Train-mounted Broadband Monopole Antenna for 5G Communication

Hao Xiang Li [1], Lu Xu [1], Feng Qian [1,*], and Yong Jin Zhou [1,2,*]

[1] Key Laboratory of Specialty Fiber Optics and Optical Access Networks
Shanghai University, Shanghai 200444, China

[2] State Key Laboratory of Millimeter Waves, School of Information Science and Engineering
Southeast University, Nanjing 210096, China
*yjzhou@shu.edu.cn, *hayiji2015@shu.edu.cn

Abstract **—** As a convenient and efficient public transport system, high speed railway (HSR) was rapidly deployed in China. Since the fifth generation (5G) mobile communication system is commercially applied, it is necessary for mobile terminals antennas to cover multiple operating bands to be compatible with various communication systems. Here a HSR-mounted broadband and high-gain monopole antenna is proposed. By using the meander technology and introducing the tapered structure, the proposed antenna operates over a bandwidth of 694-960 MHz and 1350-5975 MHz (VSWR<1.8), which covers both 2G-5G mobile communication and WiFi frequency bands. The dimensions of the proposed antenna are 400 mm × 330 mm × 78 mm. The measured average gain is 6.11 dBi over the entire bandwidth.

Index Terms **—** 5G, antennas, broadband, high-gain, High Speed Railway (HSR).

I. INTRODUCTION

As a fast and convenient public transportation means, high-speed railway (HSR) has attracted a lot of attention in recent years [1]. On the one hand, the surrounding environment of HSR is much more complicated than other scenarios [2]. On the other hand, communication interruption caused by handover failures could seriously degrade the users' quality of service because of frequent handovers in wireless communication system for high-speed trains [3].

At third generation (3G) era, existing railway broadband communication systems were mainly suitable for low mobility environment and low data rate transmissions [3]. The railway network coverage mostly depends on both urban and rural base stations, which can meet the needs of users when the train runs with low speed and the data rate is low. However, there would be increasing handovers and drop-offs due to high mobility of 350-500 km/h [4]. Besides, the signals could suffer severe penetration loss when coming through the carriage body made of aluminum and stainless steel [5]. Traditional mobile communication networks could not fulfill the increasing users' requirements at 4G era [6]. Hence, massive multiple-input multiple-output (MIMO) beam forming and distributed antenna system were used to solve the above problems [7-9]. A dual-antenna in distributed antenna system [2], MIMO antennas system [4], efficient multiple-group multiple-antenna (MGMA) scheme [10], and linearly located distributed antenna system [11] are presented for HSR. However, multiple antennas increase the complexity of the system. One kind of potential solution was proposed by using a relay station mounted outside the train to communicate with base stations [1]. The relay station consists of a train-mounted relay antenna communicating with the base station and a WiFi AP where the mobile station signal can be converted into WiFi signal. The communication system is shown in Fig. 1, where radio signal penetration loss and the coverage problem can be avoided, because radio signals do not need to penetrate into/from the carriages. The 5G mobile communication system is a good choice for huge traffic volume of wireless data service. The train-mounted antennas of the relay station need cover wide frequency band or multiple operating bands to be compatible with various communication systems, to cover both 2G-5G mobile communication and WiFi frequency bands. Besides, wide beam width of the antenna is also necessary to keep the stable link between the relay station and the base station.

The most widely used 2G-5G frequency spectrum in the world today is 700 MHz, 800-900 MHz, 1800-1900 MHz, 2100 MHz, 2600 MHz, 3.5 GHz and 4.9 GHz. Recently, 700 MHz was allocated to China Broadcasting Network Corporation Ltd. (CBN). By using 700 MHz, the investment of 5G network deployment would be saved, because it will use fewer base stations for its large-area network coverage. In addition, the 700 MHz frequency also offers good signal penetration through buildings, basements and elevators. Hence broadband antennas which can simultaneously

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cover multiple service bands are in great demands [1], especially covering 700 MHz. Furthermore, to extend the radio transmission distance, the use of high-gain antennas is important [12, 13]. Vehicle mounted antennas for vehicle-mounted VHF/UHF communication system [14], vehicle-to-everything (V2X) communication [15], and car-to-car (C2C) communication [16, 17] have been designed. However, antenna in Ref. 14 operates from 80 MHz to 600 MHz, the gain of the antenna in Ref. 16 is very low, and Ref. 17 needs two antennas to realize broadband. A top-mounted train antenna operating in the bands of 825-960 MHz, 1.7-2.7 GHz, and 5.7-5.9 GHz by loading an asymmetrically folded branch was proposed [18], but it cannot cover 700 MHz. Dedicated antennas for HSR applications are rarely presented [19].

