Progress In Electromagnetics Research Letters, Vol. 88, 113–119, 2020

A Dual-Band Antenna for LTE-R and 5G Lower Frequency Operations

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Abstract—The goal of this paper is to design a dual-band antenna for the integration of LTE-R 700-MHz band along with 5G (3.5 GHz) band applications for future advanced railway communication. A design study of the dual-band antenna is proposed and discussed in detail. An ellipse-shaped ring patch is designed for the LTR-R 700-MHz band, and the 5G (3.5 GHz) band is added by keeping the circular patch in proximity to the feed line of the antenna to make it a stacked antenna configuration. Circular patches with varying dimensions are used to increase the bandwidth at 3.5-GHz band. The antenna has a size of 180 mm × 60 mm and is fabricated on an FR4 substrate with dielectric constant 4.4 ($\tan\delta = 0.025$). The observed bandwidth is approximately 100 MHz and 500 MHz for each frequency band respectively.

1. INTRODUCTION

The evolution of wireless technology has grown dramatically. In the future, it is estimated that the need to access the internet will increase along with ever increasing mobility [1]. The presence of service for higher data rate will be the solution to answer the needs. In order to overcome this issue, LTE (Long Term Evolution) technology was launched [2]. LTE is a step towards advanced radio technology which is designed to improve network capacity and speed for required bands of operation. The wireless communication devices used for the communication need more frequency bands to be added because of increasing wireless service requirements [3]. As these devices also want limited dimensions for real estate environments, antennas need to be smaller in their dimensions and perform in more than one operating frequency bands while maintaining their performance in terms of bandwidth, gain, etc. Due to these specifications, the demand for dual-band antenna design is increasing continuously for future advanced communication systems [4–15].

Conventionally, railway has used robust communication link over the public network frequency in LTE-R band. To provide faster communication service for passengers, the adaptation of 5G operation is essential. The necessity of this research is for the future communication in the Department of Railways, enabling the secure and simultaneous communication over both LTE-R band and 5G frequency band [15–17]. The frequency band for the next generation railway network (LTE-R) and e-navigation network has been assigned to 700 MHz as the public safety network. The LTE-based networks use 718–728 MHz for uplink and 773–783 MHz for downlink frequencies. The proposed work provides the investigation on design studies of the antenna for a integrated system module for LTER and 3.5 GHz (5G) bands for the simultaneous communication. Section 2 describes the proposed antenna geometry and design parameters. The simulation studies are presented in Section 3, and results and discussion are presented in Section 4. Section 5 describes the conclusion.

Received 15 August 2019, Accepted 11 December 2019, Scheduled 21 December 2019
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2. PROPOSED ANTENNA GEOMETRY

The proposed antenna is designed using two substrates in a multilayer configuration. The lower substrate has a main patch radiator which is in elliptical form on the upper layer and slotted ground plane in the bottom layer. The upper substrate has 5 circular patches with varying radius. The center patch is coupled electromagnetically to the feed line. The four parasitic patches have been used for the bandwidth enhancement purpose near 3.5 GHz band. The detailed antenna geometry along with the front view, back view, elliptical ring patch, cross sectional view, circular patches on the upper substrate for 3.5 GHz band, and the ground plane is shown in Figs. 1(a)–(f). The substrate used for the proposed antenna is FR4 (dielectric constant 4.4 with the loss tangent of 0.025 and thickness of 1.6 mm).

