Ahmed Jamal Abdullah Al-Gburi[1], IM Ibrahim[2], Z Zakaria[3], M. Y. Zeain[4], Husam Alwareth[5], Ayman Mohammed Ibrahim[6], Hussam Hamid Keriee[7]

Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia.
Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, , Johor, Malaysia.

doi:10.15199/48.2021.05.11

High Gain of UWB CPW-fed Mercedes-Shaped Printed Monopole Antennas for UWB Applications

***Abstract**. This paper proposes a high gain, and a new shape of an Ultra-wideband (UWB) Mercedes-Shaped printed monopole (MPM) antenna feds by a coplanar waveguide (CPW) designed to use for UWB applications. The Mercedes patch shaped consists of a circular ring embedded with three-legged leads to enhance the antenna bandwidth. The antenna has an electrical dimension of $1.2\lambda_o \times 1.2\lambda_o \times 0.039\lambda_o$ at the centre operating frequency of 7.35 GHz. The MPM antenna provides a bandwidth of 10.5GHz covering the licensed UWB frequencies, starting from 2.1 GHz to12. 6 GHz. The MPM antenna exhibited a max gain of 6.88 dB at 8.6 GHz with a significant radiation efficiency of 97.4%. The coverage bandwidth of the proposed MPM antenna is wide enough to be used for UWB and radar applications.*

***Streszczemnie.** W artykule zaproponowano duży zysk i nowy kształt ultraszerokopasmowej (UWB) drukowanej anteny jednobiegunowej (MPM) w kształcie Mercedesa, zasilanej przez falowód współpłaszczyznowy (CPW) zaprojektowanej do zastosowań UWB. Element w kształcie Mercedesa składa się z okrągłego pierścienia osadzonego w trójnożnych przewodach w celu zwiększenia przepustowości anteny. Antena ma wymiar elektryczny 1,2λo × 1,2λo × 0,039λo przy środkowej częstotliwości roboczej 7,35 GHz. Antena MPM zapewnia szerokość pasma 10,5 GHz pokrywającą licencjonowane częstotliwości UWB, zaczynając od 2,1 GHz do 12. 6 GHz. (**Wysoki zysk z jednobiegunowych anten drukowanych UWB zasilanych CPW w kształcie Mercedesa do zastosowań UWB**)*

Keywords: CPW-Fed MPM antenna, UWB applications, high gain, efficiency
Słowa kluczowe: antena szerokopasmowa, drukowana antena jednobiegunowa, zysk

Introduction

The Federal Communications Commission (FCC) certified the use of the band from 3.1 to 10.6 GHz for UWB applications without the need for any permission, and to prevent interference with existing bands; UWB technology permits the spread of extremely short pulses in a wide range of frequencies [1].

The UWB systems have been frequently used in the market for their affordable fabrication cost; the complexity level is low and high pulse speed of 500 Mbps at 10 feet using most insufficient power.

UWB printed monopole antennas are extensively Spread to their excellent characteristics such as uncomplicated structure, making them easy to fabricate and less fabrication cost. However, these kinds of antennas are still struggling with unsatisfactory performance, such as low gain, limited bandwidth, and poor efficiency [2]–[7]. The UWB antennas are usually feeds using partial ground plane [8] (PGP) and Coplanar waveguide (CPW) [9]. The CPW fed has more attention to use due to the fact that it is easy to combine with the integrated circuit board (ICB). There are many researchers designed and proposed UWB antenna for UWB applications using different techniques. Referenced in [10], [11], presented U-shaped split ring resonator (SRR) in order to create the UWB response. In [12], Usman presented a semi-circular patch UWB antenna covering a bandwidth from 3GHz to 11.5 GHz with a poor peak gain of 1.8dB, respectively. In 2020, Fang [13], presented a low UWB antenna profile covering a fractional bandwidth of 60% from 4.3 GHz to 8GHz. The peak gain was only 3.8 dB at 7.4 GHz. Moreover, different shapes of UWB antennas such as broken-heart and maple leaf-shaped are given in [14], [15]. A few more techniques were proposed to obtain a high antenna gain [16]–[18].

At this point, a Mercedes shaped antenna with high gain of 6.88 dB, for UWB application is proposed. The total dimensions of the proposed antenna are 50×50×1.6mm with respect to the center frequency of 7.35 GHz. The MPM antenna showed a response in the range of 2.1GHz to 12.6GHz, which can be used in many UWB applications.

Design of CPW-Fed MPM Antenna:

The geometry of the presented CPW-fed Mercedes-shaped printed monopole (MPM) antenna is displayed in Fig. 1. The MPM antenna consists of a Mercedes-shaped patch with a three-legged radiating patch. The Mercedes radiating patch of the antenna is printed on the one surface of the dielectric substrate. The FR4 substrate was used for the simulation process and had an Epsilon (dielectric constant) of 4.5 with a dissipation factor (tan δ) of 0.034. The total antenna dimensions are 50×50×1.6mm, which are the length (L) and the width (W), with 1.6mm of the FR4 substrate thickness (ht), all antenna parameters are listed in Table.1.

