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European Journal of Advances in Engineering and Technology, 2017,4(12):902-906

Research Article **ISSN: 2394 - 658X**

An Analysis of Resonant Frequency and Radiation Performance of Different Patch Shape of Microstrip Antenna

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ABSTRACT

This article establishes that the shape and mode of patch elements in Microstrip antennas can affect their resonant frequency, polarization, radiation pattern, and impedance. Adding any reactive load sandwiched between the metallic patch and the metallic ground plane such as pins and diodes can also influence these factors. The majority common shapes for patch elements are square, rectangular, dipole and circular because they are easy to manufacture and analyze and have favourable radiation characteristics. Dipoles, in particular, are attractive for arrays because they have large bandwidths and occupy less space. In recent times the researchers are undertaking the unconventional and complex shapes in Microstrip antennas as patch but the mathematical analysis of these patch geometries is very rigours due to various boundary conditions involve. Researchers are using electromagnetic software and other mathematical tools to ease the analysis of these patch shapes with multiple alterations. A brief mathematical formulation related to resonant frequency which available in different resources is presents here for researchers for convenience and ease of understanding.

Keywords: IEEE, Microstrip Antennas, Radiation Characteristics, Resonant Frequency, Shapes

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INTRODUCTION

Antennas are an essential component in any wireless communication system. They are designed to radiate or receive electromagnetic waves, and have been a key building block in the construction of every wireless communication system since the early days of wireless technology. It's fascinating to think that the word 'antenna' is derived from the Latin word 'antenna', with the meaning of sail yard. The term antenna was first applied by Marconi, and according to the IEEE standard definition of terms for antenna, it is a means of emitting or receiving radio waves. The recent advancements in microstrip antenna technology are impressive, as they can achieve both linear and circular polarizations using either single elements or arrays. Arrays, whether with single or multiple feeds, can greatly enhance scanning capabilities and directivities. It's amazing how technology continues to drive advancements in various fields [1].

All antennas work on similar central standards of electromagnetic hypothesis. All in all, the antenna is the middle person structure between guided waves and a free space waves. Further we can say, a transmit antenna is an instrument that takes the flag from a transmission line, convert them into electromagnetic waves and after that appropriate them into the free space. It gathers the occurrence electromagnetic waves and changes over them once again into electric signs. The shape and measurement of antenna is relying on the necessity of the correspondence gear. So as to meet the specific application, different types of the antenna exist for example wire antennas, reflector antennas, focal point antennas, leaky wave antennas, horn antennas and conformal antennas [2-3]. Among all the mentioned antennas, Microstrip Antenna is the most popular due to its various merits includes the cost, size, shape, integration with other elements etc.

This article offers a brief discussion on the resonant frequencies of various patch structures and their radiation performance. For conventional shapes the formulas and equations are easily accessible from literature though for rigorous shapes or modified shapes it is not easy to find the empirical formulas for calculation of resonant frequency and other antenna parameters. To ratify the issue machine algorithms based on artificial neural networks (ANN) are employed to be acquainted with the all resonant frequencies.

COMMON MICROSTRIP PATCH ANTENNA SHAPES AND THEIR RESONANCE FREQUENCY

Microstrip patch antenna is a basic antenna made up of three components: a radiating element or patch, a dielectric layer that sits between the patch and the ground plane, and an infinite ground plane. The patch is located on top of the dielectric substrate and emits radio waves. The infinite ground plane is located below the patch and helps to enhance the antenna's performance [4]. In a Microstrip patch antenna occurs due to the fringing field between the fringe of the patch and the ground plane. It's amazing how such a simple design can have so many complex variations. And interestingly enough, the different shapes of the patch can have an impact on various calculations. There are various conductor shapes proposed [5] and studied for a Microstrip patch antenna include rectangular, crescent, circular, triangular, elliptical, annular ring, and sector ring as shown in Fig. 1.

