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TECHNICAL NOTE

New Low Cost Printed Antenna CPW-Fed for Global Positioning System, Personal Communication System and Worldwide Interoperability for Microwave Access Band Applications

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ABSTRACT

This paper presents a new design of a Coplanar Waveguide (CPW)-fed multi-bands planar antenna. This antenna can be integrated easily with passive and active elements. The proposed antenna is suitable to operate for GPS, PCS and WiMAX bands. Its entire area is 52.3x52.6 mm^2 and is employed on an FR-4 epoxy substrate and fed by a 50 Ohm coplanar line. The antenna parameters have been analyzed and optimized using Advanced Design System (ADS). Before passing to the fabrication of this antenna structure, we conducted a study into simulation using CST microwave studio and Ansoft's HFSS solvers in order to verify the ADS results. The fabrication and test of the final circuit permits to have a good agreement between simulation and measurement results.

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1. INTRODUCTION

Due to the rapid growth of the modern wireless communication technologies, there has been an increasing and intensive demand for the development of the multi-band antennas in order to meet the needs of the global System for Mobile Communication (GSM), Personal Communication System (PCS), Global Positioning System (GPS), Universal Mobile Telecommunications System (UMTS) and the Worldwide Interoperability for Microwave Access (WiMAX) [1-5]. Another reason for choosing multi-band antenna is that its compact size is suitable for mobile phone applications and wireless integrated systems. For such applications, Coplanar Waveguide (CPW)-fed coplanar antennas have many attractive features, such as having a low radiation loss, less dispersion, single metallic layer for the feed network and easy integration with passive and active elements. However, they have limitations, the gain is low and their size becomes larger at lower frequencies [6-11].

There are several methods which can be used with CPW-fed coplanar antenna to obtain multi-band behavior: higher order resonances, resonant traps, combined resonant structures and parasitic resonators have been introduced to achieve this objective [12]. We can also find another technique based on the use of shorted-circuit [13, 14]. The aim of this study is to use a coplanar configuration permitting to obtain a novel multiband antenna structure.

In this paper, a simple structure composed of four arms of different lengths in the shape of a fork, a U-shaped slot and a L-shaped shorted strip which is connected between the small vertical arm and the ground plane is considered. To design an antenna with these characteristics, we used optimization techniques integrated into Advanced Design System (ADS) to

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realize and validate an antenna which can operate for GPS, PCS and WiMAX bands. After optimization and miniaturization using ADS, we compared the obtained results with other solvers including CST-Microwave studio and Ansoft's HFSS. The last part of this paper presents a comparison between simulation and measurement results.

2. ACHIEVEMENT TECHNIQUES OF MULTIBAND ANTENNAS

Many techniques are used to realize multiband antennas. Among these techniques, we use higher order resonances [12]. This is illustrated in Figure 1 which shows the resonant modes of monopole antenna.

Monopole antenna is frequently used with a length of λ/4. For this case, the antenna resonates at f_0 while electric field at the feed is minimum and the current density is maximum. However, a similar condition exists when the same antenna's length corresponds to 3λ/4. Hence, the monopole antenna can also resonate at $3f_0$, other natural resonances will also exist at higher frequencies at $5f_0$. Another method which is used to obtain the multiband behavior is the use of multiple resonant structures [12] often used for mobile communication systems. Two or more resonant structures can be closely located or even co-located with a single feed point in order to achieve multiband operation. This is illustrated in Figure 2, which shows two closely spaced, adjacently located monopoles with a common feed point.

The larger element is operational at the lower frequency f_1, while the smaller one is operational at the higher frequency f_2.

The use of parasitic resonators to the antenna system [12] can achieve the multiband function. This is illustrated in Figure 3, here the parasitic antenna is shown with a load, which can be used for tuning.

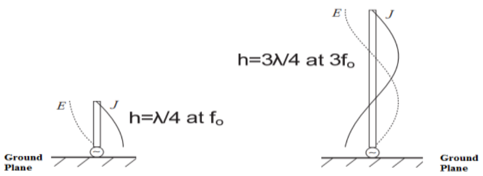

Figure 1. Higher order resonances

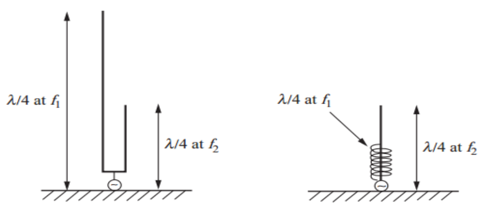

Figure 2. Combined resonant structures

Usually, the load would be reactive so as to maintain high antenna efficiency.

