Optimization of a Wide-Band 2-Shaped Patch Antenna for Wireless Communications

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Abstract: - A design of a novel single-patch wide-band microstrip antenna: the 2-shaped patch antenna for wireless communications is proposed. Two opposite parallel slots are incorporated into the patch of a microstrip antenna to expand it bandwidth. The slot length, width and height of substrate are optimized to achieve a wide bandwidth. Finally, a 2-shaped patch antenna, resonating at frequencies of 2.4 GHz, 2.65 GHz and 2.90 GHz and having a bandwidth of 26.84%.
The analysis and optimization have been performed using the simulator HFSS (High Frequency Structure Simulator) based on the finite element method. Next, in order to validate our simulation, we use another electromagnetic simulator CST MWS (Computer Simulation Technology- MicroWaves Studio) which is based on the finite integration method. The simulation results of the two simulators agree well practically.

Key-Words: 2-shaped, patch antenna, parallel slots, wide-band, bandwidth, wireless communication, simulators HFSS and CST.

1 Introduction

The rapid progress in wireless communication promises to make interactive voice, data, and video services available anytime and anyplace. The technology to support these applications has been made possible by recent advances in high-density RF and microwave circuit packaging. Wireless communications systems come in a variety of different sizes ranging from small hand-held devices to backpack-style "man-pack" radio units to wireless local area networks to devices mounted on vehicles. The current focus in electronics packaging and interconnects has led to the development of low-cost multichip modules and circuitry that can readily be incorporated into a broad spectrum of systems. For optimum system performance, the antennas must also have high radiation efficiency, small volume, isotropic radiation characteristics, simple and low-loss impedance matching to the receive and transmit paths, and simple mechanical construction [1]. Microstrip patch antennas are widely used because of their many advantages, such as the low profile, light weight, and conformity. However, patch antennas have a main disadvantage: narrow bandwidth. Researchers have made many efforts to overcome this problem and many configurations have been presented to extend the bandwidth. The conventional method to increase the bandwidth is using parasitic patches. In [2], the authors presented a multiple resonator wide-band microstrip antenna. The parasitic patches are located on the same layer with the main patch. In [3], an aperture-coupled microstrip antenna is described with parasitic patches stacked on the top of the main patch. In [4], two layer of substrate in gap coupled parasitic patch microstrip antenna. However, these methods typically enlarge the antenna size, either in the antenna plane or in the antenna height. With the rapid development of wireless communications, single-patch wide-band antennas have attracted many researchers' attention [5, 6].

In a previous work [7], the author has simulated a kind of 2.45 GHz frequency band microstrip patch antenna. He found a bandwidth about 18.8% for single-patch and 19.5% for an array antenna.
In this paper, we present a novel single-patch wide-band microstrip antenna: the 2-shaped patch antenna. When two opposite parallel slots are incorporated into the antenna patch, we have two bandwidths respectively 17.12% and 6.92%. When we vary the height of the substrate h ((h = 4 mm, h = 4.1 mm, h = 4.2 mm and h = 4.5 mm), the previous two bands have been merged into a single bandwidth of 26.84% (at -10 dB). The 2-shaped patch antenna is simpler in construction and designed to cover both 2.4 GHz, 2.65 GHz and 2.90 GHz. These ranges of frequencies are very desirable in modern wireless communications.

2 Microstrip Antenna Theory

In modern communications, low cost and low profile antennas are demanded. Microstrip patch antenna due to its conformal nature and capability to integrate with the rest of the printed circuitry satisfy those requirements. In antenna design feeding mechanism plays an important role. Coaxial probe feeding is sometime advantageous for applications like active antennas, while Microstrip line feeding is suitable for developing high gain Microstrip array antennas [8].
In general, patch antennas have the length of half-wave structures at the operation frequency of fundamental resonant mode. Since the fringing field acts to extend the effect length of patch, the length of the half-wave patch is slightly less than a half wavelength in the dielectric substrate material. Approximate value for the length of a resonant half-wavelength path is given by [9].

$$L = 0.49\,\frac{\lambda}{\sqrt{\varepsilon_r}} \tag{1}$$

Where, λ is the free-space wavelength and ε_r is the substrate dielectric constant.
Various analytical approximated approaches may be used to meet the initial design requirements. In this work, we have used transmission line model. All the dimensions of the patch antenna are calculated based on equations (2)-(5) [10]. The width is given by:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

