoles with passive elements at (a) 2.6 GHz (b) 3.6 GHz (c) 5 GHz.

structure. This behavior is distorted by adding a gap between the dipole arms. As shown in Fig. 7, when a gap is introduced between elements, S parameters are distorted, and the antenna is transformed into two separate radiators (case $G1 = 7mm$). To preserve dipole operation, the gap should be kept as small as possible.

Lastly, one should focus on the flaring angle of the dipole arms. A sizeable flaring angle defines the shortest path of the surface current distribution. Therefore, it defines the limit of the high-frequency operating point. As the flare angle increases, the antenna experience sharp passage to its sides and thus has a smaller current path. Consequently, an antenna having a larger flare angle also operates at higher frequencies. Apart from the maximum resonating frequency, the flaring angle impacts the input impedance in general since the flare angle increases the capacitive load on the antenna. This load compensates for the inductive part of the input impedance due to the length of the antenna which yields a broader bandwidth [9].

C. Filtering Dipole

In modern communication systems, preventing interference due to adjacent frequency bands can be realized by filtering structures. In this design, we want to integrate the filtering property of a communication link into the antenna structure. The main goal of the design is to obtain a sharp reflection coefficient change to suppress signals at the following frequency band. This filtering effect is utilized by adding parasitic components close to the printed broadband dipole structures. In Fig. 5, the top view and feeding structure of the designed 'filtering antenna' is provided. In the figure, grey parts denote parasitic parts, while yellow represents radiating structures. In Antenna D, $|S_{11}|$ parameter of the antenna at the upper end of its operating frequency can be changed abruptly. This filtering effect is introduced by the parasitic element that covers the dipole. The filtering of this parasitic part can be explained by investigating the surface current distributions seen in Fig. 9.

In the corresponding figure, the surface current of Antenna D at different frequencies can be seen. At all frequencies, the net surface current direction is opposite for radiating patch and parasitic element. For low-frequency applications, the surface current induced on the parasitic element is negligible compared to the ones excited on the radiator, as seen in Fig. 9. However, when the operating frequency increases, the surface current on the parasitic elements becomes more pronounced. As the induced current on the parasitic element gets more robust, it affects antenna performance. In other words, the current on the parasitic elements and the current on the dipole cancel each other and they create a radiation null at a specific frequency. At this specific frequency point, the antenna's parasitic part is induced heavily to yield a resonance point. This resonance makes a sharp change in the impedance and S-Parameter of the antenna, creating a filtering effect. Because the resonance of the parasitic element creates the filtering effect, the filtering frequency is determined by the dimensions of the parasitic element. The gap between the parasitic element and dipole (G2) and the length of the parasitic element (W3) play an essential role in the filtering frequency. To be able to excite parasitic elements, gap G2 should be chosen to be as small as possible. Due to manufacturing considerations, the G2 value is chosen as 0.2 mm in this design. The effect of another critical parasitic element parameter, namely the length of W3, can be seen in Fig. 10. As shown in Fig. 10, increasing the length of the parasitic element decreases the filtering frequency. The shorter parasitic element length

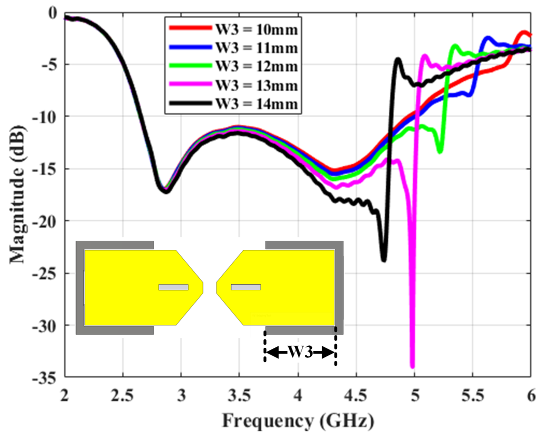

Fig. 10: Effect of passive and W3 on the $|S_{11}|$ parameter of the dipole antenna. (W3=13mm bandwidth 61.44%)

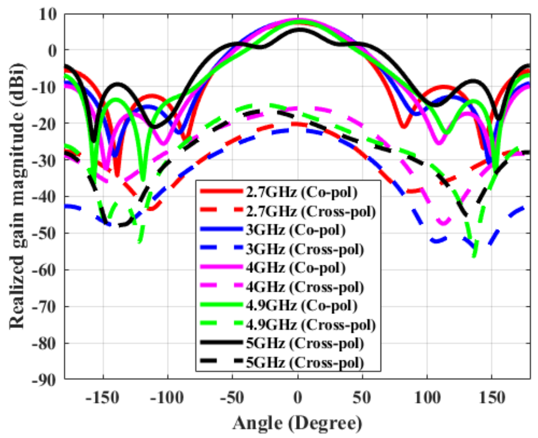

Fig. 11: Simulated realized gain of the proposed antenna at different frequencies.

would be insufficient to create compelling resonance, so the filtering effect for cases W3=10mm and 11mm cases are feeble compared to other lengths.

In this study, a filtering dipole antenna is designed by considering the points mentioned above, and the best antenna performance is achieved by using the dimensions given in Table I. The radiation pattern simulations of the optimum case can be seen in Figure 11. This figure shows the co, and cross-pol radiation pattern of the antenna $\phi = 90^0$ cut for different frequencies. As seen in the figure, the antenna has the same radiation pattern within its impedance bandwidth. One of the superior points of the proposed design is to have almost constant realized gain for the whole operating frequency bandwidth.

III. Conclusion

In this study, a dipole filtering antenna with enhanced bandwidth for communication is proposed. The antenna is designed in three stages. In the first stage, the printed dipole is adapted to have radiating arms at the same layer to increase both the impedance and radiation pattern bandwidth of the antenna. The bandwidth enhancement is achieved by increasing the width of the printed dipole structure. As the adjacent frequencies of the upper operating band are used by other applications, the proposed design needs a filtering property. The final step of the design introduces parasitic elements. The addition of parasitic U-shaped metals introduces sharp variation at $|S_{11}|$ value and supplies a filtering effect. Important parameters and their effect on radiation and impedance performance of the structure are investigated such as; the distance between dipole arms, dimensions of parasitic elements, and flare angle of the radiators. The proposed design has both impedance and radiation pattern bandwidth of at least 61.44%.

Acknowledgement

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