3. THE PROPOSED ANTENNA DESIGN

Figure 4 illustrates the geometry and configuration of the proposed antenna with a tuning stub in the shape of a fork, an inverted L-shaped element joined to the ground plane and a U-shaped slot in the CPW feed line. This antenna is printed on an FR-4 epoxy substrate with relative permittivity ε_r=4.4, a tangent loss tan (δ) =0.025, a metallization thickness t=0.035 mm and a substrate thickness h=1.6 mm. The antenna is fed by a 50 Ohm coplanar line with a fixed strip G=4 mm and a gap S=0.4 mm. In the design, two finite ground planes with the same dimensions of length L_b and width W_b are situated symmetrically on each side of the CPW feed line.

The antenna structure, the ground plane and the feeding line are implemented on the same plane. The dimensions of the antenna are optimized and miniaturized using ADS. After many series of optimization using the different optimization methods integrated in the electromagnetic solver, the final optimized antenna is validated with the following parameters shown in Table 1.

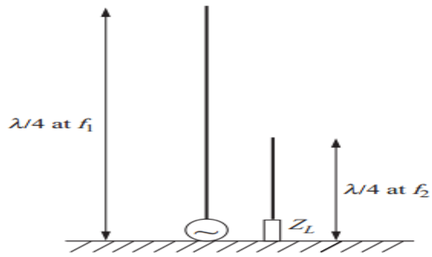

Figure 3. Parasitic resonators

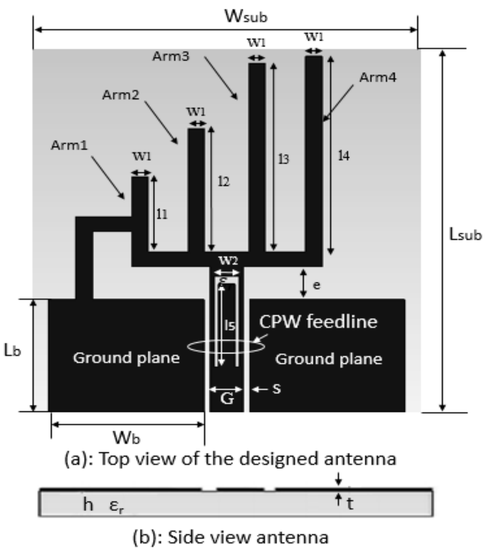

Figure 4. Geometry of the proposed antenna

The total volume of the proposed antenna is (52.3x52.6x1.6) mm^3 (L_{sub} x W_{sub} x h).

The design procedure is as follows. Firstly, the proposed antenna consists of two monopoles which are centered and connected to the end of the CPW feed line. This method was previously mentioned in part 2, especially for multiple resonant structures as shown in Figure 2. The resonant frequency (f_1) and (f_2) can be calculated using Equations (1) and (2) [15]:

$$f_i = \frac{c}{\lambda_g \cdot \sqrt{\varepsilon_{eff}}} \quad where \quad l_j = \frac{\lambda_g}{4} \tag{1}$$

$$\sqrt{\varepsilon_{eff}} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c is the free space velocity of light, ε_r is the relative permittivity of substrate and λg is the wave length.

To reduce the overall weight and size of the proposed antenna and to obtain another resonant frequency, two L-shaped elements of different lengths are placed symmetrically on both sides of the two monopole antenna. Then an inverted L-shaped shorted strip with the tuning stub is joined to the ground plane. At the final step, an inverted U-shaped slot is created in the transmission line to enhance the three resonant frequencies. Figure 5 shows the evolution of the proposed antenna.

Figure 6 shows the different reflection coefficients corresponding to each antenna 1 to 4.

After many series of optimization, it became evident that every geometrical parameter has different effects on the performance of proposed antenna. As shown in Figures 7 and 8, we can conclude that the length of arm 3 and arm 4 is an important parameter which influences the frequency band.