Where f_r the resonant frequency of the patch antenna, ε_r is the dielectric constant of the substrate and c the free-space velocity of light. The effective dielectric constant for ($\frac{W}{h} > 1$) is given by

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right] \tag{3}$$

The extension of patch length due to fringing effects can be determined by

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

The effective length of patch after taking into fringing effect can be calculated by

$$L = \frac{c}{2\,f_r\,.\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{5}$$

3 Features of 2-Shaped Patch Antenna

The antenna geometry is shown in Fig.1. The antenna has only one patch, which is simpler than traditional wide-band microstrip antennas. The patch size is characterized by (L_p , W_p , h) and it is fed by microstrip line the length L_m and width W_m . To expand the antenna bandwidth, two opposite parallel slots are incorporated into this patch. The topological shape of the patch resembles the number "2", hence the name 2-shaped patch antenna. The slot length (L_s) and width (W_s) are important parameters in controlling the achievable bandwidth.

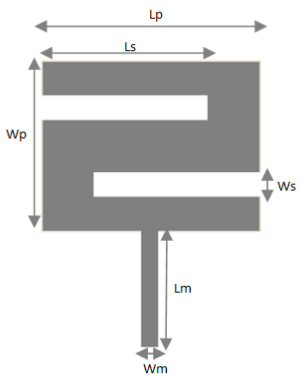

Fig.1: Geometry of a wide-band 2-shaped patch antenna

4 Design and Optimization of Patch Antenna

4.1 Software for Simulation

The software HFSS (High Frequency Structure Simulator) of Ansoft Corporation is commercial software which calculates the electromagnetic behavior of a structure in the frequency domain. It performs electromagnetic modeling by solving Maxwell's equations using the finite element method.

The simulation technique used to calculate the three dimensional electromagnetic field inside a structure is based on the finite element method (FEM). The principle of the method is to divide the study area into many small regions (tetrahedrons), then calculate the local electromagnetic field in each element. The local fields $\vec{E}$ and $\vec{H}$are calculated in each tetrahedron from the following equations [11]:

$$\vec{\nabla}\Lambda\frac{1}{\mu_r}\vec{\nabla}\Lambda\vec{E}(\vec{r}) - K_0^2\varepsilon_r\vec{E}(\vec{r}) = \vec{0} \quad (6)$$

$$\vec{H}(\vec{r}) = -\frac{1}{j\omega\omega_r}\vec{\nabla}\Lambda\vec{E}(\vec{r}) \quad (7)$$

ε_r and μ_r are respectively the permittivity and relative permeability of materials.

$K_0 = 2\pi f_r\sqrt{\mu_0\varepsilon_0}$ is the wave vector in vacuum, $\omega = 2\pi f_r$ is the pulsation angular frequency.

HFSS uses an interpolation method combined with an iterative process in which a mesh is created automatically and redefined in the critical regions. The simulator generates a solution based on the predefined initial mesh. Then, it refines the mesh in regions where there is a high density of errors, and generates a new solution.

The S_{ij} microwave parameters are calculated with the given following steps:

- Division the structure into a finite number of elements.
- Excitation of each port of the structure with a wave propagating along a wave guide structure or a uniform transmission line which has the same section as the port.
- Calculation of the total configuration of the electromagnetic field inside the structure.
- Calculation of matrices S_{ij} generalized from the reflected and transmitted powers.

4.2 Design and Optimization

In the typical design procedure of the microstrip antenna using transmission line model, the desired resonant frequency, thickness and dielectric constant of the substrate are known or selected initially.

In this design of single-patch wide-band microstrip antenna (Fig.1), Rogers RT/duriod 5880 (tm) dielectric material is selected as the substrate with 3.8 mm height. Then, a patch antenna that operates at the specified resonant frequency (2.4 GHz) can be designed by the using transmission line model equations [9].