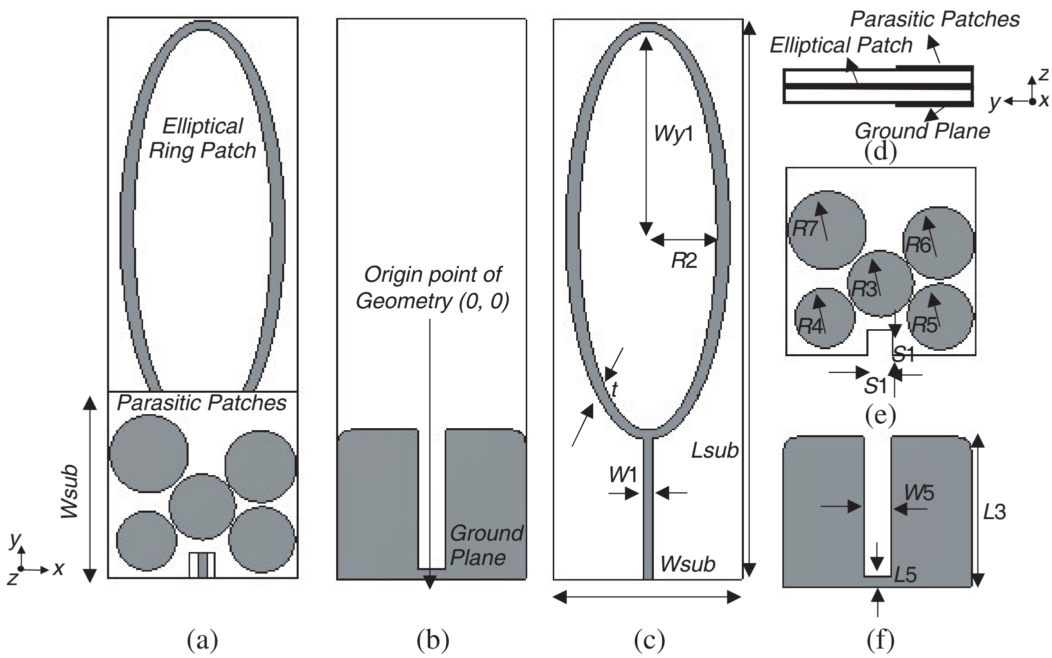

Figure 1. Antenna geometry, (a) front view, (b) back view, (c) elliptical ring patch for 700 MHz band (middle layer), (d) cross sectional view, (e) circular patches for 3.5 GHz band (upper layer), (f) ground plane at the bottom layer.

The final antenna design parameters' values are listed in Table 1. The antenna parameters are key elements to have the impact on antenna performance. The effect of parameters, such as the ground plane slot dimensions, elliptical ring patch dimensions, and feed line widths, are studied in detail and discussed in the next section.

Table 1. Final antenna design parameters (all dimensions are in mm).

$Wy1$	64	$R3(x,y)$	10.5(0, 22.8)	$R6(x,y)$	11.25(18.5, 35.8)	$L5$	3.5	$Wsub$	60
$R2$	22	$R4(x,y)$	9.5(−17.8, 11.9)	$R7(x,y)$	12.5(−17, 39.8)	$L3$	48	$S1$	8
t	3	$R5(x,y)$	10.5(19, 12.3)	$W5$	8.5	$Lsub$	180	$W1$	2.5

3. DESIGN STUDIES

The design and simulation have been carried out by using the CST Microwave Studio. At first, the elliptical ring patch has been designed with a partial ground plane, and then the parametric study has