Table 1. The proposed MPM antenna parameters

Parameters	Values (mm)
Substrate width (W)	50
Substrate length (L)	50
Substrate thickness (h_t)	1.6
The radius of the desk (R)	15
The circular radius width (R_{in})	4.6
The legs width (L_{in})	4.6
The legs width (L_{out})	7.7
Ground width (G_w)	22.2
Ground length (G_l)	14.8
The feed width	4
The spaces between the CPW feed (S)	0.8

The value of R can be calculated by using the circular patch disk equations as the following [19]:

(1)
$$R = F/[1 + (2h/\pi\varepsilon_r F)(\ln(\pi F/2h) + 1.7726]^{1/2}$$

where: R=present radius, $F = 8.791 \times 10^9/f_r(\varepsilon_r)^{1/2}$, f_r – resonance frequency, h - hight of the substrate, ε_r - substrate dielectric constant,

The width of the feed-line (Fw) can be calculated from Characteristic impedance Zo, as shown in the equation below:

(2) $Z_o = \left[30\pi/\left(\varepsilon_{reff}\right)^{1/2}\right] \times [K(k')/K(k)]$

where: $K = G_w/(G_w + 2S)$, G_w – width of the CPW, S – the spaces between the feed-line and the CPW

Now, we have to calculate the ratio of K/K' as a given equation below:

(3) $K(k)/K(k') = (1/\pi)ln\left[2 \times (1+\sqrt{K})/(1-\sqrt{K})\right]$

(4) $K(k)/K'(k) = (1/\pi)ln\left[2 \times (1+\sqrt{K})/(1-\sqrt{K})\right]$

$for\ 0.707 \le k \le 1$

(5) $K(k)/K'(k) = \pi/ln\left[2 \times (1+\sqrt{K'})/(1-\sqrt{K'})\right]$

$for\ 0 \le k \le 0.707$

The relative permittivity ε_{reff} calculated using:

(6) $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}\left[\begin{matrix}\tan h\{1.785\log(h/W) + 1.785\} + \\ \frac{KW}{h}\left\{\frac{0.04 - 0.7k + 0.01}{(1-0.1\varepsilon_r)(0.25+k)}\right\}\end{matrix}\right]$

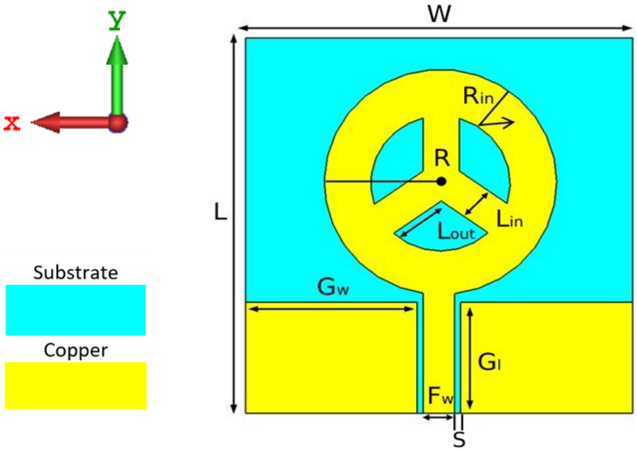


Fig. 1. The geometry of the proposed MPM antenna

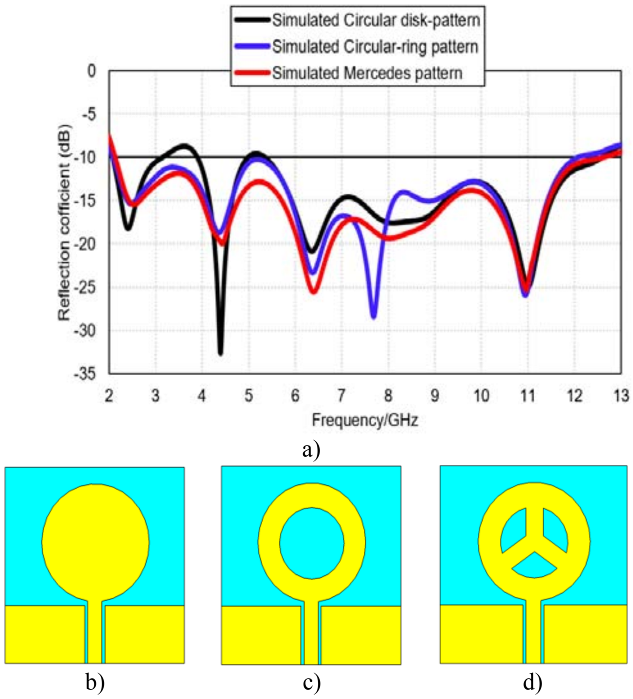


Fig.2. a) The simulated reflection coefficient (S11) in the three different pattern designs of the MPM antenna, (b) Circular-disk pattern, (c) Circular-ring pattern, (d) Mercedes pattern