The dimensions of the proposed patch antenna are shown in the Table 1:

Table 1: Parameter of the patch antenna

Antenna parameter	**Value (mm)**
L_p	50
W_p	56
L_m	41
W_m	3.8

In order to study the performance of our antenna, we will proceed to a series of simulations of the reflection coefficient S_{11} on a frequency range of 1.5 GHz to 3.5 GHz. We keep the same dimensions shown in Table 1 and we do vary the length L_s and width W_s of the slots. The simulation results of the reflection coefficient are represented in Fig.2.

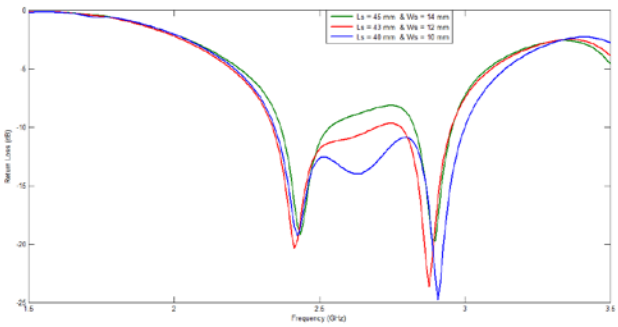

Fig.2: Return loss vs. frequency of the patch antenna

The simulation results show that the reflection coefficient S_{11} at the entrance of the patch antenna initially presents two frequency bands for each variation of the dimensions of the slots (see Table 2). Note also that when decrease the length and width of the slots, the width of the bandwidth increases progressively for the two bands (S_{11}< -10 dB).

Table 2: Results of the first optimization of 2-shaped patch antenna

Length of the slot L_s (mm)	Width of the slot W_s (mm)	First Band				Second Band			
		f_{r1} (GHz)	Return loss S_{11} (dB)	VSWR	Bandwidth (%)	f_{r2} (GHz)	Return loss S_{11} (dB)	VSWR	Bandwidth (%)
45	14	2.43	-19.23	< 2	6.53	2.89	-19.72	< 2	4.50
43	12	2.41	-20.33	< 2	13.91	2.87	-23.64	< 2	5.59
40	10	2.42	-19.29	< 2	17.12	2.90	-24.79	< 2	6.92

We will proceed to a new optimisation touching this time around the height h of the substrate (h = 4 mm, h = 4.1 mm, h = 4.2 mm and h = 4.5 mm) order to expand the bandwidth and recover any resonance frequencies. The simulation results of the reflection coefficient are represented in Fig.3.

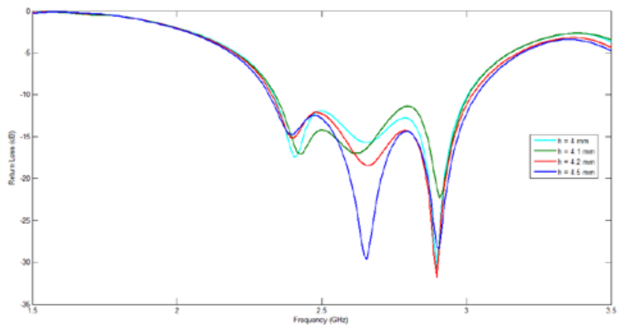

Fig.3: Return loss vs. frequency of the patch antenna

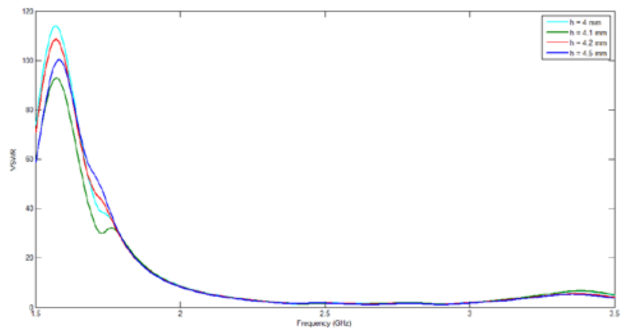

Fig.4: VSWR vs. frequency of the patch antenna

Figure 3 presents the variations of the reflection coefficient at the input of the patch antenna on a range of frequencies from 1.5 GHz to 3.5 GHz. It is found that when increases the height of the substrate progressively, the bandwidth increases. However, there is an appearance of resonance frequencies.
In table 3, one can observe that the 2-shaped patch antenna resonates at 2.4 GHz, 2.65 GHz and 2.90 GHz. These frequencies correspond to wireless applications.

