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Review paper on Microstrip Patch Antenna for Ultra Wide-band Applications

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Abstract: Ultra-Wideband (UWB) technology has emerged as a promising solution for modern wireless communication systems due to its high data transmission rate, low power consumption, wide bandwidth, and precise localization capabilities. Among various antenna structures, the microstrip patch antenna has gained significant attention because of its compact size, low profile, lightweight design, ease of fabrication, and compatibility with integrated circuits. However, conventional microstrip patch antennas inherently suffer from narrow bandwidth, limiting their direct application in UWB systems. To overcome this limitation, numerous bandwidth enhancement techniques have been proposed, including slot loading, defected ground structures (DGS), parasitic elements, electromagnetic band-gap (EBG) structures, metamaterials, and various feeding mechanisms. This review paper presents a comprehensive survey of recent developments in microstrip patch antennas designed for UWB applications. It examines different antenna geometries, substrate materials, bandwidth enhancement techniques, impedance matching methods, gain improvement strategies, and performance optimization approaches. Furthermore, the paper compares the reported antenna designs in terms of operating frequency range, bandwidth, return loss, voltage standing wave ratio (VSWR), gain, radiation efficiency, and radiation characteristics. The review also highlights the advantages, limitations, and practical applications of UWB microstrip patch antennas in wireless communication, radar imaging, medical diagnostics, Internet of Things (IoT), vehicular communication, and wearable devices. Finally, the paper discusses current research challenges and future directions, including the integration of artificial intelligence, machine learning-based antenna optimization, flexible substrates, and reconfigurable antenna technologies to enhance UWB antenna performance for next-generation wireless networks.

Keywords:- Microstrip Antenna, U-shaped slot, Partial ground plane, Ultra-wide band

I. INTRODUCTION

Antennas are very important component in wireless communication system. There are different types of antennas exit practically which we used for transmit and receive EM waves. Out of these microstrip antenna is one of the most important antenna nowadays due to their attractive features such as low profile, light weight, low cost and ease in fabrication. Therefore, they are compatible with wireless communication integrated circuitry. But it has some disadvantages such as narrow bandwidth, low gain and low efficiency. There are some drawbacks in order to reduce these drawbacks such as slot loading over patch, reduction in length of ground plane etc. [1] [2].

Federal Communication Commission (FCC) allocated a bandwidth of 7.5 GHz i.e. from 3.1 GHz to 10.6. It is generated by very short duration pulses generally in picoseconds therefore it provides very high data rate in the range of Mbps. There are several advantages of short duration pulses like it avoids multi path fading etc. This is widely used in radars and remote sensing applications. UWB antennas having return loss (S11< -10dB) high radiation efficiency over ultra wide band from 3.1 GHz to 10.6 GHz.

In the present paper, a double U-shaped slot loaded rectangular microstrip antenna is designed and analyzed. Two U-shaped slots reduce the overall impedance of antenna. The slot reduces the area of copper sheet which leads to less value of quality factor hence bandwidth increases. The microstip line is used for feeding because of its ease in fabrication and simple to match by controlling inset positions. A VSWR< 2 and S11< -10 dB is achieved for a frequency range of 6.5-14.8 GHz with stable E- and H-plane radiation patterns.

II. LITERATURE REVIEW

Jun Jiat Tiang et al. (2024) proposed a novel microstrip patch antenna for millimeter-wave Beyond 5G (B5G) communication systems. The antenna was designed to operate in the mmWave frequency spectrum while providing high gain, wide impedance bandwidth, and stable radiation characteristics. The authors employed optimized patch geometry and feeding techniques to improve impedance matching and radiation efficiency. Experimental and simulated results demonstrated that the proposed antenna is suitable for high-speed B5G wireless communication applications, offering compact size and reliable performance for future wireless networks.

R. Gupta et al. (2024) presented a large X-band microstrip antenna array intended for spaceborne Synthetic Aperture Radar (SAR) applications. The array was designed to achieve high gain, narrow beamwidth, and enhanced radiation efficiency required for satellite-based imaging systems. The proposed configuration demonstrated excellent impedance matching and low sidelobe levels, making it suitable for high-resolution Earth observation. The study highlighted the advantages of microstrip antenna arrays in aerospace applications due to their lightweight structure and ease of fabrication.