After that, to determine the most proper UWB antenna design, three different patterns with the same external dimensions are simulated and analysed. These patterns are circular disk pattern, circular ring pattern and Mercedes pattern. It is worth mentioning that the exact dimensions of the CPW-fed ground plane are the same for all designs, which are $G_l \times G_w$, and their values were given in Table. 1. The simulated reflection coefficients (S11) with the three patterns are presented in Fig .2.

From the proposed patterns in Fig.2, the antenna with the Circular disk pattern has four main resonant frequencies, the frequency band from 3.1GHz to 3.9GHz is out of -10dB range, which not incorporate the UWB spectrum. Then, the circular ring pattern achieves a wide impedance bandwidth of 2.1GHz to 12.08GHz. However, the UWB frequencies have less resonates through the bands; for example, the resonant frequency at 5.2GHz has a -10.1dB of return loss performance. Finally, the Mercedes pattern obtained a wide range frequency from 2.1GHz to 12.6GHz with better return loss performance of -13.5dB at 5.2GHz.

Simulation Results and Analysis

Fig. 3a. proposed the three patterns max gain over frequencies. It can realise that the simulated Mercedes pattern antenna (red colour) obtain a high gain of 6. 88dB. Meanwhile, it can also be admitted that the gain is more stable through the UWB frequencies unlike those for circular disk-pattern and circular-ring pattern. Moreover, the MPM antenna exhibited a high radiation efficiency of 0.974 (in linear scale) around 97.4% in the operational band as shown in Fig. 3b.

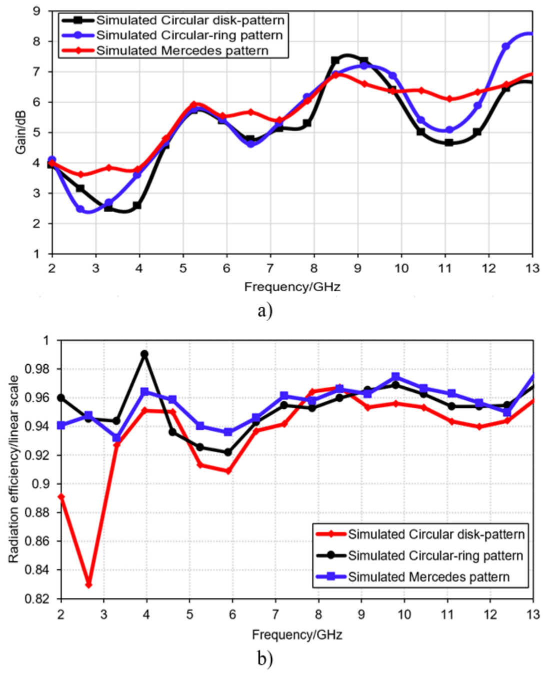


Fig.3. The simulated three-antenna patterns in both a) gain, b) efficiency.

The simulated radiation patterns of the proposed UWB CPW-fed MPM antenna in both H and E field are presented in Fig.4. The radiation pattern was simulated in varies frequencies such as 3GHZ, 6GHz and 9GHz.Where the vary step, angels are Theta=90^o and Phi=90^o, respectively. According to the radiation pattern graph, the simulated results proved that the antenna is almost Omni-directional Radiation at H and E plane.

