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Design of a Compact Wideband Circular Monopole Antenna for 5G Applications

***Abstract**. A circular monopole antenna incorporated with notched slots and modified partial ground plane for 5G applications is demonstrated in this paper. The proposed antenna is fed by a 50 Ω tapered microstrip line, and printed on a FR4 substrate material with relative permittivity of 4.3 and height of 1.6 mm. All suitable parameters have been accomplished to attain the 10 dB return loss bandwidth over 2-6 GHz.This antenna produces a stable omnidirectional pattern with minimum and maximum gains of 2.04 dBi and 4.67 dBi, respectively over the interested band. In addition, the proposed design was fabricated and the prototype was verified to have comparable S-parameters and radiation patterns with that of the simulated results. Evidently, simulated results are reasonably in excellent agreement with the experimental results.*

***Streszczenie.** Przedstawiono promieniową antenę z wbudowaną szczeliną I zmodyfikowaną płytką do zastosowań w sieciach 5G. Antena jest drukowana na podłożu FR4 o wysokości 1.6 mm. Antena charakteryzuje się wielokierunkowością przy paśmie ponad 2.4 GHZ. Przedstawiono wyniki badania anteny. (**Projekt promieniowej kompaktowej anteny szerokopasmowej do zastosowań w sieciach 5G**)*

Keywords: circular monople antenna; wideband antenna; 5G applications.
Słowa kluczowe: antena szerokopasmowa, sieici 5G

Introduction

Nowadays, the breakthrough of the emerging technologies in modern wireless communication has caused a luxurious of modern electronic devices, especially the wide use of compact sizes and wide operating bands, are more appealing for actual applications. As a specific matter, a compact wideband patch antenna, covering the universal mobile telecommunications system (UMTS) 2100, LTE2300, LTE2500, 5G (3300–3600 MHz), wireless local area network (WLAN) 2400 and 5000 MHz, and fixed worldwide interoperability for microwave access (Wi-Max) 2500, 3500 and 5800 MHz [1-5] is compelling. Wideband antennas are a good development in the modern multi-functionality wireless communication systems, as it would operate at multiple frequencies consequently deducting the use of multiple antennas in a single device.

Lately, many techniques have been reccommended for the design of broadband patch antenna [6-9]. Designing compact size with widen impedance bandwidth antenna is a challenging task which has attracted many researchers to expand all kind of possible techniques including the multiple radiators technique [2, 9-10], the modified radiator or ground plane structures [2, 9, 11-14], the crossed tapered slot radiation, the dielectric loading and parasitic, etc. [2-3, 15]. Another favorite technique is using balun and coupled-fed method [16], which allows a convenient matching tuning mechanism. Nevertheless, these methods sometime cannot simultaneously meet both requirements of wideband operation and compact size. Therefore, it is a fascinating challenge to design a wideband and compact size antenna.

In this work, a compact wideband antenna for UMTS 2100, LTE2300, LTE 2500, 2400/5000 WLAN, fixed Wi-Max and middle band of 5G apllications with the size of 37×47×1.6 mm^3 is proposed. To notch an unwanted frequency band and enhance the antenna gain, a pair of I-shaped-notched-slots (ISNS) integrated on the circular monopole with slot antenna [14] is introduced in this paper. The effect of this pair slots and its distance will be analyzed and investigated. In the process, the CST microwave studio [17] is used to demonstrate the appropriated parameters. Simulation results and its validation are reported in the detail.