R. B. Sagar et al. (2024) developed a slotted stepped microstrip patch antenna for Ka-band communication systems. Different slot configurations were incorporated into the patch to improve bandwidth and impedance matching while maintaining compact dimensions. The antenna exhibited improved return loss, enhanced gain, and stable radiation characteristics across the desired Ka-band frequencies. The proposed design is suitable for satellite communication, radar, and next-generation high-frequency wireless applications.

L. Yang et al. (2023) introduced a pattern reconfigurable antenna array operating at 5.8 GHz for Wireless Body Area Network (WBAN) applications. The antenna utilized electronic switching techniques to dynamically modify its radiation pattern according to communication requirements. Simulation and measurement results demonstrated high radiation efficiency, improved gain, and reliable pattern reconfiguration with minimal complexity. The proposed antenna enhances communication reliability and energy efficiency for wearable healthcare devices.

Z. Ahmad et al. (2023) proposed a dual-band shared aperture antenna for fifth-generation (5G) communication systems. The design integrates two frequency bands within a common aperture while minimizing mutual coupling and maintaining high isolation between the operating bands. The antenna achieved stable radiation patterns, improved bandwidth, and satisfactory gain, making it suitable for compact 5G base stations and wireless communication terminals where space efficiency is critical.

Abhishek Javali et al. (2022) designed a rectangular microstrip patch antenna for Wi-Fi applications with the objective of improving bandwidth and gain. Various design optimizations, including patch dimension modification and feeding technique enhancement, were implemented to overcome the narrow bandwidth limitation of conventional microstrip antennas. The proposed antenna demonstrated enhanced impedance bandwidth, higher gain, and satisfactory return loss, making it suitable for IEEE 802.11 wireless communication standards.

Maifuz Ali et al. (2021) proposed a microstrip antenna integrated with a superstrate layer to enhance bandwidth and gain while suppressing cross-polarization. The addition of the superstrate improved antenna directivity and radiation efficiency without significantly increasing antenna dimensions. Experimental results indicated considerable improvements in gain, impedance bandwidth, and polarization purity, making the antenna appropriate for modern wireless communication systems requiring high-performance radiation characteristics.

Bifta Sama Bari et al. (2020) presented a modified Ultra-Wideband (UWB) microstrip patch antenna employing a reflecting layer to improve antenna performance. The reflecting layer effectively increased forward radiation while reducing back radiation, resulting in enhanced gain and wider operating bandwidth. The proposed antenna achieved good impedance matching throughout the UWB frequency range and demonstrated stable radiation patterns, making it suitable for UWB communication, radar imaging, and sensing applications.

Akbar SA et al. (2019) designed a T-shaped Ultra-Wideband microstrip antenna incorporating inverted U-shaped and C-shaped slots to achieve dual-band rejection characteristics. The antenna successfully eliminated interference from WLAN and satellite communication bands while maintaining wide impedance bandwidth across the UWB spectrum. The slot-based approach effectively enhanced frequency selectivity without degrading radiation performance, making the design suitable for practical UWB wireless communication systems.

Antara Ghosal et al. (2018) developed a multiband microstrip patch antenna capable of operating across multiple communication frequency bands. The antenna incorporated modified patch geometry to achieve multiple resonant frequencies while maintaining compact size and acceptable radiation performance. Simulation results showed satisfactory return loss, gain, and bandwidth, demonstrating its suitability for modern wireless communication systems requiring multiband functionality within a single compact antenna structure.

III. MICROSTRIP ANTENNA

Microstrip antennas received considerable attention starting in the 1970s, although the idea of a microstrip antenna can be traced to 1953 and a patent in 1955. Microstrip antennas, as shown in figure (2.1). It consist of a very thin metallic strip (patch) placed above ground plane. The patch and the ground plane are separated by a dielectric sheet (referred to as the substrate). There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.2 \leq \epsilon_r \leq 12$.

The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size. Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element sizes; however, because of their greater losses, they are less efficient and have relatively smaller bandwidths. Often microstrip antennas are also referred to as patch antennas. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration.

