A Novel Broadband Compact Circular Disk Microstrip Antenna for Wireless Applications

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Abstract—A novel shape of microstrip antenna which is electromagnetically coupled to a conventional circular disk microstrip antenna (CMSA) mounted on a ground plane and spaced by a layer of foam is studied by simulation and experiment to operate at 5.2 GHz for Wireless Local Area Networks (WLANs). The novel shape proposed has a size reduction of 85% as compared to the conventional circular disk patch antenna operating at the same frequency. It is found that the bandwidth of this antenna ranges from 4.8 GHz up to 6.15 GHz considerably when an optimum foam thickness is provided. The suggested design is optimized using the full wave simulation software package Zeland IE3D based on the method of moments (MoM). The experimental results agree well with the simulated one.

1. INTRODUCTION

Microstrip antennas have the attractive features of low profile, light weight, easy fabrication process, and conformability, but these antennas inherently suffer from the narrow bandwidth. Since the world is going wireless, current advancements in communication technology and significant growth in the wireless communication market and consumer demand demonstrate the need for smaller, broadband and reliable antennas. Therefore, bandwidth enhancement and size reduction are becoming the major design considerations for practical applications. Several useful techniques applied to improve the bandwidth and size reduction are presented in [1]. In particular, adding a capacitive component to the input impedance of the radiating patch that compensate for the inductive component of the feeder by embedding a cutting slots in it such as E-shape [2, 3], V-shape [4], and U-shape [5, 6] leads to increasing the percentage bandwidth as long as the resonance frequencies of the patch and the slot are close to each other. Moreover, using more than one layer of resonance patch that is coupled electromagnetically to each other instead of planar structure in order to meet the demand of small size will effectively enable the bandwidth to increase. These parallel layers are incorporated to introduce another resonance. Since the bandwidth is inversely proportional to the dielectric constant $\varepsilon_r$ of the substrate, a layer of foam is employed to decrease the effective dielectric constant $\varepsilon_{eff}$ and increasing the total thickness of the antenna at the same time.

![Figure 1: Configuration of CMSA (a) CMSA with shorting pin (b) CMSA with U-slot.](image-url)
bandwidth that is inconvenient for our applications. On the other hand, the bandwidth of CMSA with U-slot is found to be increased to 21%. The configurations of these antennas are illustrated in Figure 1, and the return loss is shown in Figure 2. A study of CMSA supported by a layer of foam was done in both the normal and inverted configurations by changing the foam thickness where the optimum percentage bandwidth is found to be 15.5% and 12.36%, respectively. Consequently, more than one of aforementioned technique are combined together to obtain compactness and broadband. In this paper, a novel shape of CMSA is proposed having a reduction of size by 85% compared to the conventional circular disk patch antenna which is electromagnetically coupled to a circular patch spaced by a layer of foam at an optimum thickness is investigated. Alternatively, the feeding patch is simple CMSA and the radiating patch considered is the novel shape. The dimensions of the two patches are optimized to attain over 30% impedance bandwidth for WLANs operating at 5.2 GHz.

![Figure 2: Return loss Vs Frequency of CSMA.](image)

Conventional: $a = 10.65$ mm, $\varepsilon_r = 2.20$, $h = 1.575$ mm, $X_f = 3.3$ mm, $r_f = 0.3$ mm, BW = 3.4%.

Shorted: $a = 3.47$ mm, $\varepsilon_r = 2.20$, $h = 1.575$ mm, $X_f = 2.585$ mm, $X_p = 3$ mm, $r_f = r_p = 0.4$ mm, BW = 2.7%.

U-slot: $a = 10.65$ mm, $h = 1.575$ mm, $\varepsilon_r = 2.20$, $r_f = 0.3$ mm, $(X_f, Y_f) = (0, -1)$, BW = 21%.

![Figure 3: Configuration of the radiating and feeding patches.](image)

2. ANTENNA CONFIGURATION

The feeding layer contains a simple CMSA of radius 10.65 mm which is fed by 50 Ohms-SMA connector of diameter 1.27 mm located at 6 mm from the center of the patch, while the radiating
layer contains a novel shaped patch as shown in Figure 3. The proposed shape is based on a square cut of length 3 mm in the edges of the circular patch of radius 9.65 mm. A finite number of slits (8-slits) is incorporated to obtain a compact size. The structure of this design is illustrated in Figure 4. A layer of foam $\varepsilon_r = 1.07$ at an optimum thickness of 3.2 mm is employed between the two layers in order to decrease the effective dielectric constant and increase the total thickness of the antenna.