Antenna design

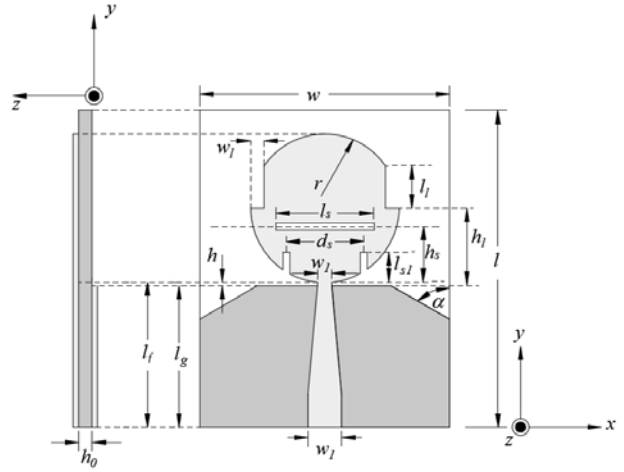
Figure 1 shows a fabric of proposed compact wideband circular monopole antenna (CWCMA). It consists of a radiating circular monopole (CM) of radius r of 11 mm incorporated with a narrow slot (NS) of length l_s of 14 mm and a height of h_s of 8 mm above lower edge of CM to improve its impedance. Note that the radius r is calculated by using (1) [6, 14]. This model is our previous work [14], which offers an ultra-widband operating covered 3.1-10.6 GHz. To notch an unwanted frequency band (the frequency beyond 6 GHz) and increasing antenna radiation properties, a pair of ISNS of length l_{s1} separated by a distance d_s is integrated on the CM with NS. In addition, to fine-tune the impedance bandwidth and increase the antenna gain, both sides of CWCMA are cut off with a like L-letter of length l_l and width w_l above the bottom edge of CM of high h_l. For the radiating section, a CM lies on a coper layer of 0.035 mm which is supported by a FR4 substrate of thickness 1.6 mm and relative permittivity 4.3. The length and width of dielectric substrate are fixed and denoted l of 47 mm and w of 37 mm, respectively. In this work, the CWCMA is fed by a tapered microstrip line [12, 14], which can be regarded as an impedance transformer that smoothly transforms the impedance of the CWCMA to 50 Ω of an SMA connecter. Accordingly, the width of the microstrip feed line is fixed at w_1 = 2 mm and w_2 = 3.8 mm [14]. While the length of feeding line l_f is set around $\lambda_L / 4$, where λ_L is the wavelength at 3.1 GHz [14]. This feed line prints on the same side of the radiating CWCMA. At the rear of the substrate, there is a partial ground plane (PGP) of length l_g covered the feeding section, and this PGP is modified by using technique of a diagonal cut at the top corners (DCTCs) with the angle α to further improve the antenna gain [14, 18]. In this work, the length l_g is designed to be the same length of the feeding line l_f.

$$f_r = \frac{72}{2.25r} GHz \,, \tag{1}$$

where f_r is the resonance frequency at 3.1 GHz.

All suitable parameters are carried out using the CST simulation, and listed in Table 1. To verify the numerical results, a prototype of CWCMA was invented with the designed dimensions in Table 1 as shown in Fig. 1 b). This prototype antenna was connected to a coaxial feeding port via a 50-ohms SMA connector. The impeadance and radiation characteristics of the proposed antenna are tested by using an E5063A network analyzer.

a)



b)

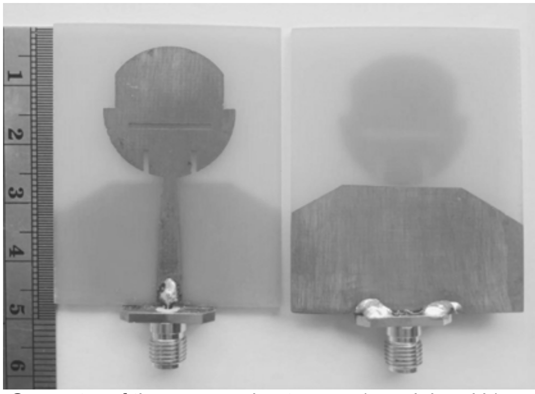


Fig.1. Geometry of the proposed antenna: a) model and b) prototype

Table 1. The parameters of the designed antenna

Parameters	Physical size (mm.)	Parameters	Physical size (mm.)
w	37	l_s	14
l	47	h_0	1.6
r	11	l_{s1}	5
h	0.5	w_l	2
h_s	8	l_l	6
l_g	21	h_l	11.5
l_f	21.5	d_s	4
w_1	2	α	60°
t	0.035	w_2	3.8

