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Microstrip Patch Antennas: A Review of Design Parameters, Simulation Tools, and Metamaterial Integration for Modern Wireless Applications

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Abstract: Microstrip patch antennas are among the most widely used antenna types in modern wireless communication systems. Their simple structure, low manufacturing cost, and ability to fit on flat surfaces make them attractive for many applications. This review paper focuses on three important aspects of microstrip patch antenna technology. The first part explains the basic design parameters including patch dimensions, substrate properties, feed point location, and ground plane size. The second part discusses the software tools commonly used to simulate and analyze these antennas, such as HFSS, CST, and FEKO. The third part explores how metamaterials – specially designed artificial structures – can be integrated with patch antennas to improve performance. Metamaterials can make antennas smaller, increase their gain, and widen their frequency range. This paper serves as a basic guide for students and researchers starting work with microstrip patch antennas.

Keywords: Microstrip patch antenna, design parameters, HFSS, CST, metamaterial, antenna simulation.

I. INTRODAUCTION

Microstrip patch antennas were first developed in the 1970s and have since become one of the most common antenna types in use today. A typical microstrip patch antenna consists of three layers: a metallic patch on top, a dielectric substrate in the middle, and a ground plane at the bottom [6], [9].

The popularity of these antennas comes from several advantages. They are thin and lightweight. They can be made using standard circuit board manufacturing processes. They can be easily mounted on rockets, satellites, and handheld devices. They can also be designed to work at many different frequencies by changing the size and shape of the patch [6].

However, microstrip patch antennas also have some drawbacks. Their frequency range is limited. Their gain is low compared to larger antennas. They also lose efficiency when used at very high frequencies [9], [18].

To overcome these problems, researchers have developed many techniques. One of the most promising approaches is the use of metamaterials. Metamaterials are artificial materials not found in nature. They have unusual electromagnetic properties that can be used to improve antenna performance [11], [15][21][22].

II. DESIGN PARAMETERS OF MICROSRTIP PATCH ANTENNAS

A microstrip patch antenna has several parameters that control its performance. Understanding these parameters is essential for designing an antenna that works as intended.

A. Patch Dimensions

The patch is the part of the antenna that radiates the signal. Most patches are rectangular because this shape is easy to analyze and design. The length and width of the patch determine the frequency at which the antenna works [6].

For a rectangular patch, the width (W) is calculated using the formula:

$W = c / (2f_0 \sqrt{((\varepsilon_r+1)/2)})$…………(1)

The length (L) is slightly shorter than half the wavelength in the substrate because of fringing fields at the edges. The fringing fields make the patch look electrically longer than its physical length [9].

Table I. Typical Patch Dimensions for Different Frequencies

Frequency (GHz)	Substrate (ε_r)	Patch Length (mm)	Patch Width (mm)
2.4	*FR-4 (4.4)*	*28.0*	*35.0*
3.5	*RO4003C (3.38)*	*18.5*	*22.0*
5.8	*RT5880 (2.2)*	*12.5*	*15.8*
28	*RT5880 (2.2)*	*2.5*	*3.2*

B. Substrate Properties

The substrate is the material between the patch and the ground plane. Two properties of the substrate are very important: dielectric constant (ε_r) and loss tangent (tan δ) [6]. The dielectric constant affects the size of the antenna. Higher ε_r makes the antenna smaller but reduces its frequency range. Lower ε_r gives wider frequency range but makes the antenna larger [9]. The loss tangent tells how much energy is lost as heat in the substrate. Lower loss tangent means higher efficiency. For good performance, loss tangent should be below 0.005 [18].

Table II. Common Substrate Materials and Their Properties

Material	ε_r	*tan δ*	*Typical Use*
FR-4	*4.4*	*0.020*	*Low-cost consumer products*
RO4003C	*3.38*	*0.0021*	*Mid-performance designs*
RO4350B	*3.66*	*0.0037*	*Automotive and base stations*
RT5880	*2.20*	*0.0009*	*High-performance mmWave*
LCP	*3.20*	*0.0020*	*Flexible and wearable devices*

C. *Substrate Thickness*

The thickness of the substrate (h) affects three things: bandwidth, efficiency, and surface waves. Thicker substrates give wider bandwidth and better efficiency but also create stronger surface waves that can disturb the radiation pattern [2], [18]. The bandwidth increases roughly in proportion to h/λ_0. However, when h becomes larger than about $0.05\lambda_0$, surface waves become a serious problem. The best thickness is usually between $0.01\lambda_0$ and $0.05\lambda_0$ [9].

D. *Feed Point Location*

The feed point is where the signal enters the antenna. Its location controls the input impedance. When the feed is at the edge of the patch, the impedance is high (150 to 200 ohms). When the feed moves toward the center, the impedance decreases. At the center, the impedance is zero [6]. To match the antenna to a standard 50 ohm system, the feed point is placed at a distance from the edge where the impedance equals 50 ohms. This distance is found using formulas or by running simulations [2].

