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Ultra-Wide Band MIMO Antennas with Notched-Band Characteristics of Various Slot Geometries for Wireless Applications

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Abstract: Ultra-Wide Band (UWB) technology has experienced rapid growth over the last few years due to its various applications. Antennas developed for UWB applications are desired to have notch characteristics for avoiding interference from other existing radio communication systems. Different techniques related to the design and development of band-notched antennas is utilized to improve the antenna performance. This paper presents a comprehensive study of UWB antennas with band-notch characteristics and the effect of taking different slot geometry for multiple-input multiple-output (MIMO) applications.
Keywords: Ultra-Wide Band (UWB), Slot Antenna (SA), notch-characteristics, MIMO

I. INTRODUCTION

In every wireless communication application, the essential part of the system is an antenna. The antenna must be of low profile and should be compact enough to be integrated within the portable devices. Among the different types of antennas, slot antennas are a suitable candidate to fulfill the requirements of UWB technology. Ultra-Wide Band (UWB) technology is the most prolific wireless communication technology having the advantages of faster data transmission rate, simplicity, inexpensiveness, and low power sprectral density.

The slot antennas have relatively large magnetic fields that tend not to couple strongly with nearby objects, which make them suitable for applications wherein the near-field coupling is required to be minimized.

II. SLOT GEOMETRY

Muvvala and Reddy [1] considered the gain and current distribution for slots of different shapes on hexagonal patch antenna. The hexagonal patch of 14mm dimensions is considered with substrate dimensions of 46x52 mm, and a ground plane of 42x18.2mm is taken.

The analysis is done by comparing the values of gain with and without slots. The various slot shapes considered for analysis are circle, triangle, square, and hexagonal. The operating frequency range for all the calculations is 2 to 13.5 GHz.

Rahayu [2] presents antenna with various slots operable in Ultra Wide Band frequency range (3.1GHz-10.6 GHz). The proposed antenna is designed on FR-4 substrate with thickness of 1.6 mm and relative dielectric constant of 4.6. The radiator is fed by a microstrip line of 3 mm width. The slot antennas considered for analysis are T slotted for patch and feeding strip, couple a ring and L slots, and dual asymmetry L slots.

III. NOTCHING METHODS

Shaalan [3] suggested two designs for compact monopole hexagonal antennas fed by a single microstrip line for UWB applications. The first antenna is a simple hexagonal patch monopole antenna with a rectangular ground.

The radiating patch and the 50Ω feed line is printed on the same side of the substrate, and the ground plane is located on the other side.

The second antenna has an additional asymmetrical U-shape slot to achieve dual circular polarization for UWB applications. The analysis is done over the frequency band of 4GHz to 14GHz. The notched band ranging from 6.05-7.33 GHz is achieved from the simulation results by inserting a U-shaped slot. Due to the notch characteristics, the proposed antenna has two bandwidths.

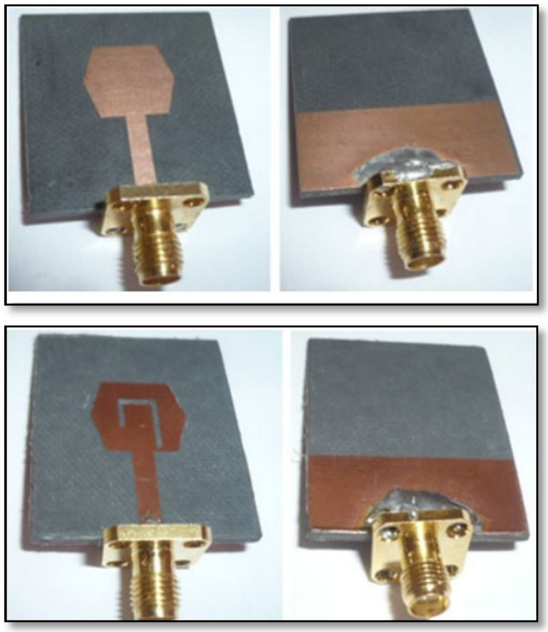

Figure 1: Fabricated prototype of Proposed Antenna [3] (a) Hexagonal monopole antenna (b) Hexagonal monopole antenna with asymmetrical slot.

Azim [4] proposes a slot antenna with dual-band-notch characteristics for ultra-wide band applications. The primary antenna encompasses a tuning stub of a rectangular shape and a ground plane with a tapered-shaped slot. One angle-shaped parasitic slit is etched along with the tuning stub in the proposed design to generate a notched band characteristic for WiMAX. For adding notched characteristics for WLAN, two symmetrical parasitic slits are placed inside the slot of the ground plane. By doing so, he attained an ultra-wide operating band with the dual-notched band by appropriately adjusting the size and location of the parasitic slits without altering the overall antenna size.