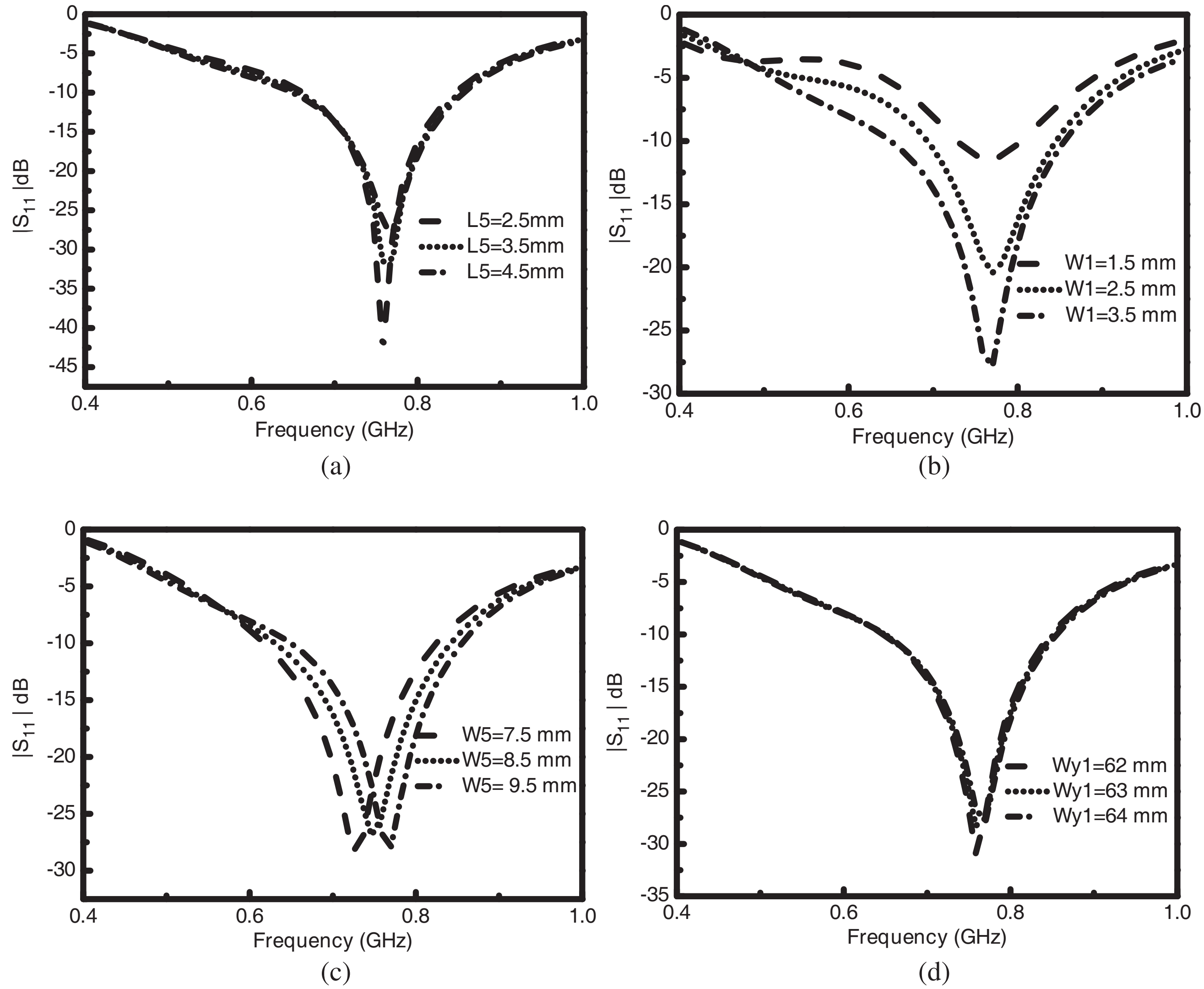

Figure 2. S-parameters (single frequency-study 700), (a) $L5$ variations, (b) $W1$ variations, (c) $W5$ variations, and (d) $Wy1$ variations.

been done for optimizing the antenna results for the lower band 700 MHz frequency. From Fig. 2, it can be seen that $W1$ parameter has the most critical effect on the S-parameter of the antenna at 700 MHz, where $W1$ is the width of the feed line. Also the design study for other parameters, such as $L5, W5$ and $Wy1$, has been carried out and shown in Figs. 2(a)–(d).

The small ground plane near the feeding end $L5$ also plays an important role for the matching at 700 MHz frequency band, as clearly observed from Fig. 2(a). The variations in the rectangular slot in the ground plane width $W5$ and elliptical ring patch major axis $Wy1$ are also studied and can be utilized for fine tuning of impedance matching at 700 MHz.

Further, the circular patches with various dimensions for the resonance at 3.5 GHz are studied in detail and presented in Fig. 3. It can be seen that if there is a single patch (coupling patch) at the center point above the feed line, the bandwidth is low. The nearby patches act as parasitic patches and create new resonance resulting in the enhancement in the frequency band at 3.5 GHz. The wide bandwidth is essential for the high data rate at 5G technology. From Fig. 3, it is observed that when four patches are added near the main coupling patch with varying radius, bandwidth enhancement is observed which fulfills the required application (BW $\geq$ 500 MHz). Fig. 4 shows the study of the size of parasitic patches in terms of radius. It can be observed that if all the parasitic patches have the same

