Design of Triple Band Antenna for Indoor 4G-LTE and 5G-NR Distributed Antenna System

Chawalit Rakluea
Department of Electronics and Telecommunication Engineering
Rajamangala University of Technology Thanyaburi
Pathumthani, Thailand
chawalit@rmutt.ac.th

Norakamon Wongsin
Department of Electronics and Telecommunication Engineering
Rajamangala University of Technology Thanyaburi
Pathumthani, Thailand
norakamon@rmutt.ac.th

Sudarat Anantasuk
Department of Electronics and Telecommunication Engineering
Rajamangala University of Technology Thanyaburi
Pathumthani, Thailand

Benjawan Prachit
Department of Electronics and Telecommunication Engineering
Rajamangala University of Technology Thanyaburi
Pathumthani, Thailand

Tawan Thianthong
Siam Airport Ground Services Co.,Ltd.
431/57 Song Prapha Rd. Don Mueang,
Bangkok, Thailand.
tawan_absg@hotmail.com

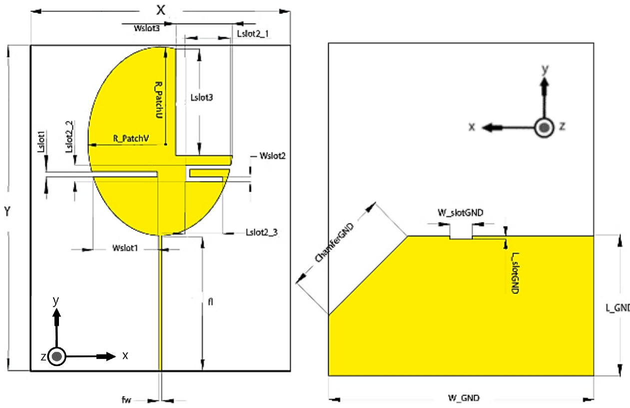
Nattapong Duangrit
Centre of Observatory Operation and Engineering
National Astronomical Research Instituite of Thailand
Chiangmai, Thailand
nattapong.d@narit.or.th

***Abstract*— A low-profile triple band antenna is designed, investigated and developed to use as the indoor mounted ceiling antenna for 4G-LTE and 5G-NR distributed antenna system. The proposed antenna is implemented on 0.8-mm thickness PCB substrate and obtains the compact size of 120 ×135 mm^2, which composes of oval patch trimmed by three slots and microstrip feed line on chamfered ground plane with tuning slot. A prototype antenna is measured impedance bandwidth which covers three operating frequency bands of 690 – 960 MHz, 1710 – 2700 MHz and 3300 – 4000 MHz. Also, the average antenna gains are 1.8, 3.2, and 2.6 dBi at each operating band, respectively. The proposed antenna obtains omnidirectional pattern over the entire frequency ranging from 700 until 2500 MHz and bidirectional pattern for the frequency above 2500 MHz. According to comparisons, the measured results are in good agreement with the simulated one.**

Keywords—triple band antenna, omnidirectional, 4G-LTE, 5G-NR, distributed antenna systems (DAS)

I. Introduction

Generally, the electromagnetic signals from outdoor base station are much attenuated by building wall, glass, and any obstacle resulting in such signal for communication does not cover the whole indoor area. Therefore, the indoor distribution antenna systems (DAS) have been introduced to solve such issue [1]. Nowadays, with the rapid development of mobile communication technology, such as, 4G-LTE and 5G-NR (New Radio), the demand for indoor communication using DAS has been increased to cover 4G-LTE and 5G-NR frequency spectrums. Generally, DAS employ the wideband omnidirectional antennas as transmitting and receiving terminal part, which should low-profile, simple installation on the ceiling, and easy fabrication [2]. The classical structures of wideband omnidirectional antenna are discone [3] and biconical antennas [4] which have to large in size to keep the property of wide impedance bandwidth. In order to reduce a structure size of the classic wideband antenna, many extra methods have been ordinarily applied like top-loading plate and short-loading pins [5] – [7]. In 2014, a wideband ceiling mount antenna using both top-loading disk and short-loading pins has been proposed with operating frequency