E. *Ground Plane Size*

The ground plane is the metal layer below the substrate. It reflects the signal and helps direct the radiation upward. If the ground plane is too small, the antenna's gain decreases and the radiation pattern becomes irregular. A good rule is to make the ground plane at least three times larger than the patch on each side [6].

Table III. Design Parameter Effects

Parameter	**Increasing the Parameter...**
Patch length	*Lowers the resonant frequency*
Patch width	*Increases bandwidth*
ε_r (dielectric constant)	*Reduces antenna size, reduces bandwidth*
tan δ (loss tangent)	*Reduces efficiency*
Substrate thickness	*Increases bandwidth, increases surface waves*
Ground plane size	*Increases gain (up to a point)*

III. SIMULATION TOOL FOR MICROSTRIP PATCH ANTENNA

Before making a real antenna, designers use computer software to simulate how it will work. Simulation saves time and money because problems can be found and fixed on the computer instead of after the antenna is built [7], [10].

A. *How Antenna Simulation Works*

Antenna simulation software solves Maxwell's equations – the basic laws of electromagnetism – for the shape of the antenna being designed. The software divides the antenna into many small pieces (called meshing) and calculates the electric and magnetic fields at each piece [7].

Different software uses different methods to solve these equations. Each method has strengths and weaknesses.

B. *Finite Element Method (FEM) – ANSYS HFSS*

HFSS (High Frequency Structure Simulator) from ANSYS is one of the most popular antenna simulation tools. It uses the Finite Element Method. The software divides the space around the antenna into small tetrahedral shapes (like pyramids with triangular bases) [10].

FEM is very accurate for complex shapes and for antennas with multiple layers. It can handle different materials in different parts of the antenna. The main drawback is that FEM requires a lot of computer memory and time, especially for large antennas or high frequencies [7].

C. *Finite Difference Time Domain (FDTD) – CST Studio Suite*

CST (Computer Simulation Technology) uses the Finite Difference Time Domain method. Instead of solving for one frequency at a time, FDTD solves for many frequencies in one run by stepping forward in time [7].

FDTD is good for antennas that need to work over a wide frequency range. It is also good for studying how the antenna behaves in the time domain, such as when sending pulses. CST uses a grid of cubes (hexahedral mesh) which can be less accurate for curved surfaces than the tetrahedral mesh used by HFSS [10].

D. *Method of Moments (MoM) – FEKO and IE3D*

The Method of Moments is different from FEM and FDTD. Instead of dividing the whole space into small pieces, MoM only divides the metal surfaces of the antenna. This means fewer pieces to calculate, so MoM is faster than FEM or FDTD for antennas that are mostly flat [7].

MoM is excellent for simple patch antennas and for arrays of many patches. However, MoM has difficulty with antennas that have thick substrates or complex 3D shapes. FEKO (from Altair) and IE3D are two popular MoM-based software packages [7].

IV. METAMATERIAL INTEGRATION WITH MICROSTRIP PATCH ANTENNAS

Metamaterials are artificial structures that have electromagnetic properties not found in natural materials. They get their properties from their shape and arrangement rather than from their chemical composition [11], [15].

A. *Metamaterials*

Natural materials have dielectric constant (ε) and magnetic permeability (μ) that are positive. Metamaterials can be made to have negative ε, negative μ, or both. Materials with both negative ε and negative μ are called left-handed materials because they bend electromagnetic waves in the opposite direction to normal materials [11].

Metamaterials are made by arranging small structures (called unit cells) in a repeating pattern. The size of each unit cell is much smaller than the wavelength of the signal. Common shapes for unit cells include split rings, wires, and patches with slots [15].

B. How Metamaterials Help Patch Antennas

Metamaterials can improve microstrip patch antennas in several ways [5], [11], [15]:

Size Reduction: A patch antenna with a metamaterial substrate can be much smaller than a normal patch antenna at the same frequency. This is because the metamaterial makes the wavelength shorter. Size reductions of 50 to 80 percent are possible.

Gain Enhancement: Metamaterial layers placed above the patch can focus the radiated beam, increasing gain by 3 to 6 dB. These layers act like lenses for electromagnetic waves.

Bandwidth Widening: Normal patch antennas have narrow bandwidth (typically 5 to 10 percent). Metamaterials can create additional resonances that combine to give wider bandwidth, up to 20 to 30 percent.

Mutual Coupling Reduction: In antennas that have multiple patches close together (such as MIMO antennas), metamaterial structures placed between the patches can reduce interference. Coupling can be reduced by 10 to 20 dB.

V. Conclusion

This review paper has covered three important areas related to microstrip patch antennas: design parameters, simulation tools, and metamaterial integration.