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required. Presently there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet these requirements, microstrip antennas can be used.

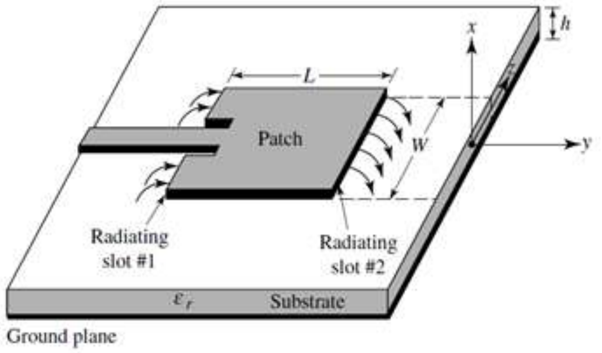

Figure 1: Microstrip Antenna

These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance.

Major operational disadvantages of microstrip antennas are their low efficiency, low power, high *Q* poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent. However, there are methods, such as increasing the height of the substrate that can be used to extend the efficiency (to as large as 90 percent if surface waves are not included) and bandwidth (up to about 35 percent). However, as the height increases, surface waves are introduced which usually are not desirable because they extract power from the total available for direct radiation.

IV. SHAPES OF MICROSTRIP ANTENNA

The radiating patch may be square, rectangular, thin strip (dipole), elliptical, circular, triangular, or any other configuration as shown in figure 2. Rectangular patches are probably the most utilized patch geometry. It has the largest impedance bandwidth compared to other types of geometries. Rectangular and circular patch configurations have received enormous attention of researchers for their convenient analysis and design concept.

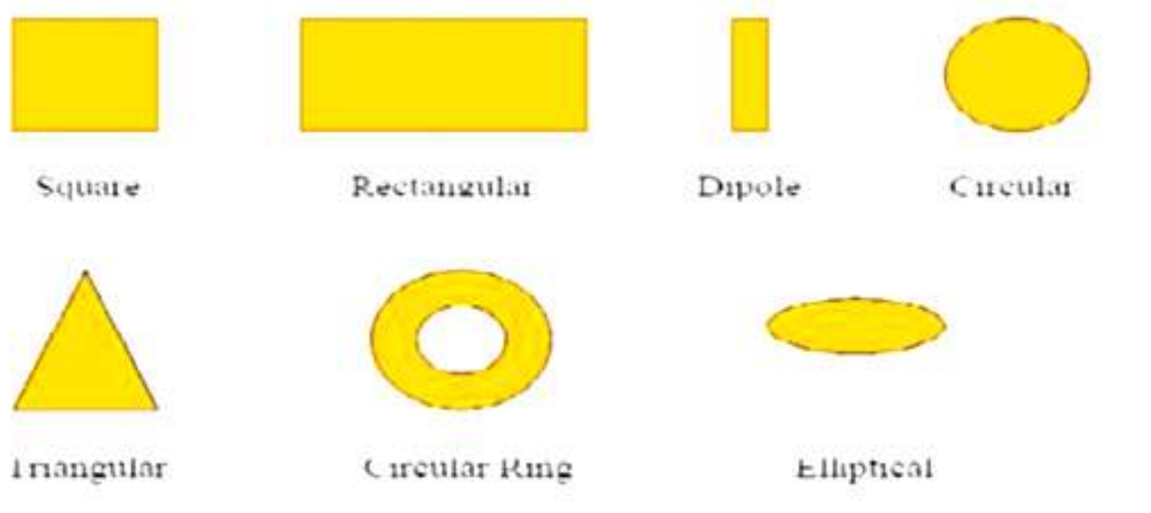

Figure 2: Common shapes of microstrip patch element

But there are certain sophisticated applications which require the analysis of other shapes such as pentagonal, triangular, patch ring, etc. But researchers paid least attention toward the analysis of the above mentioned shapes due to their structural complexity.

Circular and elliptical shapes are slightly smaller than of rectangular patches. Thus it will have smaller bandwidth and gain. This circular geometry patches were difficult to analyze due to its inherent geometry. Microstrip dipoles are attractive because they inherently possess a large bandwidth and occupy less space, which makes them attractive for arrays.