TABLE 1. Dimensions of the proposed antenna (unit in mm)

Parameter	Value	Parameter	Value
Wsub	52.6	w_2	3
Lsub	52.3	l_1	10
Lb	15	l_2	16.4
Wb	18.6	l_3	25
w_1	2	l_4	28
e	4.3	l_5	11.0568
G	4	s	0.4

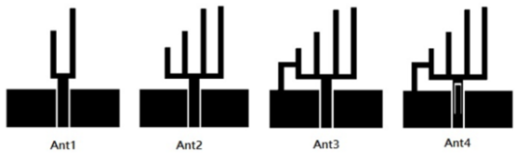

Figure 5. Followed steps to develop the proposed antenna

As shown in Figure 9, we have an antenna which is validated with the first resonant frequency of 1.582 GHz and a bandwidth (1.527-1.634 GHz). These resonant frequency and bandwidth match the GPS band. The second resonant mode occurs at the frequency of 1.879 GHz with a bandwidth (1.846-1.924 GHz), which is the PCS band. We can also notice that the third resonant mode occurs at the frequency of 2.519 GHz with a bandwidth (2.437-2.679 GHz), which covers the WiMAX band.

Figure 10 presents a comparison using ADS, CST-MW and Ansoft's HFSS solvers. We can conclude that there is an agreement between the three solvers with a small difference which is due to the different numerical methods used in these electromagnetic solvers [16].

In order to better understand the antenna behavior, the current distribution of the three bands at frequencies of 1.582, 1.879 and 2.519 GHz are simulated using ADS as shown in Figure 11.

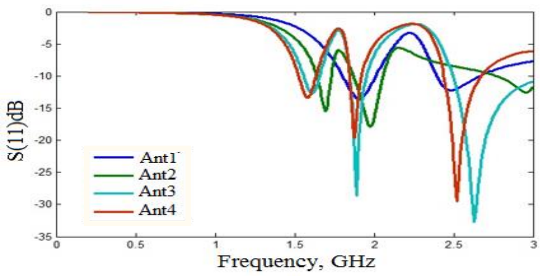

Figure 6. Different reflection coefficients obtained for each antenna

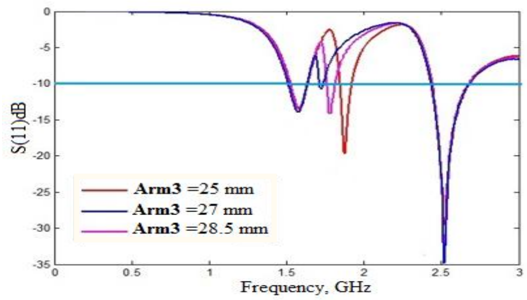

Figure 7. Reflection coefficient for different values of (arm 3) parameter with other parameter fixed

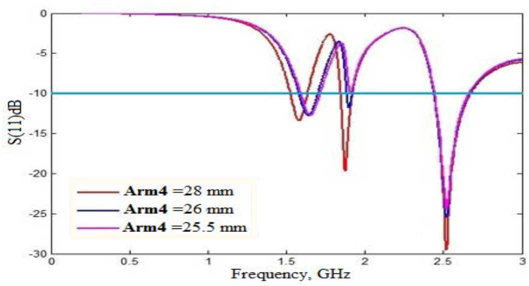

Figure 8. Reflection coefficient for different values of (arm 4) parameter with other parameter fixed

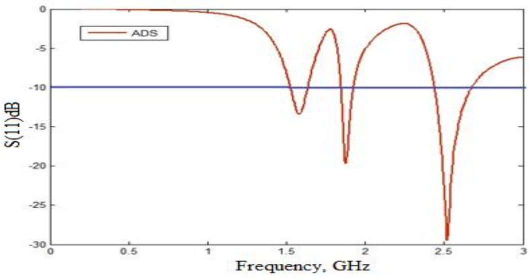

Figure 9. Final result of the reflection coefficient on ADS

The current distribution differs according to the resonant frequencies as shown in Figure 11. Concerning the first resonant mode at 1.582 GHz band, a large surface current density is observed along the amr 4. When it reaches 1.879 GHz, the current distribution is concentrated on the edge of fork-shaped antenna especially along the arm 3 and arm 4. As for the third resonant mode at resonant frequency 2.519 GHz band, the current distribution becomes more concentrated on the other edge of fork-shaped antenna.