The design of a microstrip patch antenna involves selecting the right patch dimensions, substrate material, substrate thickness, feed point location, and ground plane size. Each parameter affects the antenna's performance in specific ways. Patch length controls the operating frequency. Patch width affects bandwidth. Substrate dielectric constant determines the trade-off between size and bandwidth. Substrate thickness balances bandwidth against surface wave problems. Feed point location sets the input impedance. Ground plane size influences gain and radiation pattern.

Simulation tools are essential for modern antenna design. HFSS uses the Finite Element Method and is excellent for complex, multilayer antennas. CST uses the Finite Difference Time Domain method and is good for wideband simulations. FEKO uses the Method of Moments and is fast for flat antennas and arrays. These tools provide designers with S-parameters, Smith charts, radiation patterns, gain values, and current distributions.

Metamaterials offer a powerful way to improve patch antenna performance beyond what is possible with conventional designs. Metamaterial substrates can reduce antenna size by 50 to 80 percent. Metasurface superstrates can increase gain by 3 to 6 dB. CRLH structures can widen bandwidth to 20 to 30 percent. EBG structures can reduce mutual coupling by 10 to 20 dB. However, metamaterials also bring challenges including higher cost, more complex fabrication, and potential additional losses.

Future work in this area may focus on making metamaterial structures easier to manufacture, developing tunable metamaterials that can change their properties in real time, and combining multiple metamaterial techniques in a single design. As wireless systems continue to evolve, microstrip patch antennas with metamaterial enhancement will likely play an important role in meeting the demands of faster, more reliable communication.

VI. References

[1] W. Hong et al., "Millimeter-wave 5G antennas and systems," Proceedings of the IEEE, vol. 105, no. 7, 2017.

[2] K. K. Kishor and S. V. Hum, "Impedance and gain optimization of mmWave patch antennas," IEEE TAP, vol. 63, no. 5, 2015.

[3] M. Khattak et al., "Design of 28 GHz patch antenna for 5G," Wireless Personal Comms, vol. 113, 2020.

[4] J. Zhang et al., "Substrate integrated waveguide fed patch antenna at 60 GHz," IEEE AWPL, vol. 16, 2017.

[5] N. Ojaroudi et al., "Millimeter-wave slot antenna with defected ground," Microwave and Optical Tech Letters, vol. 61, 2019.

[6] R. Garg, Microstrip Antenna Design Handbook, Artech House, 2001.

[7] Y. Rahmat-Samii and J. Volakis, Antenna Engineering Handbook, McGraw-Hill, 2018.

[8] S. K. Sharma et al., "mmWave MIMO patch array for 5G smartphones," IEEE TAP, vol. 67, no. 12, 2019.

[9] D. M. Pozar, "Microstrip antennas," Proc. IEEE, vol. 80, no. 1, 1992.

[10] A. Al-Zoubi et al., "Low-profile mmWave patch antenna using superstrates," IET MAP, vol. 14, 2020.

[11] Z. Chen et al., "Metasurface-based patch antenna gain enhancement at 28 GHz," Scientific Reports, vol. 9, 2019.

[12] H. Ullah and F. Tahir, "Wideband mmWave patch antenna for 5G," IEEE Access, vol. 8, 2020.

[13] T. S. Rappaport et al., "Overview of mmWave communications for 5G," IEEE Comms Mag, vol. 52, no. 12, 2014.

[14] M. M. Khan and Z. A. Bhatti, "Optimization of patch antennas using PSO," Applied Computational EM, vol. 34, 2019.

[15] L. Zhang et al., "Liquid crystal-based reconfigurable mmWave antenna," IEEE TAP, vol. 68, no. 3, 2020.

[16] A. J. Alazemi and M. I. Waly, "60 GHz patch antenna on liquid crystal polymer," Electronics Letters, vol. 56, 2020.

[17] F. A. Dicandia et al., "Machine learning for mmWave antenna design," IEEE TAP, vol. 69, no. 8, 2021.

[18] S. K. Podilchak et al., "Surface wave suppression in mmWave patches," IEEE TAP, vol. 66, no. 11, 2018.

[19] M. S. Sharawi, "Printed MIMO antenna systems for 5G," IEEE AP Mag, vol. 59, no. 3, 2017.

[20] GPP TR 38.901, "Study on channel model for frequencies from 0.5 to 100 GHz," 2018.

[21] M. Sabir and G. Ratnu, "A design of compact T-shaped fractal patch antenna for X-band applications," Materials Today: Proceedings, vol. 29, pp. 295–299, Jan. 2020.

[22] K. Parveen, M. Sabir, M. Kumari, and V. Goar, "Compact size microstrip patch antenna for 5G wireless network," in Smart Innovations in Communication and Computational Sciences: Proceedings of ICSICCS-2018, Singapore: Springer, 2018, pp. 173–178