Microstrip patch antenna fabricated and simulated results for S-Band, C-band and X-band antenna for space and communication applications

Antena de microfita fabricada e resultados simulados para antenas de banda S, banda C e banda X para aplicações espaciais e de comunicação

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Muhammad Yasir
M.Phil Physics
Institution: Department of Computational Physics, University of Okara
Address: Pakistan
E-mail: yasir.yahoo2222@gmail.com

Ali Raza
PhD. in Electrical Engineering
Institution: Department of Electrical Engineering, University of Sao Paulo
Address: São Paulo, Brazil
E-mail: rmalikali286@gmail.com

Muhammad Adnan
M. Phil Physics
Institution: Department of Computational Physics, University of Okara
Address: Pakistan
E-mail: adnansehr@gmail.com

Hina Maryam
PhD in Physics
Institution: Department of Computational Physics, University of Okara
Address: Pakistan
E-mail: hinamaryam56@gmail.com

Musaddaq Mukhtar
Ph.D in Electrical Engineering
Institution: Department of Electrical Engineering, Universidade Federal de Pernambuco
Address: Pernambuco, Brazil
E-mail: mukhtar.musaddik@gmail.com
Maryam Liaqat  
PhD in Electrical Engineering  
Institution: Department of Computational Physics, University of Okara, Universidade Federal de Pernambuco  
Address: Pernambuco, Brazil  
E-mail: drmmaryam liaqat@uo.edu.pk

ABSTRACT
Different Microstrip patch antennas (MPA) designed and used for different applications from medical to wireless technology to satellite applications. Frequency range of S, C and X band are designed with different substrate of FR4 and polyimide. MPA are easy to fabricate in compact form with 4 to 18 array of antennas. Bow-Tie antenna designed for S-Band and an array of compact X-band antenna is designed and analyzed to achieve fixed satellite service (FSS) as shown in figure with band of 7.89 GHz-10.49GHz with gain up to 35dB. Another design with 6 GHz frequency designed with a plan background categorize in C-Band. Third design is with SSR background to simulate the antenna with X band. Antennas have been simulated and the fabricated using chemical etching process and the results were compared. Impedance, S11, gain and directivity were observed with different shapes of antennas at different frequency band. Moreover, the proposed antenna design can be used as an element in an array configuration to achieve high gain in both transmission and reception modes of FSS.

Keywords: microstrip patch antenna, SMA connector, vector network analyzer (VNA).

RESUMO
Diferentes antenas de patch de microfita (MPA) foram projetadas e usadas para diferentes aplicações, desde a área médica até a tecnologia sem fio e aplicações de satélite. As faixas de frequência das bandas S, C e X foram projetadas com diferentes substratos de FR4 e poliimida. As MPA são fáceis de fabricar em formato compacto com 4 a 18 conjuntos de antenas. A antena Bow-Tie foi projetada para a banda S e um conjunto de antenas compactas para a banda X foi projetado e analisado para obter um serviço fixo de satélite (FSS), conforme mostrado na figura, com uma banda de 7,89 GHz a 10,49 GHz com ganho de até 35 dB. Outro projeto com frequência de 6 GHz foi projetado com um plano de fundo categorize na banda C. O terceiro projeto é com fundo SSR para simular a antena com banda X. As antenas foram simuladas e fabricadas usando o processo de gravação química e os resultados foram comparados. A impedância, o S11, o ganho e a diretividade foram observados com diferentes formatos de antenas em diferentes bandas de frequência. Além disso, o projeto de antena proposto pode ser usado como um elemento em uma configuração de matriz para obter alto ganho nos modos de transmissão e recepção do FSS.

Palavras-chave: antena de patch de microfita, conector SMA, analisador de rede vetorial (VNA).

RESUMEN
Se han diseñado y utilizado diferentes antenas de parche Microstrip (MPA) para diferentes aplicaciones, desde aplicaciones médicas hasta tecnología inalámbrica y aplicaciones de satélite. El rango de frecuencias de las bandas S, C y X se ha diseñado con diferentes sustratos de FR4 y poliimida. MPA son fáciles de fabricar en forma compacta con 4 a 18 matriz de antenas. Se ha diseñado y analizado una antena Bow-Tie.
para la banda S y un conjunto de antenas compactas para la banda X con el fin de lograr un servicio fijo por satélite (FSS), como se muestra en la figura, con una banda de 7,89 GHz-10,49 GHz y una ganancia de hasta 35 dB. Otro diseño con frecuencia de 6 GHz diseñado con un plan de fondo categorizar en la banda C. El tercer diseño es con fondo SSR para simular la antena con banda X. Las antenas se han simulado y fabricado utilizando el proceso de grabado químico y se han comparado los resultados. Se observó la impedancia, S11, ganancia y directividad con diferentes formas de antenas en diferentes bandas de frecuencia. Además, el diseño de antena propuesto se puede utilizar como un elemento en una configuración de matriz para lograr una alta ganancia en ambos modos de transmisión y recepción de FSS.