(a) (b)

Fig. 1 Configulation of the proposed triple band omnidirectional antenna on (a) top layer and (b) bottom layer.

response from 650 MHz to 6 GHz [5]. Also, a low-profile wideband monopole antenna with conical radiation pattern [6] has been presented to cover frequency spectrum ranging from 1700 to 2790 MHz which does not support 5G-NR 700 MHz band. In 2021, a low-profile wideband omnidirectional antenna using multiple resonance mechanism has been initially designed to cover the operating frequency ranging from 1600 MHz to 4000 MHz for 4G-LTE and 5G-N78 [7]. However, these mentioned antennas still have a three-dimensional structure and high-profile characteristics which is difficult for massive production. To obtain extremely low-profile, thinness, lightweight antenna, the planar antenna implemented by printed circuit board (PCB) is often applied using multiple resonance modes [8]. The various advantages of a planar antenna are ease of production, comfortable installation, and good integration with the parts of building. Therefore, the planar antennas are highly suitable to be used as indoor terminal of DAS.

In this paper, a low-profile triple band antenna is presented for indoor 4G-LTE and 5G-NR DAS, which is fabricated on FR-4 substrate with the overall dimensions of $120 \times 135 \times 0.8$ mm^3. The proposed antenna is designed and optimized to cover the three frequency responses at the low-band (690 – 960 MHz), the mid-band (1710 – 2700 MHz) and the high-band (3300 – 4200 MHz). The antenna design and configuration are explained in Section. II. The simulation, optimization and measurement are explored with some discussion in Section. III. A prototype antenna is implemented and experimented that the measured performances are in good agreement with the simulated results. Finally, Section. IV summarizes the detail and the result of the proposed antenna in this paper.

II. Antenna Design and Configuration

The proposed triple band antenna with omnidirectional characteristic originates from the principle of planar monopole antenna. The proposed antenna composes of the oval patch antenna with three slots fed by microstrip line on the top layer and chamfer edge ground plane on bottom layer, as shown in Fig. 1(a) and 1(b), respectively. Generally, the oval patch can obtain wider operating frequency than the rectangular/square patch. Also, the chamfer edge ground plane is designed to maintain wide bandwidth characteristics. For the three slots, they can individually generate three resonant behaviors. In addition, the proposed antenna is designed on the low-cost FR-4 substrate with 0.8-mm thickness and dielectric constant (ε_r) of 4.3. Table I represents the optimal dimensions of the proposed triple band antenna by using EM simulation from CST Microwave Studio Suite which are going to explain the optimization process in Section. III-A with some significant parameters

III. Results and Discussion

A. *Simulation and Optimization*

In this paper, the EM simulation module of CST Microwave Studio Suite is used to design, analyze, and optimize the performances of the proposed antenna. Firstly, the horizontal radius of the oval patch (R_Patch_V) is only studied by varying from 43 mm to 44.5 mm. This parameter mainly affects to the impedance matching at frequency response above 1.5 GHz, as represented in Fig. 2. Moreover, Fig. 3 represents the frequency response of the triple band antenna when the width of feeding line (fw) is changed from 1 mm to 1.6 mm with 0.2 mm-step. It can be inferred that such parameter can tune the impedance matching on higher frequency bands (1710 – 2700 MHz and 3300 – 4200 MHz) and lower frequency band (698 – 960 MHz) remains unchanged. Moreover, the chamfered ground plane with tuning slot is also studied by varying two parameters, ChamferGND and L_slotGND. To make chamfer on ground plane, it is defined with the slope of 45 degree at left side of ground, as depicted in Fig. 1(b). The length of 45-degree chamfer, ChamferGND, is observed and is varied from 30 mm to 36 mm. As a result that shown in Fig. 4, when the length is increased, the reflection coefficient (S_{11}) at two higher frequency bands gets progressively worse. The last parameter, the length of trimmed ground slot (L_slotGND), is analyzed Fig. 5 depicts the reflection coefficient (S_{11}) results by varying such parameter between 1 mm and 2.5 mm with step width 0.5 mm. It is evident that this parameter can controls the two higher resonant frequencies, but the first resonance also maintains covering operating frequency 690 – 960 MHz. After the parameters have been studied, analyzed, and optimized in EM simulation, we can finalize the dimensions of the proposed triple band antenna, as represented in Table. I. Fig. 6 illustrates the prototype of proposed antenna which obtains the frequency response covering lower frequency band (698 – 960 MHz) and higher frequency bands (1710 – 2700 MHz and 3300 – 4200 MHz) for 4G-LTE and 5G technology.