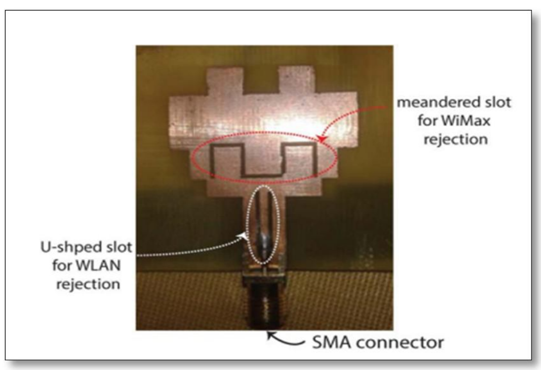

Figure 2: Fabricated prototype of proposed Antenna [5] with two slots embedded.

Sohail [5] proposed a low-profile UWB patch antenna with dual-notch band capabilities. The proposed design is realized on an FR-4 substrate having a relative permittivity of 4.4 and thickness of 1.5 mm. In the proposed method, two-step truncations are utilized for bandwidth enhancement at lower frequencies of the UWB spectrum. The frequency bands of 3.3-3.8GHz and 5.2-5.7GHz are suppressed by inserting one rectangular slot in the ground plane and one slot in the feed line respectively. The embedded slots minimized the effect caused by EM interference of WiMAX and WLAN bands.
Kapil [6] presents a MIMO hexagonal slot monopole antenna with dual notch characteristics operable on a super-wide band frequency range (2.76GHz-39.53GHz). The proposed antenna is printed on Rogers RTDuroid5880 substrate with relative permittivity of 2.2. A hexagonal slot is etched on the hexagonal patch on one plane of the substrate. Dual-notch characteristic is introduced in the proposed antenna by inserting an inverted T-shaped band stop filter to notch the WLAN band, and a C-shaped parasitic element is used to remove the interfering signals of the DSS band.

IV. ANTENNA ARRAY

Errifi [7] designed and simulated a rectangular microstrip patch array antenna using HFSS software. This paper demonstrates the comparative analysis of the performance of a single-element microstrip antenna with 2-element, 4-element, 8-element, and 16-element patch arrays for the same operating frequency for different array configurations. The considered parameters for comparisons are return loss, gain, directivity, and radiation pattern. The patch dimensions are 9.31mm×11.86mm with an inset feed at 2.5mm. The patch antennas of exact dimensions are taken for array arrangement with a distance between individual elements as $\lambda/2$ at an operating frequency of 10GHz. Kumar [8] offers the performance analysis of a four-element corporate-fed antenna array made of the identical microstrip rectangular patch antenna and a rectangular microstrip antenna array after introducing semi-circular tabs on the non-radiating edges of each element of an array. The proposed antenna is realized on an FR-4 substrate with a permittivity of 4.4 and a thickness of 1.6mm. The gain and return loss of the two arrays is compared for analysis with the results of a single-element patch antenna at 2.4GHz.

V. MIMO

Das [9] fabricated a hexagonal wide slot antenna with a combination of rectangular and elliptical fractal geometry using an FR-4 substrate to operate in ultra-wide band. In a bit-by-bit manner, the bandwidth enhancement of the wide slot antenna due to this fractal curve has been studied, followed by their corresponding mathematical analysis. Multiple input and multiple output characteristic of the proposed antenna is also analyzed. To introduce the triple band notch characteristics at 3.98 GHz, 5.56 GHz and 7.94 GHz, two pairs of L-shaped slots are etched on the ground plane and a metallic ring is inserted inside the slot. The three notch-bands can avert interference with existing WiMAX, downlink of C–band satellite communication, WLAN and uplink of X-band satellite communication. Srivastava [10] presented a compact four-element ultra-wide band MIMO antenna. The size of the proposed antenna is 42 mm x 25 mm. The UWB antenna operates in the frequency range of 3.1 GHz to 12 GHz. The measured ECC is less than 0.01 for the entire UWB band, whereas the estimated channel capacity loss (CCL) is < 0.4 bits/Hz/s for the UWB spectrum. These two parameters guarantee a good MIMO performance of the proposed UWB MIMO antenna.