The simulated antenna radiation patterns are shown in Figure 12. It can be seen that the antenna shows a bidirectional radiation pattern over each resonant frequency.

From Figure 13, we notice that the VSWR is less than 2 at the frequency range of (1.381-1.625 GHz), (1.811-2.011 GHz) and (2.442-2,998 GHz).

Figure 14 presents the variation of the gain versus frequency. After simulation we obtained the gain 1.334 dB at 1.582 GHz, 3.209 dB at 1.879 GHz and 4.542 dB at 2.519 GHz.

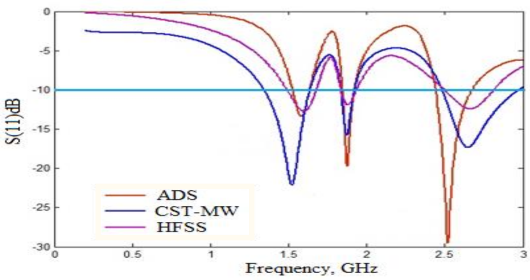

Figure 10. Comparison of reflection coefficient between ADS, CST-MW and HFSS

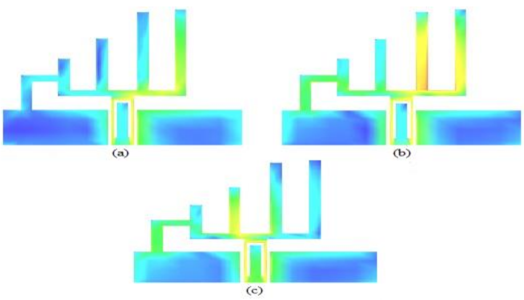

Figure 11. Surface current distribution of the monopole antenna @ (a) 1.582 GHz, (b) 1.879 GHz and (c) 2.519 GHz

Table 2 presents a comparison of the proposed antenna with bibliography taking into account the antenna size, resonance frequency and antenna purpose.

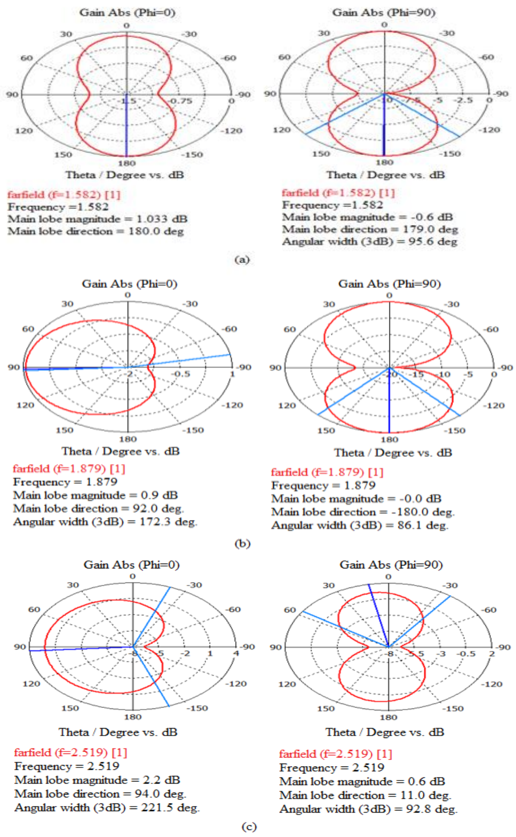

Figure 12. Radiation pattern of the proposed antenna on CST: a: @ 1.582 GHz b: @ 1.879 GHz c: @ 2.519 GHz.

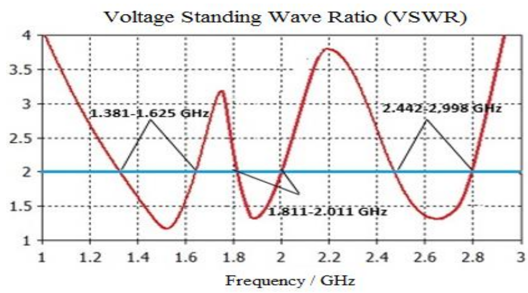

Figure 13. VSWR versus frequency

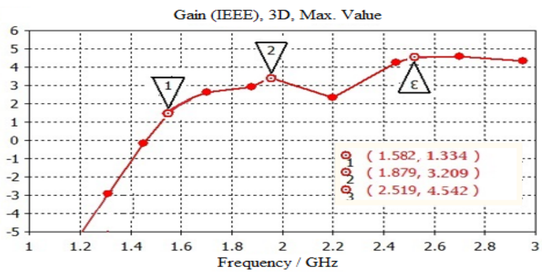

Figure 14. Gain versus frequency

As we can see from the same table, the proposed antenna is smaller in terms of size and is suitable for tri-band applications.