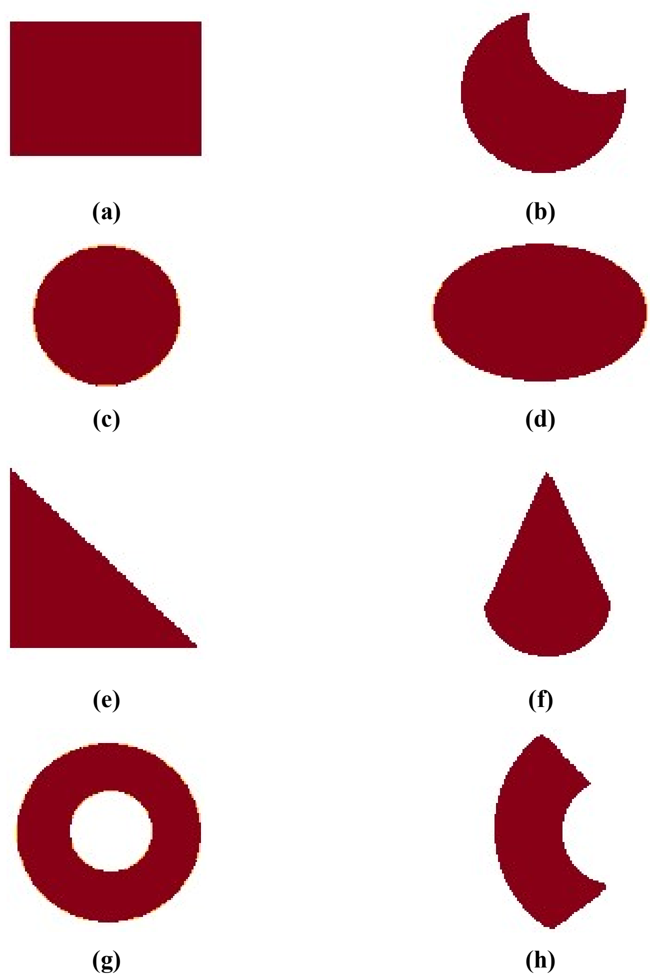

Fig. 1 Geometries of Common Microstrip Patch Antennas

It's interesting to note that the resonant frequency of a patch antenna is highly dependent on its shape and dimensions. There are a wide range of patch antenna shapes available, which can include rectangular, circular, triangular, and even more intricate geometries. Each of these shapes requires its own unique formula to determine the resonant frequency. It's important to be aware of these formulas when designing a patch antenna to ensure optimal performance.

It is crucial to determine the resonant frequency precisely when designing Microstrip antennas due to their narrow bandwidth. In order to achieve an accurate estimation of the resonant frequency, it is necessary to consider the fringing-field effects and incorporate the effective dielectric permittivity and dimensions of the Microstrip patch [6]. This attention to detail ensures the optimal performance and functionality of the antenna. The ε_{eff} can be written in terms of F as [7]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} F \tag{1}$$

Here this F can be derived empirically from the ratio of fringing area on the plane of the patch to the area of the Microstrip patch, which can be given as

$$F = 1 - \frac{c_n \varepsilon_r}{\varepsilon_r - 1} \times \left(\frac{\text{fringing area on the plane of the patch}}{\text{area of the microstrip patch}}\right) \tag{2}$$

Table -1 Resonant Frequency Formula for Some Conventional Patch Shape

Shape	Formula for Resonant Frequency	Remarks
Rectangular Patch Antenna	$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_{eff}}}$ $k_{mn} = \sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{W}\right)^2}$	Here f_{mn} is the resonant frequency. C is the speed of light ε_{eff} is the effective dielectric constant of the substrate material. L is the length of the patch and W is the width of the patch
Circular Patch Antenna	$f_{mn} = \frac{k_{mn} c}{2\pi a\sqrt{\varepsilon_{eff}}}$	Here f_{mn} is the resonant frequency For the TM_{mn}mode. For TM_{11} the value of k_{mn} is 1.84118.
Right Isosceles Triangular Patch Antenna	$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_{eff}}}$	$k_{mn} = \sqrt{2}\left(\frac{m\pi}{a}\right)$, 'a' is the patch dimension [8]
Equilateral Triangular Patch Antenna	$f_{mn} = \left(\frac{2c}{3a\sqrt{\varepsilon_{eff}}}\right)\sqrt{(n^2 + nm + m^2)}$	Side length of triangular is a. C is the speed of light ε_{eff} is the effective dielectric constant of the substrate material.
Elliptical Patch Antenna	$f_{mn} = \frac{k_{mn} c}{2\pi a\sqrt{\varepsilon_{eff}}}$	Here 'e' is the eccentricity of the ellipse $= \frac{c}{a}$ and $c = \sqrt{a^2 - b^2}$ k_{mn} is the n^{th} parametric zero of the even and odd modes of boundary equations. 'a' and 'b' are semi major and minor axis respectively.

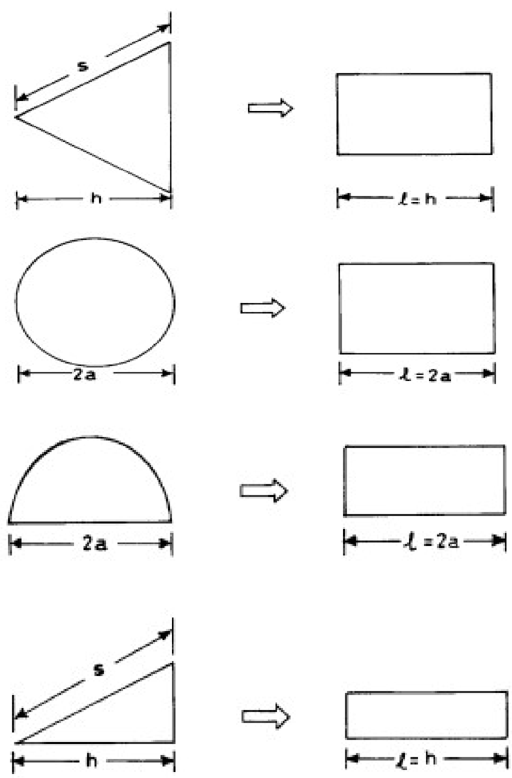

Fig. 2 Diagram for Equating the Equilateral Triangular, Semi Circular Disc, Circular Disk and 30-90-60 Triangle with Rectangular Microstrip Antenna