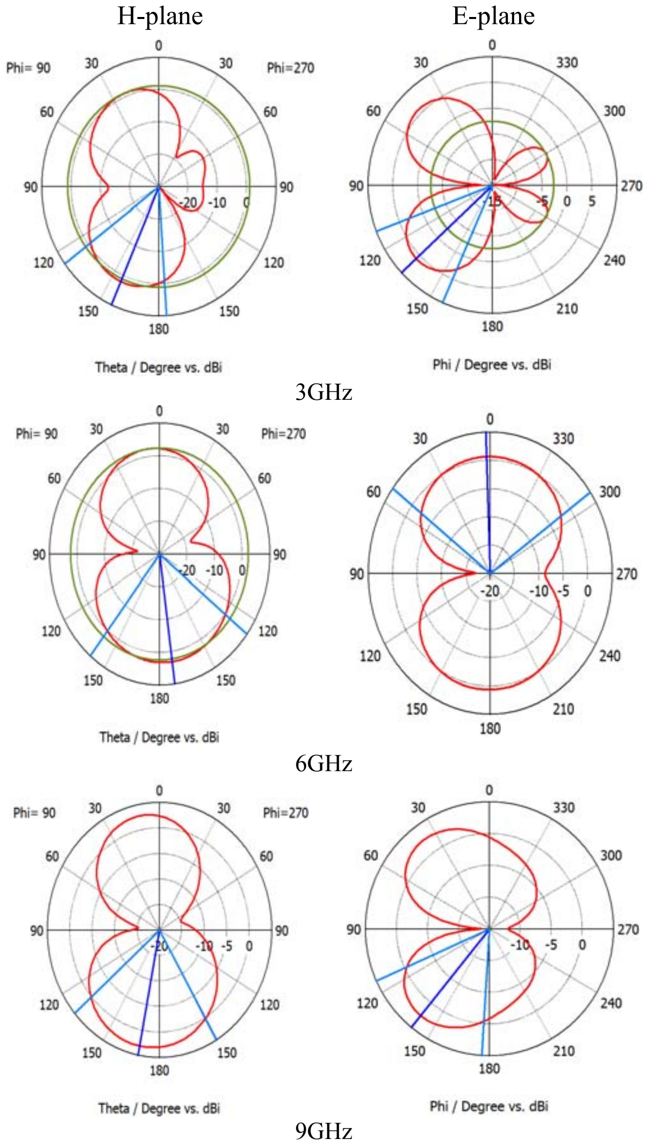
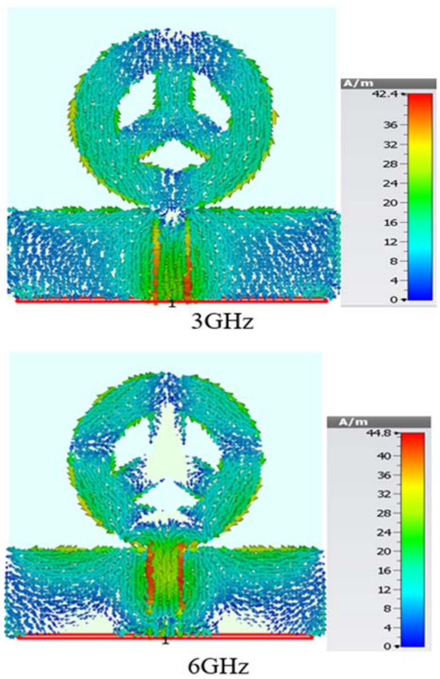


Fig. 4. The simulated radiation pattern for H and E-plane at 3GHz, 6GHz and 9GHz



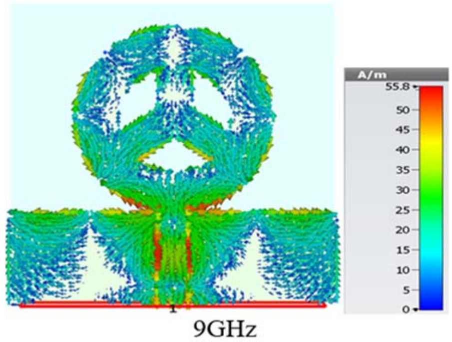


Fig.5. The surface current flow at different frequencies

The quarter-wave parts follow a series-resonant electrical component due to the standing wave started accompanying the conductor. At the resonant frequency, the standing wave has a current peak and voltage connection at the feed. This means the element has minimum reactance in electrical terms, creating the highest current for smallest voltage. The equivalent current distributions of the CPW-fed MPM antenna at various frequencies such as 3GHz, 6GHz and 9GHz are displayed in Fig.5. Respectively, the figure shows that the primary current is distributed at the sides of the CPW fed and more of the Mercedes radiating patch, which plays a crucial role in generating resonances to improve the impedance antenna bandwidth.

Conclusion

A novel UWB Mercedes shaped printed monopole antenna for high gain antenna application is presented. The proposed antenna has an electrical dimension of 1.2λo× 1.2λo× 0.039λo at the center operating frequency of 7.35 GHz. Three types of antenna patterns were compared and presented to validate the proposed design. The simulated UWB MPM antenna delivers a fractional bandwidth of 143% incorporating a bandwidth of 10.5GHz from 2.1 up to 12.6GHz. The radiation antenna efficiency was 97.4% with a peak gain of 6.88dB. The simulated results confirmed that the proposed MPM antenna is a good candidate for several UWB applications.

Authors: *The first five authors have come from the same university and faculty: Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka. The author's e-mails are as follows: engahmed_jamall@yahoo.com. imranibrahim@utem.edu.my. zahriladha@utem.edu.my. eng.moh1010@gmail.com. hussam.w@hotmail.com. ayman971972@gmail.com. Hussam Hamid Keriee, come from Universiti Teknologi Malaysia 81310 Skudai, Johor Bahru, Johor, Malaysia, Sam22.utm@gmail.com.*

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