Analysis of results

This section reveals the numerical and experimental results of the proposed antenna. In the simulation process, the SMA connector is excluded to focus on only antenna properties. In the process, it initially begins with the CM of radius r_1 of 11 mm incoropperated with the NS of length l_s of 14 mm at the height h_s of 8 mm above the feeding point and a taped fed line of length 21 mm and width w_1 and w_2 of 2 mm and 3.8 mm, respectively [14]. This model provides an ultra-wideband operating (see l_{s1} = 0 in Fig. 2). To design the 5G antenna operated at 2-6 GHz, the unwanted frequency band above 6 GHz is notched. Therefore, a pair of narrow width ISNS of length around a $n\lambda/16$ (where n is equal to 2 for this work) at 6.5 GHz with the center to center distance d_s of 8 mm is included. To consider the effect of these parameters, l_{s1} and d_s are investigated. By varing l_{s1} of 0, 3, 5 and 7 mm as ploted in Fig. 2, the shortest length provides a notched frequency above 6.5 GHz while the longest one notches frequency below 6 GHz. Note that l_{s1} of 0 is the case of excluding a pair of ISNS, which provides the 10 dB return loss over 3.1-10.6 GHz. In this work, l_{s1} of 5 mm is selected since it provides the 10 dB return loss covered the midle band of 5G ranging from 2.01–6.24 GHz; the unwanted frequency above 6.24 GHz is cut. In addition, the influence of distance d_s is also considered as shown in Fig. 3. As the closer distance as the lower notched frequency is achieved. For d_s of 4, 8 and 12 mm, the distance of 8 mm is chosen since it provides the notched frequency at 6.24 GHz with a good 10 dB return loss covered frequency range 1.98-6.28 GHz, while the distance of 4 and 12 mm offer the notched frequency below and above the unwanted frequencies, respectively. In addition, the length l_{s1} of 5 mm and diatance d_s of 8 mm generates high gain over others. Moreover, two sides of CM are slightly cut-off like L-letter to further improve impedance matching and increase antenna gain at the operating frequency above 4.5 GHz; where w_l, l_l and h_l of 2 mm, 6 mm and 11.5 mm, respectively are designed in this work.

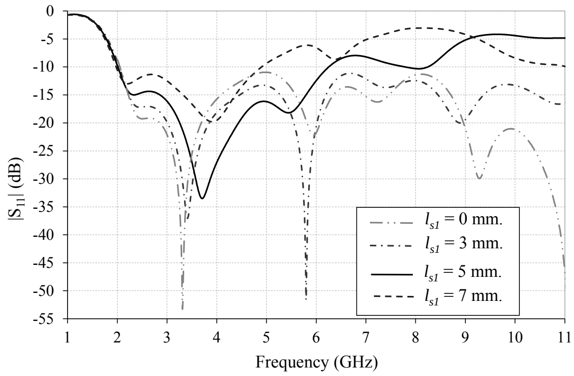


Fig.2. $|S_{11}|$ for various l_{s1}

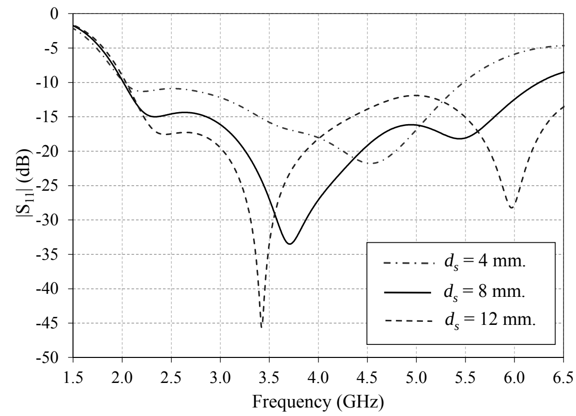
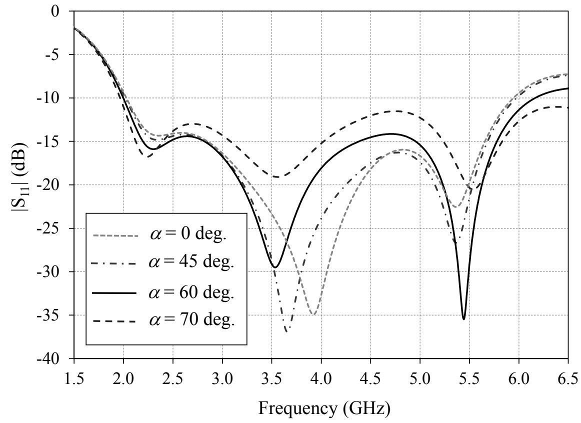


Fig.3. $|S_{11}|$ for various ds.