TABLE I. The Optimal Parameter Values of The Proposed Triple Band Omnidirectional Antenna

Parameter	Value (mm.)	Parameter	Value (mm.)
X	120	Lslot2_2	5
Y	155	Lslot2_3	17
R_PatchU	33.5	Py_slot2	13
R_PatchV	43.5	Wslot3	28
fl	63	Lslot3	50
fw	1.2	W_GND	120
Wslot1	32	L_GND	63
Lslot1	2.5	ChamferGND	34
Py_slot1	14	W_slotGND	10
Wslot2	2	L_slotGND	1.5
Lslot2_1	22		

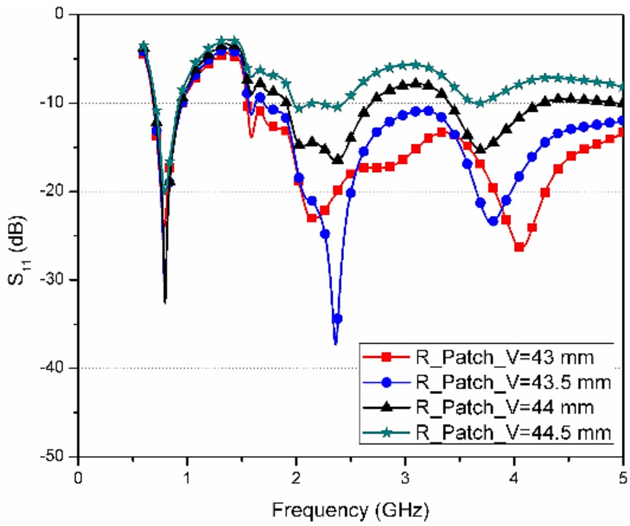


Fig. 2 Simulation of reflection coefficient (S_{11}) by varying the horizontal radius of the oval patch (R_Patch_V).

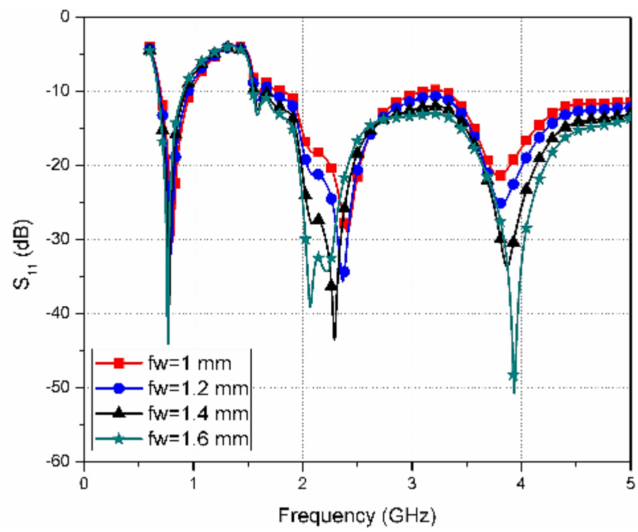


Fig. 3 Simulation of reflection coefficient (S_{11}) by varying the feeding line width (fw).