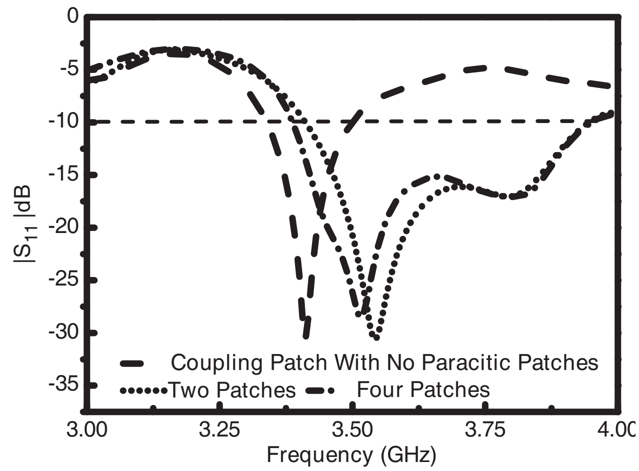

Figure 3. S-parameters. The bandwidth is enhanced by tuning the patches.

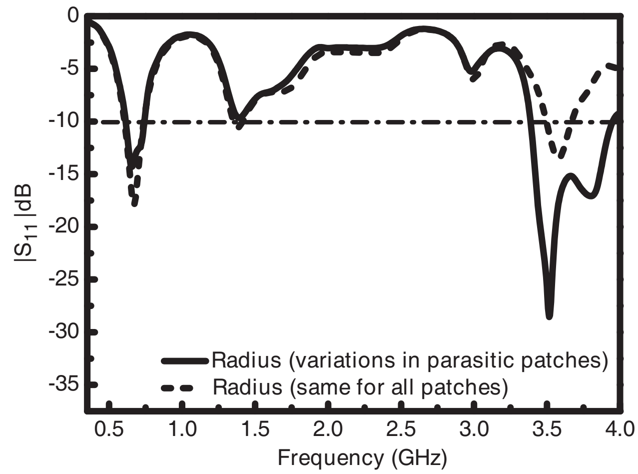

Figure 4. S-parameter. Effect of radius of the all patches.

radius as that of the main coupling patch (with radius $R3$), the bandwidth at the 3.5 GHz frequency bands degrades as compared to the radius with some variations in each. For modelling the same size of parasitic patches as that of the main patch, the main patch is shifted by 1 mm in $+y$ direction because of the overlapping of the patches with radii $R3$ and $R4$ at this point of consideration. The variations in the radius of the parasitic patches produce multiple resonances in the nearby frequencies and result in widening the bandwidth at 3.5 GHz frequency.

4. RESULTS AND DISCUSSION

The proposed antenna is fabricated on an FR4 substrate (Fig. 5), and its performance is measured with VNA. Fig. 6 shows the antenna S-parameters along with measurement results. It is observed that the measured results follow the same trend as those of the simulations which confirms the proof of the concept. The measured bandwidth is observed approximately 100 MHz for the 700 MHz frequency bandand approximately 500 MHz for the lower 5G band, i.e., 3.5-GHz band. The bandwidth is slightly less than the simulation results at 3.5-GHz band. We believe that the difference is originated from the air gap between two substrates. Since it is a multilayer structure where two substrates are used to

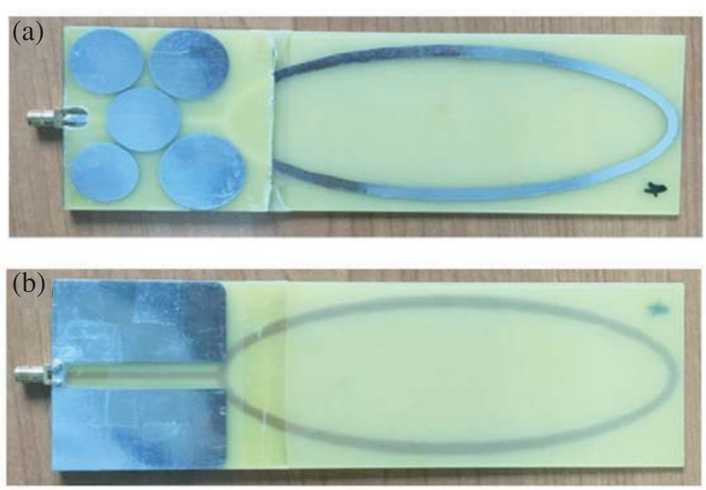

Figure 5. Fabricated antenna in (a) top view and (b) bottom view.