To further enhance its radiation performance, a technique of DCTCs of PGP with the angle of α is added and demonstrated as shown in Fig. 4. Obviously, cutting the top edges of PGP with the small angle α of 45 degree slightly affects the impedance banwidth. Nevertheless, the larger angles of 60 and 70 degrees worsen the return loss around 4-5 GHz. In contrast the return loss above the operating frequency of 5.5 GHz is improved. Moreover, the larger α also provides an increasing gain especially at the frequency above 4 GHz. In the design, a high gain antenna as well as a good 10 dB return loss are simultaneously considered. Consequently, DCTCs of PGP with α of 60 degree is chosen because it provides a good 10 dB return loss covered the middle band of 5G applications (2.01-6.16 GHz) with minimum and maximum gains of 2.04 dBi and 4.67 dBi, respectively as depicted in Fig. 4.

a)



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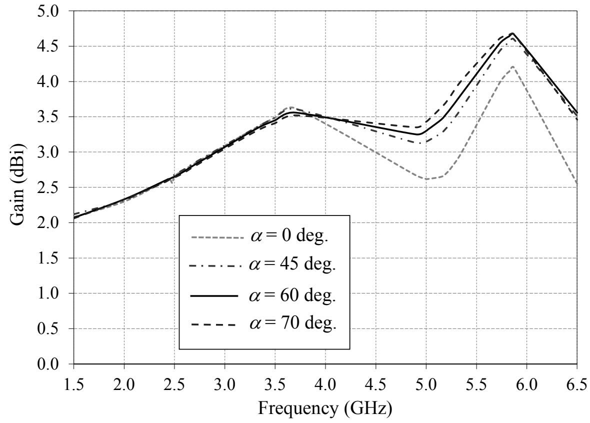
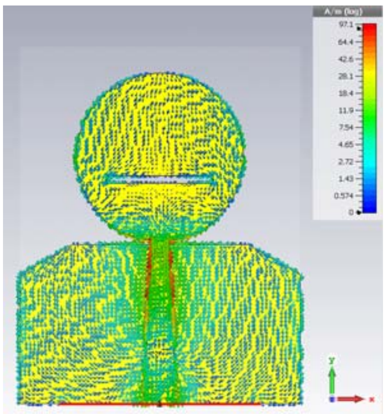


Fig.4. The effect of α to : a) $|S_{11}|$ and b) gain

a)



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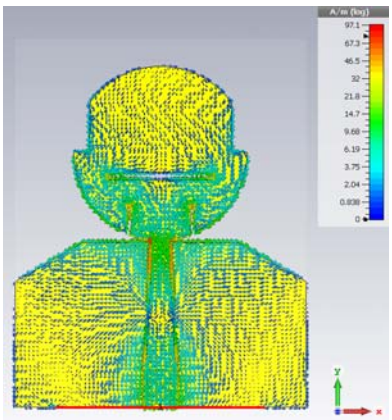


Fig.5. Surface current densities of the proposed antenna: a) without ISNS, b) with ISNS

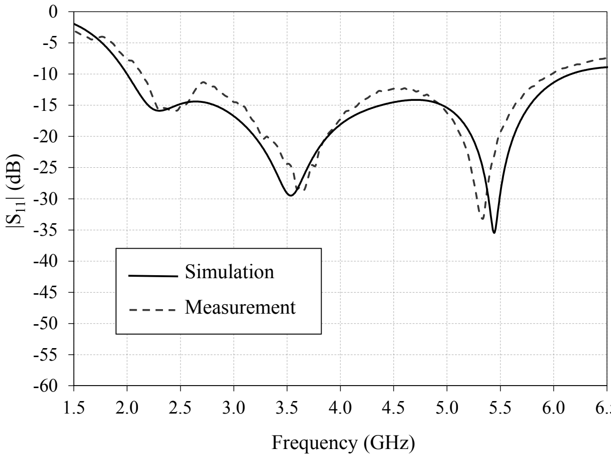
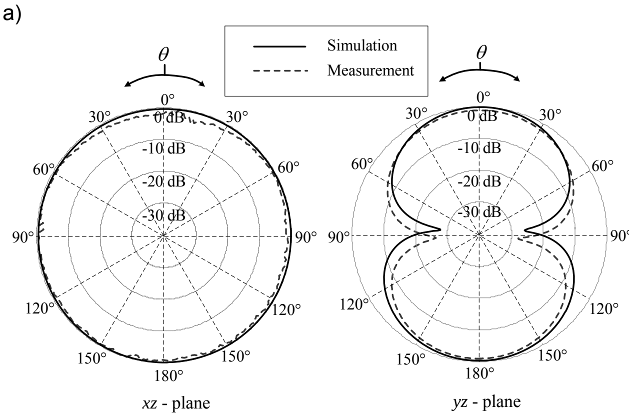
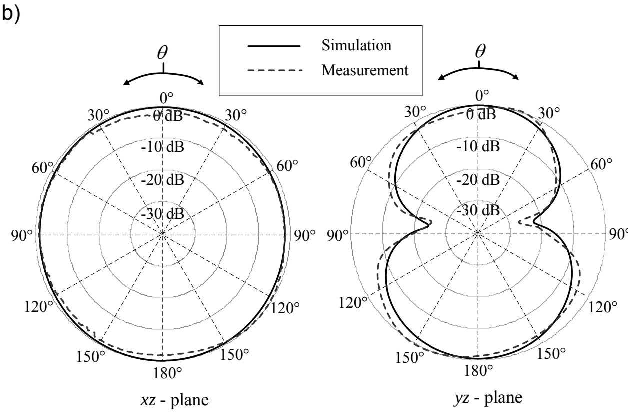