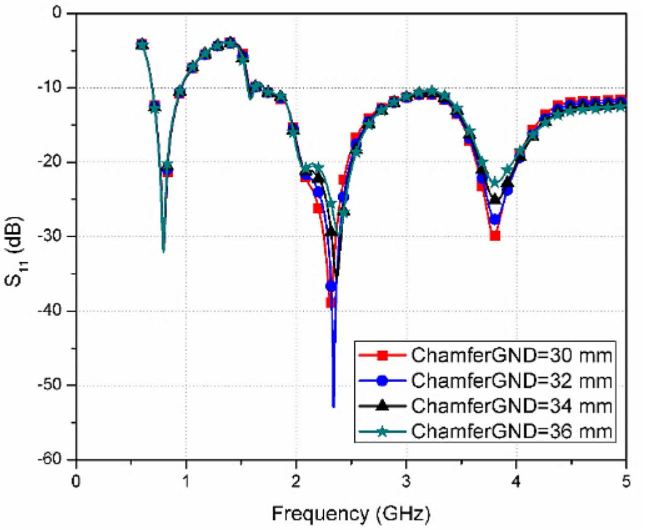


Fig. 4 Simulation of reflection coefficient (S_{11}) by varying parameter ChamferGND.

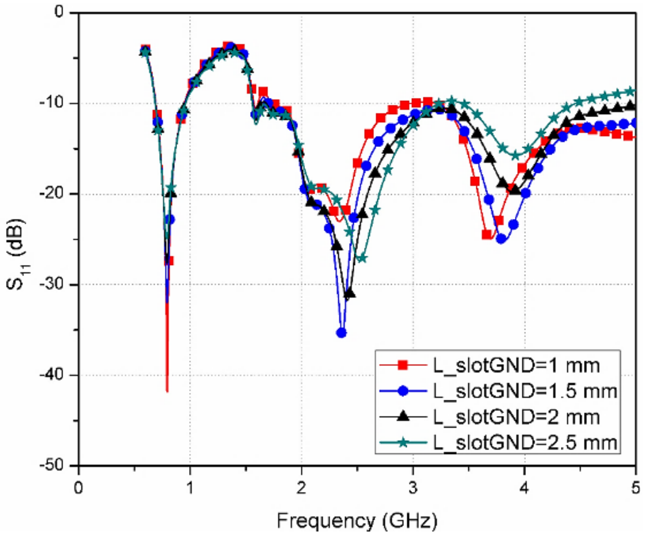
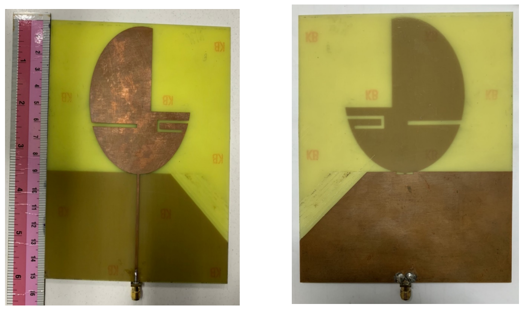


Fig. 5 Simulation of reflection coefficient (S_{11}) by varying the length of trimmed ground slot (L_slotGND).

B. Measurement and Experiment

In this section, the measured results of the proposed triple band antenna are presented compared with the simulated results in terms of reflection coefficient, antenna gain, and radiation patterns. The experiments in this work has utilized Vector Network Analyzer (VNA) from Agilent model 8363B to analyze and collect the measured results. Fig. 7 shows the comparison results of the reflection coefficient between simulation and measurement. It can be observed that both results are in good agreement and obtain three resonant frequencies. In addition, the measured impedance bandwidths of the proposed antenna are 680 – 1000 MHz (320 MHz) and 1600 – 6000 MHz (4400 MHz). Following such results, the proposed triple band antenna completely achieves the 4G-LTE and 5G operating frequency spectrums.

For the gain and radiation pattern measurement, the ETS-Lindgren's double-ridged waveguide horn has been used as the standard transmitting antenna. Fig. 8 represents the maximum antenna gain between EM simulation and measurement over the operating frequencies. For ease of comparison, the measured results are divided into three



(a) (b)

Fig. 6 Prototype of the proposed triple band omnidirectional antenna on (a) top side and (b) bottom side.