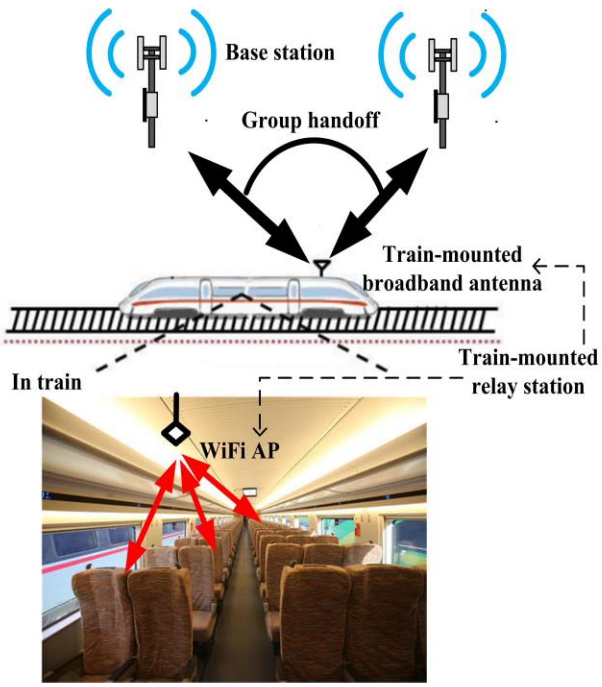

Fig. 1. Communication system by using a relay station mounted outside the train.

In this paper, we propose a train-mounted broadband and high-gain monopole antenna. The dimensions of the proposed antenna are 400 mm × 330 mm × 78 mm. By using the meander technology and introducing the tapered structure, the simulated results of the antenna achieved the desired performances. This antenna can operate over a bandwidth of 694 - 960 MHz and 1350 - 5975 MHz (VSWR< 1.8), which cover the 2G-5G and Wi-Fi communication bands. The measured average gain is 6.11 dBi over the entire bandwidth.

II. ANTENNA DESIGN

The original structure is a monopole antenna placed on the ground plane, which is illustrated in Fig. 2 (a). The monopole antenna includes a vertical radiating part, a horizontal metal strip, and a vertical metal strip shorted to the ground plane. The main radiating part is a tapered structure which can implement wideband characteristics. The final structure is Antenna D which can be seen in Fig. 2 (d).

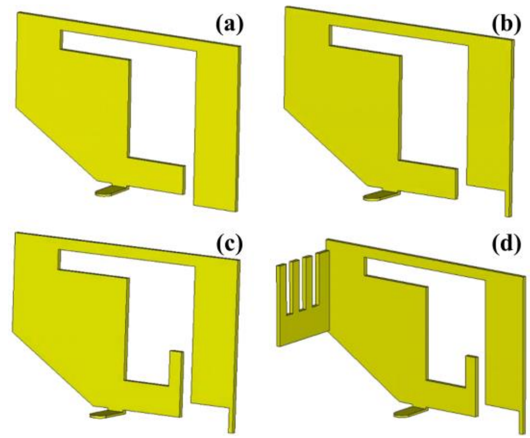

Fig. 2. (a) initial antenna A, (b) antenna B, (c) antenna C, and (d) antenna D.

Figure 3 shows the simulated VSWR of the initial antenna A and antenna B. It can be seen that the initial antenna A can operate at wideband frequencies, not including the frequency band from 1.69 GHz to 2.8 GHz. By loading a rectangle slot (shown in antenna B), the impedance matching over the band from 1.69 GHz to 2.8 GHz was obviously improved, which can be verified by the current distributions at 2.0 GHz, illustrated in Figs. 3 (b) and 3 (c). However, the VSWR is still larger than 2.0 at the frequency band.

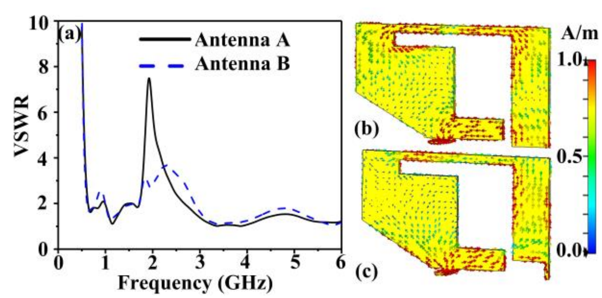

Fig. 3. (a) Simulated VSWR of the initial antenna A and antenna B, (b) the current distribution of initial antenna A at 2.0 GHz, and (c) the current distribution of antenna B at 2.0 GHz.