![Figure 4: Structure of the antenna for bandwidth enhancement technique.](image)

The change in the foam thickness is playing a role in change the total thickness of the antenna and its size which influences the bandwidth [8]. Figure 5 shows a comparison between the calculated and simulated results to determine the exact thickness required to obtain a wide bandwidth. The calculated results are obtained according to [9]:

$$\text{BW} = \frac{\text{VSWR} - 1}{Q_T\sqrt{\text{VSWR}}}$$  \hspace{1cm} (1)

The bandwidth is taken at VSWR = 2, so that

$$\text{BW} = \frac{1}{\sqrt{2Q_T}}$$ \hspace{1cm} (2)
where

\[ Q_T = \left[ \tan \delta + \frac{1}{h_T \sqrt{\pi f_0 \mu_0 \sigma}} + \frac{h_T f_0 \mu_0 (k_0 a)^2 I}{30 ((ka)^2 - n^2)} \right]^{-1} \] (3)

\[ \tan \delta = 0.001, \ f_0 = 5.2 \text{ GHz}, \ \mu_0 = 4.7 \times 10^{-7} \text{ H/m}, \ h_T = h_1 + h_2 + h_{foam}, \ h_1 = h_2 = 1.575 \text{ mm}, \]
\[ k = \sqrt{\varepsilon_r k_0} \text{ and } k_0 = \frac{\omega_0}{v_0} \text{ speed of light}. \]

For the dominant mode, \( n = 1 \). By substituting Equation (3) into Equation (2), then

\[ \text{BW} = \frac{1}{\sqrt{2}} \left[ \tan \delta + \frac{1}{h_T \sqrt{\pi f_0 \mu_0 \sigma}} + \frac{h_T f_0 \mu_0 (k_0 a)^2 I}{30 ((ka)^2 - 1)} \right] \] (4)

where

\[ I = \int_0^{2\pi} \left[ J_1^2 (k_0 a \sin \theta) + \cos^2 \theta \frac{J_1^2 (k_0 a \sin \theta)}{(k_0 a \sin \theta)^2} \right] \sin \theta d\theta \] (5)

This integration is evaluated numerically yields to \( I = 0.1957 \). Obviously, the calculated bandwidth according to Equation (4) is found to be 1 GHz at an optimum thickness of 3 mm which coincided with the maximum bandwidth simulated using IE3D electromagnetic simulator as shown in Figure 5.

![Figure 6: Simulated and measured return loss.](image)

3. RESULTS

The simulated results are optimized based on IE3D software. Numerous iterations were done to obtain the optimum configuration. The optimized configuration is fabricated using photolithographic technique. Figure 6 shows the measured and simulated results of the return loss. Obviously, the general shapes of both results are very close. Furthermore, the simulation clears that a bandwidth ranges from 4.8 GHz up to 6.15 GHz which is quite enough to cover the band of 5 GHz compared to a slight shift in the measured results. It is seen that around the resonant frequency the antenna input impedance is very close to 50 \( \Omega \) as shown in Figure 7. The measured antenna gain and radiation efficiency were 7.47 dB and 90\%, respectively. The simulated radiation patterns are illustrated in Figure 8. Through the simulation it has been noticed that the most important parameter that affect the resonance performance is the width of the cutting slits. The fabricated antenna is photographed in Figure 9.
4. CONCLUSIONS
Two stacked layers of microstrip antennas have been designed and investigated experimentally. The feeding patch is CMSA coupled electromagnetically to a compact novel shaped spaced by a layer of foam. Simulation and experimental studies are performed. When the thickness of the foam layer is changed, variation in the percentage bandwidth could be obtained. The advantage
of simplicity and compactness of this structure make it useful for WLANs applications than other designs. This approach is clearly enhancing the percentage bandwidth of the microstrip antennas used for WLANs. Using combinations of several techniques is promising idea to obtain a broadband microstrip antenna. There will be advantages and disadvantages which means that a trade-off have to be considered in the design.

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