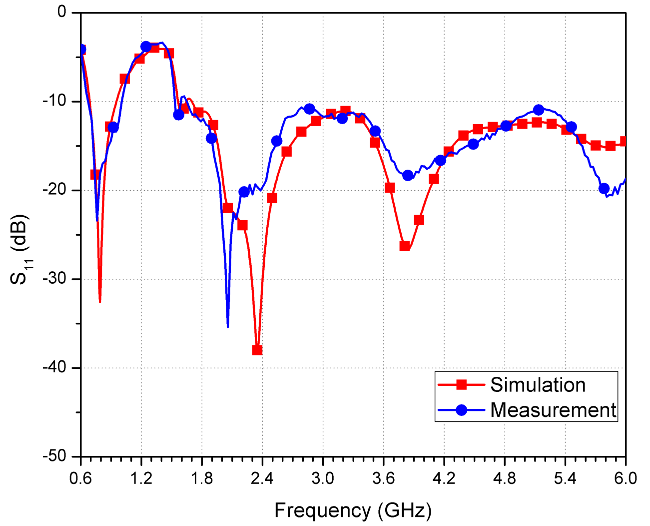


Fig. 7 Comparison of reflection coefficient (S_{11}) between simulation and measurement of the proposed triple band antenna

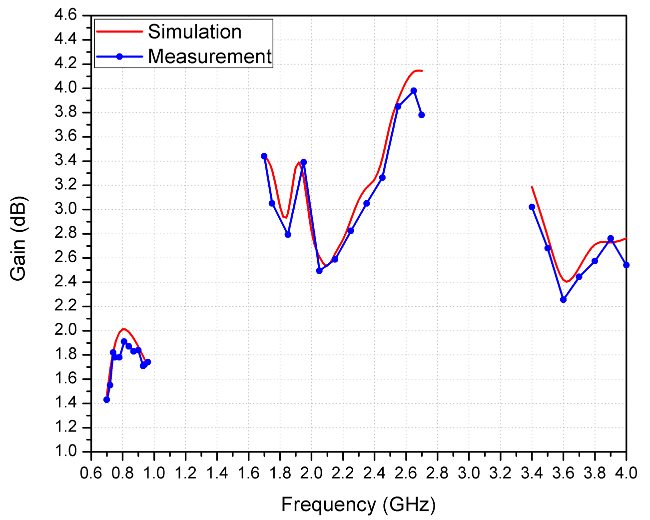


Fig. 8 Simulated and measured antenna gain of the proposed triple band antenna

frequency ranges, 698 – 960 MHz (low-band), 1710 – 2700 MHz (mid-band), and 3300 – 4200 MHz (high-band). In low-band frequency range, the proposed antenna attains the antenna gain between 1.5 – 2.0 dBi. Moreover, the antenna gain at the mid-band frequency range accomplishes above 2.5 dBi with the maximum value of 4.0 dBi at 2700 MHz. The antenna gain of the proposed antenna significantly drops to 2.3 – 3 dBi at the high-band frequency range. The radiation patterns on *xz*-plane and *yz*-plane were measured

Research foundation scholarship of Rajamangala University of Technology Thanyaburi (RMUTT).

and investigated at 740, 940, 1850, 2150, 2650, and 3600 MHz with co- and cross polarization, which are illustrated in Fig. 9 and Fig. 10, respectively. According to the radiation results, it is clear that the proposed triple band antenna achieves omnidirectional pattern at frequency of 740 MHz until 2150 MHz. When the operating frequency is at 2650 and 3600 MHz, the radiation pattern is bi-directional in *xz*-plane and split into four directions in *yz*-plane, as shown in Fig. 9(e) - 9(f) and Fig. 10(e) - 10(f), respectively. This is caused by high order harmonic effect at such frequency ranges.

IV. Conclusion

The triple band antenna for 4G-LTE and 5G distributed antenna system has been designed and developed in this paper. The optimized triple band antenna can achieve the operating frequency spectrum covering frequency band 690 – 960 MHz, 1710 – 2700 MHz and 3300 – 4200 MHz for 4G-LTE and 5G technology. In addition, the proposed thiple band antenna obtains the average antenna gain of 1.8 dBi , 3.2 dBi, and 2.6 dBi for mentioned frequency band, respectively. The omnidirectional radiation behavior is accomplished at frequency below 2300 MHz. For frequency band above 2300 MHz, the proposed antenna has a radiating pattern with bidirectional radiation behavior instead because of high order harmonic phenomenon.