By loading a rectangular branch (shown in antenna C), the impedance matching around 2.0 GHz was further improved, as shown in Fig. 4 (a), where it can be seen that VSWR is smaller than 2.0 at the frequency band from 1.69 GHz to 2.8 GHz, which has been verified by the current distributions shown in Figs. 4 (b) and 4 (c). Furthermore, the VSWR at the lower stop-band was increased.

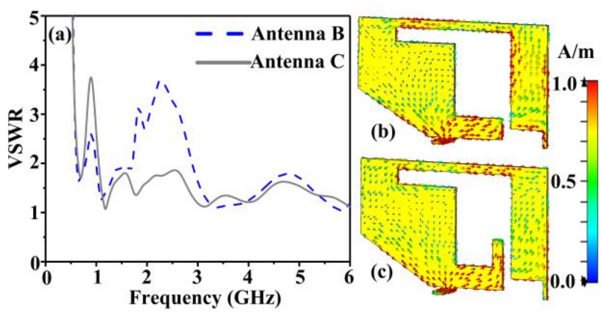

Fig. 4. (a) Simulated VSWR of antenna B and antenna C. (b) and (c) Current distributions of antenna B and antenna C at 2.0 GHz.

However, the central frequency of antenna C at the lower stop-band needs further adjustment. Antenna D shown in Fig. 2 (d) can operate at lower stop-band by loading a comb-like structure. The lower stop-band is from 960 to 1350 MHz, as shown in Fig. 5 (a). It can be seen that the operating frequency of Antenna D is from 694 to 960 MHz and from 1350 to 5975 MHz when VSWR < 1.8, which has been verified by the current distributions at 900 MHz illustrated in Fig. 5 (b) and Fig. 5 (c). From the surface current shown in Fig. 5(c), it can be seen that the comb-like structure reduces the effect of attenuating current cancellation. And the simulation setting for solving dispersion curves of comb-like structure is shown in Fig. 5 (d), where periodic boundary condition (PBC) is used in x direction and perfect electric conductor condition (PEC) is used in the other directions.

The detailed structure of Antenna D is illustrated in Fig. 6. And the dimensions of Antenna D shown in Table 1. The fabricated antenna is shown in Fig. 6 (d) (the material is copper), whose thickness is 2 mm.

III. RESULTS AND DISCUSSION

The simulated VSWR and gain are obtained by using CST. The measured VSWR and gain are shown in Fig. 7. From Fig. 7 (a), it can be seen that the simulated operating frequency is from 694 to 960 MHz and from 1350 to 5975 MHz (VSWR < 1.8) and the measurement results agree well with the simulation results. From Fig. 7 (b), we can see that the measured gain is a little lower than the simulation results. The simulated average gain is 7.67 dBi over the entire bandwidth. The measured average gain is 6.11 dBi over the entire bandwidth.

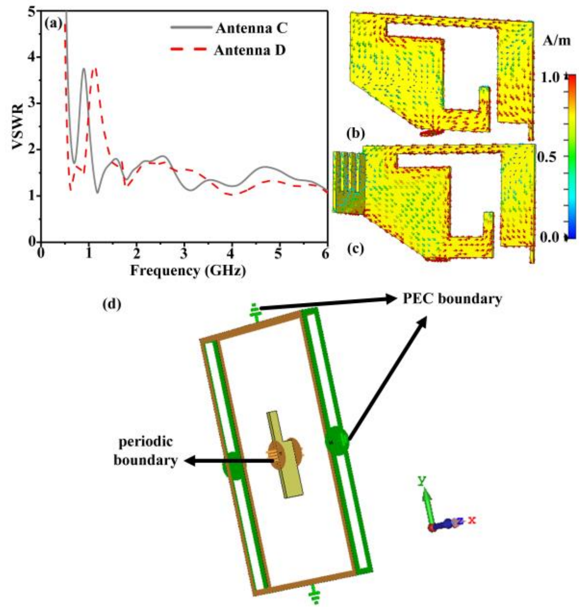

Fig. 5. (a) Simulated VSWR of antenna C and antenna D, (b) and (c) current distributions of antenna C and antenna D at 900 MHz, and (d) the details on simulation of comb-like structure.