Table 1 summarizes the resonant frequency formula for some conventional patch shapes. An empirical formula for the resonant frequency of bow-tie microstrip antenna based on the cavity model of microstrip patch antennas is offered in [9]. It is claimed by the authors that it will provide accurate results for bow-tie antenna design.

To determine the resonant frequencies of rectangular, circular, and triangular Microstrip Antennas (MSAs) using the single hybrid method, the areas of the circular and triangular patches are matched to that of the rectangular MSA, as described in references [10-11]. Subsequently, the formulas provided below are employed to derive the equivalent dimensions for the circular and triangular patches, with Fig. 2 serving as a reference guide. Here

For ETMSA, $W = \frac{S}{2}$, where s is the side length ,
For CMSA, $W = \frac{\pi a}{2}$, where a is the radius and
For SCMSA, $W = \frac{\pi a}{4}$, where a is the radius.

Since the annular ring microstrip antenna (ARMA) is obtained through slot loading of a circular patch, illustrated in Fig 1(g), the resonant frequency expression for a circular disk microstrip can be adapted to calculate the resonant frequency of the ARMA. To accommodate the influences of slot loading and the fringing effects along the edges, the real radius ‘a’ of the circular patch is substituted with a newly introduced effective radius ‘a_{eA}’ specific to the ARMA. Therefore, the resonant frequency for the ARMA at TM_{11} mode can be written as

$$f_{11} = \frac{X_{11}c}{2\pi a_{eA}\sqrt{\varepsilon_{eff}}} \tag{3}$$

After conducting a series of experiments, a suitable effective radius expression has been developed and is denoted by a_{eA}. This expression has been found to produce satisfactory results and is crucial in the proper assignment of the effective radius for a Microstrip patch antenna design [12-13]:

$$a_{eA} = \frac{0.85(a_0+a_i)}{\left(1-0.007\frac{a_0}{a_i}+\left(\frac{h}{(a_0-1.1a_i)\varepsilon_r}\right)\right)\left(-0.05\frac{a_0}{h}-0.13\frac{a_0}{a_i}+0.18\varepsilon_r\left(1-\frac{h}{a_i}\right)+1\right)} \tag{4}$$

Here ARMA has an annular-ring patch with outer radius of a_0 and inner radius of a_i.

DISCUSSION

Literature review suggests that following outcomes for different patch shape in regard to their radiation performance:

- The most commonly used patch shapes are rectangular and square due to their large impedance bandwidth and ability to generate circular polarization, respectively.
- Circular and elliptical patches are marginally smaller in size and exhibit slightly lower gain and bandwidth characteristics.
- Triangular and disk sector patch configurations are more compact than rectangular and circular alternatives, resulting in further reductions in bandwidth and gain. These geometries can lead to the development of dual-polarized patches; however, the resulting bandwidth tends to be narrow.
- Annular ring and sector ring geometries are the most compact conductor shapes, but they come with decreased bandwidth and gain. Achieving optimal impedance matching at resonance while exciting the lowest order mode poses a notable challenge with annular rings. These geometries usually necessitate non-contact methods of excitation.
- It is observed that modifications have been made to conventional Microstrip patch antenna configurations to enhance bandwidth. Rectangular ring and circular ring patches have been utilized instead of the traditional rectangular and circular patches. The larger bandwidth is a result of a reduction in the patch resonator's quality factor, which is due to less energy being stored under the patch and higher radiation.

CONCLUSION

The research reflects that designing irregular complex patch geometries like H shape patch antenna, Dumble shape patch antenna, Bow shaped patch antenna, star-shaped patch antenna, and more, calculating the resonant frequency can be quite challenging due to their non-uniform and irregular geometry. Unfortunately, there isn't a standard closed-form formula for determining the resonant frequency of such patch antennas. To get the most accurate results, it's recommended to use electromagnetic simulation software like CST Studio Suite, HFSS, or similar tools. These programs use numerical methods to solve Maxwell's equations, allowing them to take into account the intricate geometry and electromagnetic behaviour of the antenna. If you're designing a star-shaped patch antenna, for instance, it's best to use simulation software to model the antenna, varying its parameters and dimensions to analyze its resonant frequency and performance characteristics. This approach will provide more accurate results than trying to derive a simplified formula for complex shapes like dumble, star, and others.

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