Acknowledgment

This work was supported by New Gen Research Fund; Rajamangala University of Technology Thanyaburi (RMUTT) research foundation scholarship, in fiscal year 2022 with contact no. NRF66D0702.

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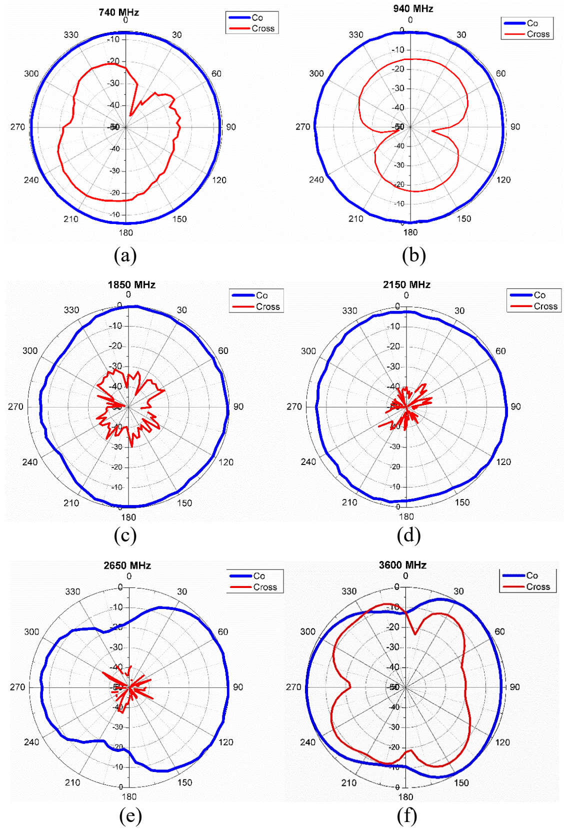

Fig. 9 Measured radiation pattern of the proposed triple band antenna on *xz*-plane at the frequency of (a) 740 MHz, (b) 940 MHz, (c) 1850 MHz, (d) 2150 MHz, (e) 2650 MHz, and (f) 3600 MHz.

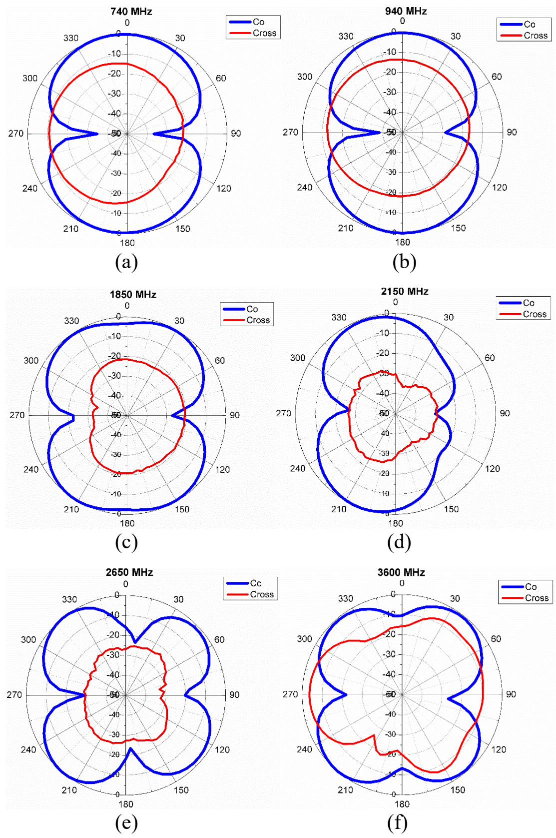

Fig. 10 Measured radiation pattern of the proposed triple band antenna on *yz*-plane at the frequency of (a) 740 MHz, (b) 940 MHz, (c) 1850 MHz, (d) 2150 MHz, (e) 2650 MHz, and (f) 3600 MHz.