Fig.6. Simulated and measured $|S_{11}|$

a)



b)



c)

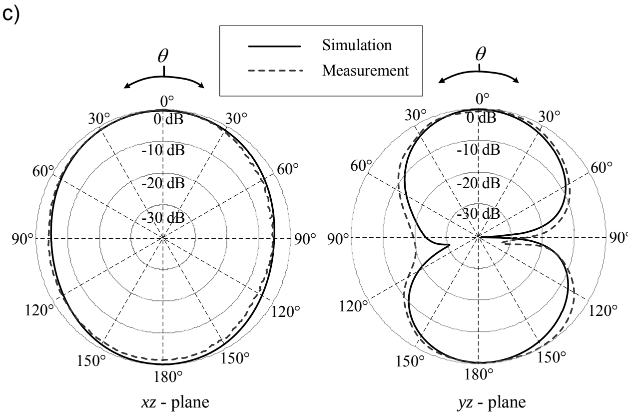


Fig.7. Radiation pattern in *xz*- and yz-planes at: a) 2.45 GHz, b) 3.5 GHz and c) 5.5 GHz

Besides, surface current distribution of the proposed CWCMA without and with a pair of ISNS is also considered as shown ih Fig. 5. Obvious that both cases provide diverse current distribution especially around the upper half-CM and below the cutting-edge corners. It affects the surface current along the feeding line to the radiating patch flowing more stregnthen. As the result, its radiation performance ameliorates particularly at the high frequency above 4 GHz.

A prototype of proposed antenna was fabricated (as seen in Fig. 1 b)) and measured to assert the simulation results. The simulated and measured $|S_{11}|$ for various frequency ranging from 1.5 GHz to 6.5 GHz are plotted in Fig. 6. Evidently, both simulated and measured $|S_{11}|$ are reasonaly in good agreement, and they provide the 10 dB return loss over the middle band of 5G applications ranging from 2.01–6.16 GHz and 2.16–5.98 GHz for the simulation and the measurement, respectively.

In addition, radiation pattern in *xz*- and *yz*-planes at the frequencies of 2.45, 3.5 and 5.5 GHz are also investigated and depicted in Fig. 7. Apparently, this CWCMA furnishes a stable omnidirectional pattern with maximum simulated gain of 2.09, 2.82 and 3.3 dBi at 2.45, 3.5 and 5.5 GHz, respectively. In addition, the simulated radiation pattern provides a similar figure and excellent agreement with measured ones.

Conclusions

To summarise this article, a compact wideband circular monopole antenna covered 2-6 GHz for 5G applications is presented. The CWCMA lies on top of FR4 substrate of height 1.6 mm with relative permittivity of 4.3. A MPGP is printed on the bottom side of the substrate to enhance the S-parameter and antenna radiation efficiency. This proposed antenna is fed by 50-ohms tapered microstrip line. It furnishes a stable omnidirectional pattern with the 10 dB return loss, minimum and maximum gains of 2.04 dBi and 4.67 dBi respectively covered the interested band. Furthermore, the numerical results are validated by the experimental ones, and they exhibit an excellent agreement. As its properties of compact size, wide impedance bandwidth, and good radiation properties, this proposed antenna is probably one of good candidates to apply for modern wireless communication services for examples UMTS, LTE, WLAN, Wi-Max and sub 5G applications, etc.

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