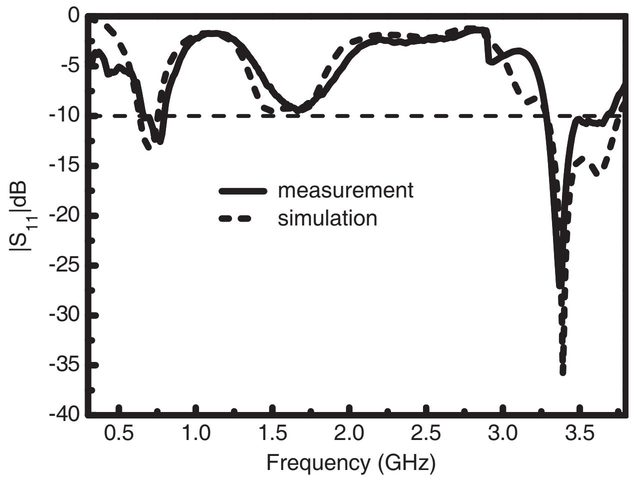

Figure 6. S-parameters of the proposed antenna.

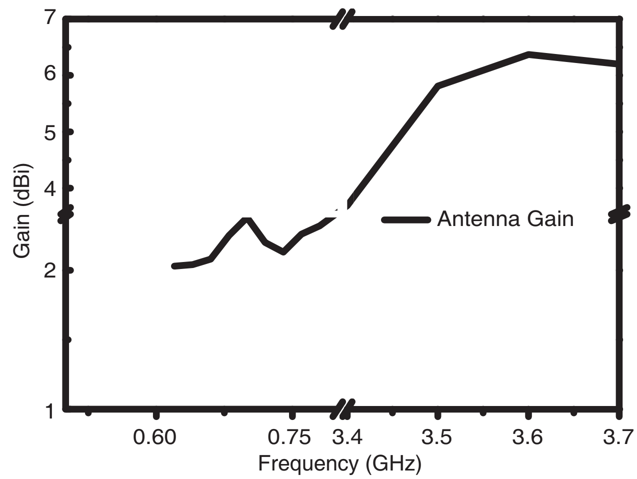

Figure 7. Gain of the proposed antenna.

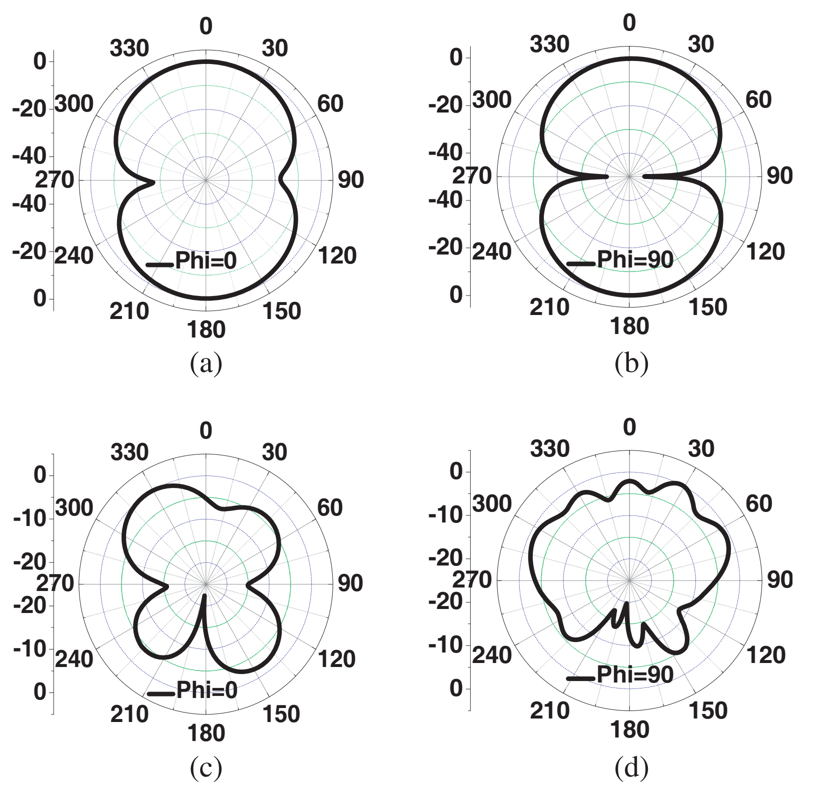

Figure 8. Proposed antenna radiation pattern, (a) 700 MHz at Phi = 0, (b) 700 MHz at Phi = 90, (c) 3.5 GHz at Phi = 0, (d) 3.5 GHz at Phi = 90.