The 2-shaped patch antenna presents a bandwidth of about 26.84% (at -10 dB). This result is optimal relatively than that found in the publication [7].

Table 3: Results of the second optimization of 2-shaped patch antenna

height of the substrate h (mm)	f_{r1} (GHz)	f_{r2} (GHz)	f_{r3} (GHz)	Max Return loss S_{11} (dB)	VSWR	Bandwidth (%)
4	2.40	2.65	2.89	-30.25	< 2	24.99
4.1	2.42	2.62	2.90	-21.77	< 2	25.10
4.2	2.39	2.64	2.89	-31.28	< 2	26.01
4.5	2.40	2.65	2.90	-29.64	< 2	26.84

5 Comparison of simulation results obtained by the simulator CST

We present in this section, for comparison, the simulation results obtained in terms of reflection coefficients, reports of standing waves, resonance frequencies and bandwidths using HFSS and CST simulators.
Note that the electromagnetic simulation software CST Microwave Studio is a specialized tool for three-dimensional electromagnetic simulation of high frequency components. It is dedicated primarily to microwave and RF communications such as wireless applications, but also can simulate measures electromagnetic compatibility and electromagnetic interference.
The main module of CST Microwave Studio proposes two engines resolution by finite differences, one in the time domain and the other in the frequency domain, operating on parallelepiped or tetrahedral grids.
It can be observed in Fig.5 and Table 4, a good agreement between the results obtained by HFSS and by those CST in terms of resonance frequencies, reflection coefficient and voltage standing wave ratio. The difference between the bandwidths is not due to the mesh used in simulation and during the simulation.

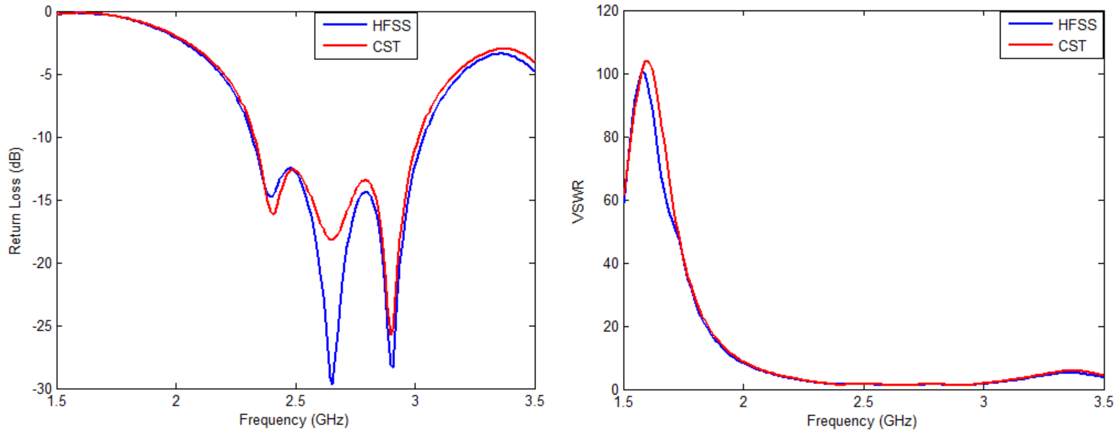

Fig.5: Comparison of simulation results in terms the reflection coefficient and voltage standing wave ratio using the simulators HFSS and CST

Table 4: Comparison of simulation results obtained with HFSS and CST

Simulators	f_{r1} (GHz)	f_{r2} (GHz)	f_{r3} (GHz)	Max Return loss S_{11} (dB)	VSWR	Bandwidth (%)
HFSS	2.40	2.65	2.90	-29.64	< 2	26.84
CST	2.404	2.645	2.897	-25.72	< 2	25.83

6 Conclusion

This paper has focused on the development of low profile integrated antennas with enhanced bandwidth performance.

The simulation result shows that the proposed antenna has a bandwidth of about 26.84%. The optimization method has allowed us to recover resonance frequencies 2.4 GHz, 2.65 GHz and 2.90 GHz used in the domains of wireless communications.

The proposed antenna has simple design structure and can easily be fabricated at low cost thus being a good solution for many wireless applications such as: RFID, Wi-Fi and WiMAX.

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