**Palabras clave:** antena microstrip patch, conector SMA, analizador vectorial de redes (VNA).

### 1 INTRODUCTION

Internet of Things (IoT) is the most fast growing emerging technology for the wireless communication protocols as well as for radio-communication and satellite based signal transportation [1]. IoT devices use controlled starring of wireless signals which use less power and more reliable. Low-Profile Microstrip Patch Antennas (MPA) are easy to design and fabricate having directional pattern with minimum cost. Three layered antenna with copper conducting material is designed using feedline of $\lambda/4$ transmission line, inset feed or coaxial probe with 50Ω impedance [2]. Several components can be integrated and accumulated on these miniaturized modules resultant in increase of efficiencies, consistency robustness and this idea can be implemented in advanced health-care, emerging smart cities, and also in armed operations. For different applications like NASA, deep space monitoring, fixed satellite services (FSS) and for military, terrestrial earth exploration and meteorological satellite can be cover up with MPAs of S-Band, C-Band and X-Band with overall frequency range of 2-4 GHz, 4-8GHz and 8-12.5GHz respectively [3]. WLAN, WiMAX and C-Band have highly attractive due to low-profile with compact size, and omnidirectional coverage and simple planar structures [4]. Frequency band of 800MHz to 12.5GHz for IoT based devices with narrow bandwidth with low gain.

MPA constitute of conducting material of any shape such as circular, rectangular, elliptical or any other shape and of compact size array [5]. The chemical etching through iron chloride and toner transfer method is an easy and economical method for feedline and radiating patch on double clad substrate of FR4 and single side copper clad of
polyimide. There are fringing fields present between the ground plane and the edge of the patch which are the primary cause for radiations in MPA antenna. FR4 and Polyimide substrate are used [6].

Microstrip antennas are utilised in Internet of Things (IoT) based systems such as wearable devices for remote health care, in car safety systems, sensor networks for wireless communication, and smart home for controlling and monitoring the home appliances [7].

2 THEORETICAL FRAMEWORK

In [8] these antennas are used in a variety of applications, including wireless local loops at frequencies of 3 to 3.6 GHz, WIMAX at 3.5 GHz, WLANs at frequencies of 5 to 6 GHz, ultra-wide band communication at 7 GHz, transmission at 8 GHz, and SART (search and rescue transmitter) reception at frequencies of 9.2 to 9.5 GHz for signals from X-band radars. These antennas are used in a variety of applications, including wireless local loops at frequencies of 3 to 3.6 GHz, WIMAX at 3.5 GHz, WLANs at frequencies of 5 to 6 GHz, ultra-wide band communication at 7 GHz, transmission at 8 GHz, and SART (search and rescue transceivers) at frequencies of 9.2 to 9.5 GHz that receive signals from X-band radars.

In [9] Different substrates have been used to study different CSSMA parameters. It has been discovered that certain antenna requirements can be satisfied by choosing an appropriate substrate. After analyzing the seven dielectrics used in CSSMA, it can be said that Roger's 4350 is the most effective and has appropriate gain and directivity values for application in WLAN and RVC.

3 METHODOLOGY

Four antennas of different shape were designed with specific frequency using the mathematical theory of antennas by Balanies for bowtie and simple patch antenna then designed were modified with and without addition of metamaterial designing with the following equations.
3.1 FORMULAS AND EQUATION

The impedance and effective permittivity of the patch antenna can be determined under the following condition given as:

For patch antenna when $\frac{w}{h} \geq 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ \left\{1 + \frac{12h}{w}\right\}^{-\frac{1}{2}} + 0.4 \left\{\frac{1-w}{h}\right\}^2 \right]$$

(1)

where

$\varepsilon_r$ = relative permittivity of dielectric material
$h$ = high of substrate
$w$ = width of substrate

And characteristic Impedance

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln \left[\frac{8h}{h} + \frac{w}{h}\right]$$

(2)

For patch antenna when $\frac{w}{h} < 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ \left\{1 + \frac{12h}{w}\right\}^{-\frac{1}{2}} \right]$$

(3)

And characteristic Impedance

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \left[\frac{120\pi}{h+1.393+\frac{2}{\pi} \ln\left(\frac{w+1.444}{h}\right)}\right]$$

(4)

For Bow-Tie antenna

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ \left\{1 + \frac{12h}{a}\right\}^{-\frac{1}{2}} \right]$$

(5)
And characteristic Impedance

\[ Z_0 = \frac{60}{\sqrt{\varepsilon_{\text{eff}}}} \ln \left( \frac{8h}{a} + \frac{a}{h} \right) \]  \hspace{1cm} (6)

The radiated electromagnetic waves are of three types. The first type of wave is the useful radiation since it is radiated into the space. The diffracted waves are the second type of electromagnetic radiations which results in the true power transmission as these waves are reflected in the space present between the ground plane and patch of the antenna. The waves which are trapped inside the dielectric substrate are the third type of electromagnetic radiation and are usually undesirable [10].