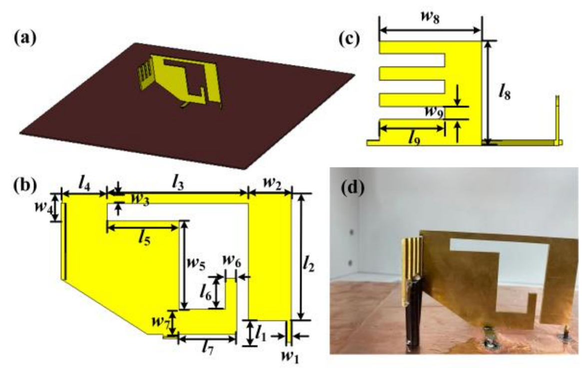

Fig. 6. (a) 3D perspective view, (b) side view, (c) side view, and (d) the sample of the fabricated antenna.

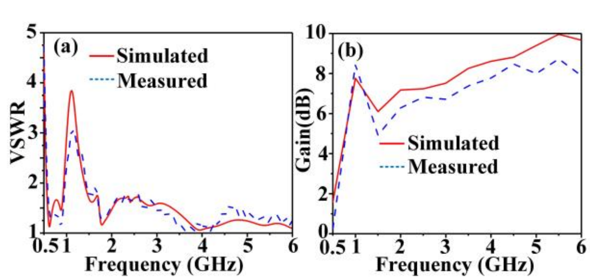

Fig. 7. Simulated and measured (a) VSWR and (b) Gain of Antenna D.

Table 1: Dimensions of the antenna D

Parameters	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9
Unit (mm)	17	65	72	23	36.6	15.7	29.6	38	25
Parameters	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9
Unit(mm)	2	22	5	14	45	6	13	39	5

The simulated and measured far-field radiation patterns of Antenna D at 1.0 GHz and 5.0 GHz are shown in Fig. 8 (a), Fig. 8 (b), respectively. It can be seen that the measured results agree well with the simulated results.

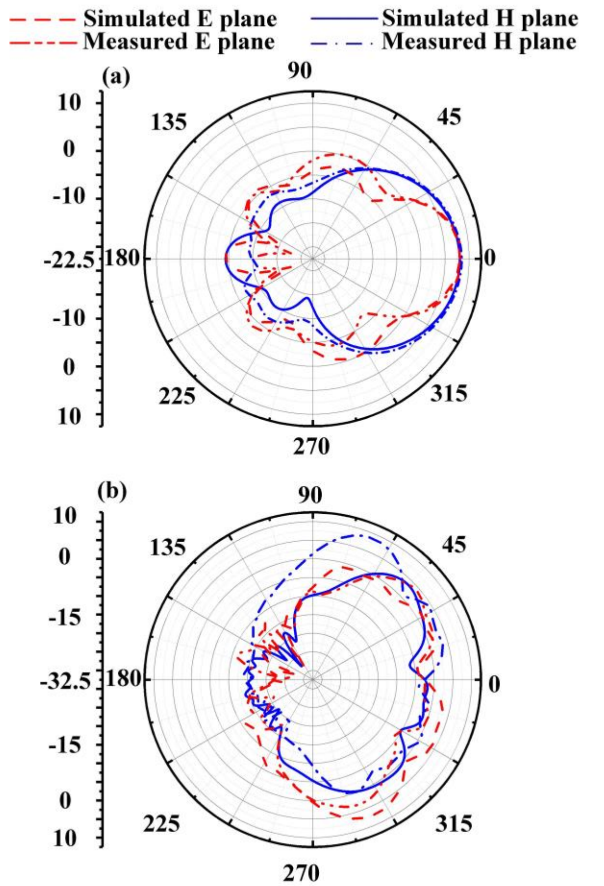

Fig. 8. The simulated and measured far-field radiation patterns at (a) 1.0 GHz and (b) 5.0 GHz.

The simulated and measured efficiencies of Antenna D are shown in Fig. 9. It can be seen that the measured results agree well with the simulation results above 1.35 GHz. The measure efficiency above 1 GHz is larger than 80%. However, the efficiency from 694 to 960 MHz is a little low, which is larger than 43.5%.

The performances of the proposed antenna are compared with other antennas in Table 2. Compared other works, Antenna D can realize broadband (cover 700 MHz) and high gain simultaneously.