Triangular patch is even smaller than both rectangular and circular geometries. However, this will produce even lower gain and smaller bandwidth. It will also produce higher cross-polarization due to its unsymmetrical geometry. Dual polarized patch could be generated from these geometries.

Mathematical Formulation

Width of microstrip antenna is simply given as

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

Where,
W= Width of Patch
ε_r= Dielectric constant of the substrate
Actual length of microstrip antenna is given as

$$L_{actual} = L_{eff} - \Delta L \quad (2)$$

Where,
L_{eff}= Effective length of the patch.
ΔL = Extended electrical length
Effective length of the patch is simply given by

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (3)$$

Where,
ε_{reff}= Effective dielectric constant

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of dielectric constant of the substrate. Its value is given by,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}} \tag{4}$$

h = thickness of the substrate

In microstrip antenna, radiation occurs due to the fringing effects. Due to fringing effects electrical length of patch is greater than its physical length. This fringing depends on the width of patch and height of substrate [2]. Now the extended electric length is given by

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.8)} \tag{5}$$

The width of microstrip line in microstrip antenna is given as follows:

For

$$\frac{W_{eff}}{h} \geq 2 \tag{6}$$

$$W_{eff} = \frac{2h}{\pi}\left\{\frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - 0.\frac{61}{\varepsilon_r}\right] + B - 1 - ln(2B-1)\right\} \tag{7}$$

and for

$$\frac{W_{eff}}{h} \leq 2 \tag{8}$$

$$W_{eff} = \frac{8he^{A}}{e^{2A} - 2} \tag{9}$$

$$W_f = W_{eff} - \frac{t}{\pi\left[1 + \ln\left(\frac{2h}{t}\right)\right]} \tag{10}$$

Where, A and B are given as follows

$$A = \frac{Z_{ol}}{60}\left(\frac{\varepsilon_r+1}{2}\right)^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}(0.23 + 0.11/\varepsilon_r)$$

$$B = \frac{377\pi}{2Z_{ol}\sqrt{\varepsilon_r}} \tag{11}$$

V. CONCLUSION

Microstrip patch antennas have become one of the most widely adopted antenna technologies for Ultra-Wideband (UWB) and modern wireless communication systems because of their compact size, lightweight structure, low fabrication cost, and ease of integration with microwave circuits. The literature reviewed in this paper demonstrates that significant research efforts have been devoted to overcoming the inherent narrow bandwidth limitation of conventional microstrip patch antennas. Various bandwidth enhancement techniques, including slot loading, defected ground structures (DGS), superstrate layers, reflecting layers, parasitic elements, shared aperture configurations, antenna arrays, and pattern reconfiguration, have been successfully employed to improve antenna performance.

The reviewed studies indicate that recent antenna designs have achieved considerable improvements in impedance bandwidth, gain, return loss, radiation efficiency, and isolation while maintaining compact dimensions. These advancements have enabled microstrip patch antennas to support a wide range of applications, including Ultra-Wideband (UWB) communication, fifth-generation (5G) and Beyond 5G (B5G) networks, millimeter-wave systems, satellite communication, Synthetic Aperture Radar (SAR), Wireless Body Area Networks (WBAN), Wi-Fi, and Internet of Things (IoT) devices. Furthermore, the integration of novel materials, optimized feeding techniques, and advanced antenna geometries has contributed to enhanced overall system performance.

Despite these developments, challenges such as achieving ultra-wide bandwidth with high gain, reducing mutual coupling in multiple-input multiple-output (MIMO) systems, minimizing antenna size, and maintaining stable radiation characteristics across the entire operating band remain active research areas. Future research is expected to focus on artificial intelligence and machine learning-assisted antenna optimization, metamaterial and metasurface-based designs, flexible and wearable antennas, reconfigurable antennas, and low-cost fabrication technologies. These emerging approaches are expected to play a significant role in developing high-performance microstrip patch antennas that can meet the demanding requirements of next-generation wireless communication systems beyond 5G and toward 6G.

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