The dimensions and shapes vary in various kinds of antenna. When the radiation of the wave in a specific direction is similar to the electric field direction then the antenna polarization is determined. A figure is traced at a time through the vector of instantaneous electric field [11]. The antenna can be linearly polarized or circular polarized. The linear polarization has further two subtypes: horizontal polarization and vertical polarization. When the electric field vector and earth are perpendicular to each other, then there is vertical polarization of electromagnetic wave and when the electric field vector and earth are parallel to each other, then there is horizontal polarization of electromagnetic waves [12]. Figure 3 shows the comparison between different kinds of Microstrip antenna. The transmitted and received field strength in the graphical form gives the radiation pattern of the antenna.
4 RESULTS AND DISCUSSIONS

Antenna I: Bowtie MPA antenna is simulate and fabricate using the chemical etching technique and provide coaxial feed at the central point of the bow which connect the ground to patch through substrate. Antenna II: Array of simple patch antenna was fabricated with circular SRR ground and 18 patches of antennas which are connect through transmission line whereas the overall feed is provided through feedline with FR4 and same antenna with polyimide substrate was designed with ground plane on the same side of substrate and as shown in figure 2(b). Antenna III: Another type of bowtie antenna was designed which are connected through the ground to patch for mutual coupling of right side of the MPA and left side was feed through 50ohm coaxial probe. Antenna IV: is a complex metamaterial antenna which deigned and only the simulated process was done.

Frequency band in S, C and X band is from 2-12.5 GHz. This band has been widely used in many applications like medical, military and space communication due to
short range features and high transmission rates. Many researchers proposed different types of antennas for S, C and X-band and equalize the parameters (size, radiation pattern) for application in era of integration of devices.

Figure 3. Return loss parameter of the Antenna I and Antenna II

Antenna I: Bowtie S11 parameter of fabricated and simulated antenna
Antenna II: S11 parameter of simulated antenna

Source: Simulated and measured results in HFSS/VNA by authors

Figure 4. Array of 18 Antennas with FR4 Substrate

Simulated results show that the resonance frequency is about 2.3GHz and the experimental results are almost the same. The gain is about -10dB at 0° (red line in Gain Plot) and at 180° (dotted line in Gain Plot).
Figure 5. Simulated and Experimental results of Flexible Antenna

Source: Simulated and measured results in HFSS/VNA by authors

The flexible array antenna was simulating and fabricate using same technique and observed that the simulated results are at frequency of 3.1GHz whereas the fabricated results shows a dual band of 2.5-2.7GHz approximately.

Antenna III: is fabricated with and without shortening the substrate through ground and patch and the results of S11 parameter is given below which shows that the design is not acceptable without shortening pins.

Figure 6. Comparison of Bowtie MPA with and without Shortening Pin

Source: Measured results with VNA by authors
Figure (a) shows the propagation of radiation through the bow patch antenna as it is clear that the propagation on the right side of the patch is due to mutual induction, the ground and the patch is also connected through shortening pin. The simulated and fabricated results show resonance peak at 2.75GHz with -19dB and -12dB respectively. The gain is positive in this obtained using which is unidirectional.

Figure 7. Antenna III: Simulated and Fabricated result of Bow-Tie MPA

![Antenna III Simulated and Fabricated result of Bow-Tie MPA](image)

Source: Simulated and measured results in HFSS/VNA by authors

Antenna IV is a metamaterial antenna with SSR on the ground which make the antenna more efficient and high in gain is 1.4 dB at 5.44GHz with S11 -10.08dB is simulated results.
5 CONCLUSION

From antenna I to antenna II, it is clear that using the small dimensions the efficiency can be changed by shortening the pin or by adding the metamaterial structure. All these antennas can be used in FSS applications, for medical imaging or can be used for 5G/6G communication technology. Copper material start rusting in laboratory level therefore an experimental analysis was taken in the laboratory to dip the fabricated antenna in epoxy resin to make a protection layer in future.
REFERENCES