4. EXPERIMENTAL RESULTS AND DISCUSSION

After the design and optimization of the multi-band antenna using different solvers, the prototype of the investigated antenna is achieved and measured to check the performance of the results obtained by simulation. The fabricated multi-band antenna is shown in Figure 15. The measurement is performed with a Vector Network Analyzer (VNA) from Rohde & Schwarz. The used calibration Kit was 3.5 mm from Agilent technologies.

After testing the achieved antenna, we conducted a comparison between simulation and measurement results as shown in Figure 16.

TABLE 2. Comparison of proposed antenna performance with other compact antennas

Published literature versus proposed work	Antenna size (mm^2)	Resonance frequency (GHz)	Antenna purpose
Ref [17]	85x85	1.8/2.4/3.5/5.2	Four-band
Ref [18]	114x60	4.7/0.9/1.8	Tri-band
Ref [19]	65x72	1.58/2.5	Dual-band
Proposed work	52.3x52.6	1.582/1.879/2.519	Tri-band

Figure 15. Photo of the fabricated antenna structure

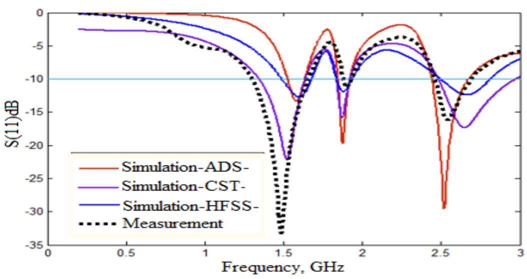

Figure 16. Comparison of simulated and measured reflection coefficient

Figure 16 shows that there is an agreement between simulation and measurement results of the reflection coefficient of the proposed antenna. The difference between the measured and simulated results is due to the fabrication constraints, uncertainties in the dielectric constant and substrate thickness and soldering effects. The results show that the proposed antenna can be suitable for GPS, PCS and WiMAX applications.

5. CONCLUSION

In this work, a study of a new low cost antenna was analyzed and validated for multiband applications. The whole volume of proposed antenna was 52.3x52.6x1.6 mm^3. Different results obtained using an optimized CPW-fed transmission line were combined with a new antenna geometry in fork-shaped and L-shaped shorted strip integrating slot technique in U-shaped. The achieved and tested coplanar antenna presented good agreement between simulation and measurement results. These results validated the antenna structure for 1.582, 1.879 and 2.519 GHz operating in specific microwave applications such as GPS, PCS and WiMAX bands. The final circuit can be integrated easily with passive and active components for wireless applications.

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چکیده

در این مقاله یک طراحی جدید از یک آنتن مسطح چند باندکه با همسطح موجبر (CPW) تغذیه می‌شود ارائه می‌گردد. این چنین آنتنی می تواند به راحتی با عناصر فعال و غیر فعال یکپارچه شود. آنتن پیشنهاد برای استفاده در GPS، PCS و باندهای وایمکس مناسب است. کل مساحت آن ۵۲/۳ × ۵۲/٦ میلی‌متر مربع است و بر روی سوبسترای اپوکسی FR-4 استفاده شده و توسط خط همسطح ۵۰ اهم تغذیه می‌شود. پارامترهای آنتن تجزیه و تحلیل شده و با استفاده از سیستم طراحی پیشرفته (ADS) بهینه سازی می‌شود. قبل از اقدام برای ساخت این ساختار آنتن، ما یک مطالعه شبیه سازی با استفاده از استودیو مایکروویو CST و حل HFSS Ansoft انجام دادیم تا نتایج ADS را بررسی کنیم. ساخت و تست مدار نهایی اجازه می‌دهد که توافق خوبی بین نتایج شبیه سازی و اندازه گیری داشته باشیم.

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