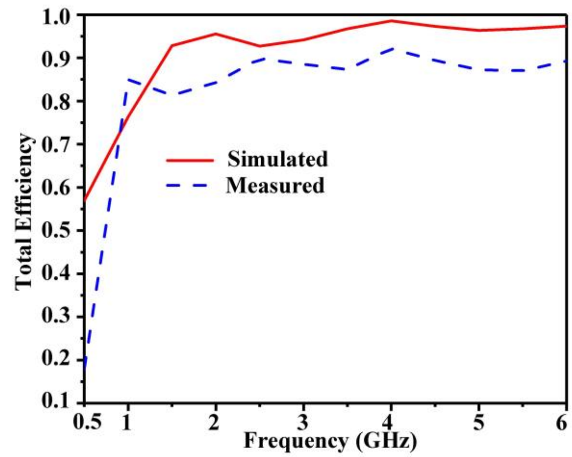

Fig. 9. Simulated and measured efficiencies of antenna D.

Table 2: Comparison of the related researches

Ref.	Dimensions (mm)	Bandwidth (MHz)	Gain
[14]	630 × 630 × 220	80 - 600	/
[15]	87 × 60	690 - 7000	/
[16]	120 × 52	698 - 2700 5000 - 6000	1.5 dBi - 4.4 dBi
[17]	40 × 40 × 60	698 - 960 1700 - 2700 5100 - 6000	/
[18]	116 × 40 × 1.6	825 - 960 1700 - 2700 5700 - 5900	4.27 dBi - 9.82 dBi
[20]	/	698 - 960 1710 - 2170 2400 - 2700 3400 - 3700 4900 - 5935	5 dBi - 8 dBi
This work	117 × 82 × 38	694 - 960 1350 - 5975	Average: 7.67 dBi

IV. CONCLUSION

Here a broadband, low-frequency, high-gain monopole antenna for HSR is proposed. The measured average gain is 6.11 dBi over the entire working bandwidth. By using the meander technology and introducing the tapered structure, the proposed antenna operates over a bandwidth of 694-960 MHz and 1350-5975 MHz (VSWR<1.8) covering 700 MHz, GSM, LTE, and Wi-Fi communication systems, which can be mounted on the top of the train for 5G communication.

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Hao Xiang Li was born in Xian, Shanxi, China, in 1996. He is currently pursuing the Master's degree of Electronic and Communications Sngineering in Shanghai University, Shanghai 200444, China. His research interests include broadband antenna, beaming scanning antenna and metamaterials.

Lu Xu was born in Yangzhou, Jiangsu, China, in 1996. She received the Master's degree of Electronic and Communications Engineering in Shanghai University, Shanghai 200444, China in 2020. Her research interests include small antenna, broadband antenna and metamaterials.

Feng Qian was born in Nantong, Jiangsu, China, in 1982. His current research interests include RF circuit and signal processing. He received the B.S. degree in Communication Engineering Xidian University, Shaanxi, China, in 2004, and M.S. degree in Communication and Information System from Xidian University, Shaanxi, China, in 2007, respectively. From 2015, he was a Senior Engineer with School of Communication & Information Engineering, Shanghai University, Shanghai, China.

Yong Jin Zhou was born in Shandong, China, in 1982. His current research interests include microwave and millimeter antenna, plasmonic metamaterials and applications, millimeter wave and THz functional devices, wireless energy transmission. He received the B.S. degree in Communication Engineering from Shandong University, Jinan, China, in 2006, and Ph.D. degree in Electromagnetic Field and Microwave Technology from Southeast University, Nanjing, China, in 2011, respectively. From 2009 to 2010, he was a Visiting Scholar of University of Houston. From 2011 to 2012, he was a Software Engineer with EEBU of Marvell Technology (Shanghai) Ltd. From 2012 to 2015, he was an Assistant Professor and from 2015 to 2020, he was an Associate Professor with School of Communication & Information Engineering, Shanghai University, Shanghai, China. Currently, he is a Professor with School of Communication & Information Engineering, Shanghai University, Shanghai, China. He has authored and coauthored over 90 papers in peer-reviewed journals and conference proceedings. He is IEEE Member, OSA Member, and Senior Member of Chinese Institute of Electronics. He is serving as a Reviewer for over 20 peer-reviewed journals, such as Nature electronics, Photonic Research, Optics Letter, Optics Express, Appl. Phys. Express, IEEE Access, IEEE MTT, IEEE MWCL, etc. He was serving as a Session Chair for several International Symposiums.