make the antenna for dual-band operation, the air gap between the two layers may cause the frequency shift or response change. Nevertheless, the antenna satisfies the required bandwidth (BW $\geq$ 500 MHz) for the particular application, so further optimization is not performed. The maximum gain for the 700 MHz band is 2.4 dBi (LTE-R) and 6.1 dBi for the 3.5 GHz band (5G) as shown in Fig. 7.

Figures 8(a)–(d) show the antenna radiation patterns. It is observed that at 700 MHz the radiation pattern is omnidirectional. The radiation pattern at the frequency 3.5 GHz is more directional because of the presence of the partial ground plane at the bottom of respective element (circular patches) and

Table 2. Performance comparison between the proposed antenna with the existing reported antennas.

	Size ($x \times y\,\text{mm}^2$)	BW (GHz) (under $\lvert S_{11}\rvert$ dB criterion)	Gain (Max.)	Applications
[4]	32×135	0.7–0.96 (-10 dB) 1.18–3.00 (-10 dB)	- -	LTE, GSM, Wi-Fi, GPS
[11]	110×40	0.69–0.8 (-6 dB) 2.33–2.44 (-10 dB) 2.50–2.69 (-10 dB)	- - -	LTE700, LTE2300, LTE2500
[12]	49×10	0.59–0.82 (-6 dB) 2.15–2.70 (-6 dB) 2.31–2.40 (-6 dB) 2.50–2.69 (-6 dB)	2.1 dBi 4.9 dBi 4.7 dBi 4.3 dBi	LTE 700 LTE2300 LTE2500 WiMAX3500
[13]	158×15	0.70–0.96 (-6 dB) 1.70–2.70 (-6 dB)	- 4.42 dBi 1.21 dBi	4G Cellular Comm.
[14]	42×32	0.60–0.64 (-10 dB) 2.67–3.40 (-10 dB) 3.61–3.67 (-10 dB)	- 3.81 dBi 3.75 dBi	LTE, WiMax
[15]	18.5×8.5	3.34–3.84 (-6 dB) 5.15–6.52 (-6 dB)	- -	5G (Sub-6 GHz)
This work	180×60	0.66–0.79 (-10 dB) 3.28–3.78 (-10 dB)	2.4 dBi 6.1 dBi	LTE(R) 5G (Lower Frequency)

reflections thereby. The omnidirectional pattern enables the robust operation regardless of change in environment and orientation for 700 MHz band frequency. The performance comparison with the previously reported research on dual-band antennas related to 700 MHz (LTE-R) and 3.5 GHz (5G) is presented in Table 2. Compared to the previous works, the proposed antenna has wide bandwidth 130 MHz and 500 MHz at both 700 MHz and 3.5 GHz frequency bands along with high gains of 2.4 dBi and 6.1 dBi, respectively. The large size of the antenna is currently affordable for the purpose of this work, because the antenna is to be carried by train, not by human. Nevertheless, the size reduction and other geometries along with the same bandwidth and similar gain for both the frequency bands will be a future scope on this research.

5. CONCLUSION

The integration of the two bands namely LTE-R and 5G lower band by the use of a single antenna with dual-band operation is studied in detail in this work. The design procedure of the novel antenna has been presented and discussed. The proposed antenna has been designed and fabricated on an FR4 substrate. The measured results are in good comparison with the simulated ones. The bandwidth is observed as approximately 100 MHz for the LTE-R band and 500 MHz for the 3.5 GHz application, which is the required bandwidth for the future communication in the LTE(R) and 5G networks. Further integration of the RF modules for the advanced railway communication can be done with this proposed antenna and will be carried out as a future research work.

ACKNOWLEDGMENT

This work was supported by National Research Foundation of Korea (NRF) grant NRF-2017R1C1B2009892, NRF-2018R1A6A1A03025708, and the Korea Railroad Research Institute (KRRI), Republic of Korea.

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