VI. RESULTS AND DISCUSSION

The results by Muvvala [1] indicate that the gain significantly increases with the insertion of slots in the given hexagonal patch antenna. It is observed that the gain is maximum for the hexagonal slotted antenna compared to the other slot shapes. The designed antenna shows a good impedance match for the band from 2 to 11 GHz. Rahayu [2] observed that to control an antenna behavior, it is necessary to observe the current distribution which plays an important role in matching performance. Once the current distribution has been identified, various slots can be added easily. It has been inferred that gain can be enhanced by adding slots of desired shapes on the patch antenna with certain limitations.[1][2]

The proposed design by Shaalan [3] has quasi-Omni directional radiation patterns in the entire UWB. It was also observed that the integration of slots for band notching makes the design compact and easy for fabrication. The proposed antennas occupy a small size while preserving a single structure and are easy to fabricate. The antenna covers a wide frequency range with a good gain and a VSWR<=2. Antenna 2, with an asymmetrical U-shape slot, provides enhanced impedance bandwidth [4]. Any single or multiple frequency bands can be notched by embedding slots in the designs near the mainstream of currents. [5]

One angle-shaped parasitic slit with radiating patch and two symmetrical parasitic slits can be embedded in the ground plane by doing so, the proposed antenna can achieve the dual notched band characteristics of 3.35-3.8 and 5.12-5.84 GHz without altering the overall antenna size. [6]

The performance analysis of the studied array antennas indicates that 16×1 patch array antenna with a series-corporate feed network performs better than the other arrays [7]. Kumar [8] observed that the gain and bandwidth were improved for the 4-element array of the optimized microstrip antenna. Also, the semicircular tabs introduced to enhance the gain and bandwidth further did not significantly improve the measured parameters. The gain and bandwidth of the proposed antenna array were almost three times the gain and bandwidth of that of a single patch antenna array. Table I shows a comparative analyses of the results obtained by Errifi[7].

Table I: COMPARISON BETWEEN SINGLE PATCH ANTENNA AND MICROSTRIP ANTENNA ARRAYS

Antenna Parameters	Single patch antenna	Microstrip 2 x 1 patch antenna array	Microstrip 4 x 1 patch antenna array	Microstrip 8 x 1 patch antenna array	Microstrip 16 x 1 patch antenna array
Gain	8.53 dB	9.93 dB	11.27 dB	14.13 dB	14.91 dB
Return Loss	-14.3 dB	-38.91 dB	-17.89 dB	-16.57 dB	-15.28 dB
Directivity	8.89 dB	10 dB	11.6 dB	14.51 dB	15.3 dB

It is convenient to say that for an array antenna with a large number of patches, the gain and directivity increase irrespective of the feeding method (series, corporate or series-corporate). [7] [8]

Das [9] shown that the bandwidth of the designed antenna is preserved while the optimization of the notched bands by variation of parameters. The error correlation coefficient ECC of the designed antenna is 0.1 for the operating band, whose practical value should be<0.5. The directive gain of the designed antenna is observed to be 9.98dB which is within the permissible values in the operating range. Also, the maximum gain of the antenna is 5.95dB, and the radiation efficiency offered is 91%.The stated features make the MIMO antenna suitable for wireless applications.

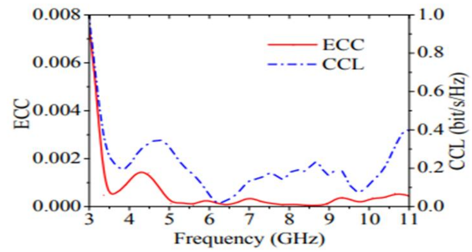

Figure 3: Measured ECC and CCL of proposed UWB MIMO antenna [10].

The behavior of the MIMO antenna is analyzed in terms of two important parameters: envelope correlation coefficient (ECC) and channel capacity loss (CCL). The acceptable limits of these two parameters are ECC< 0.5 and CCL< 0.4 bits/Hz/s. [9][10]

VII. CONCLUSION

This paper addresses various notching methods used in the past for eliminating interfering frequencies in the UWB band. It can be concluded that the antenna performance can be improved by using appropriate shapes of slots and patches in the design. The hexagonal patch offers a current distribution similar to circular (maximum for a regular geometry) but the area occupation is less for hexagonal patch geometry making the design compact. Further, different antenna configurations (series-fed, corporate-fed and series-corporate-fed) can be utilized based on the applications to enhance the gain and directivity of the given antenna design.

In a series-fed arrangement, the width of the antennas is compromised as the individual elements are connected successively along the length. Due to their compactness, series-fed arrays can be used for narrow bandwidth applications requiring fewer line losses. In a corporate-fed arrangement, the feeding strength of the signal to each element is almost the same; thus, there is lesser mutual coupling between the individual elements. Corporate-fed arrangements require long transmission lines between the input port and the radiating element, resulting in higher insertion losses affecting the system's overall efficiency.

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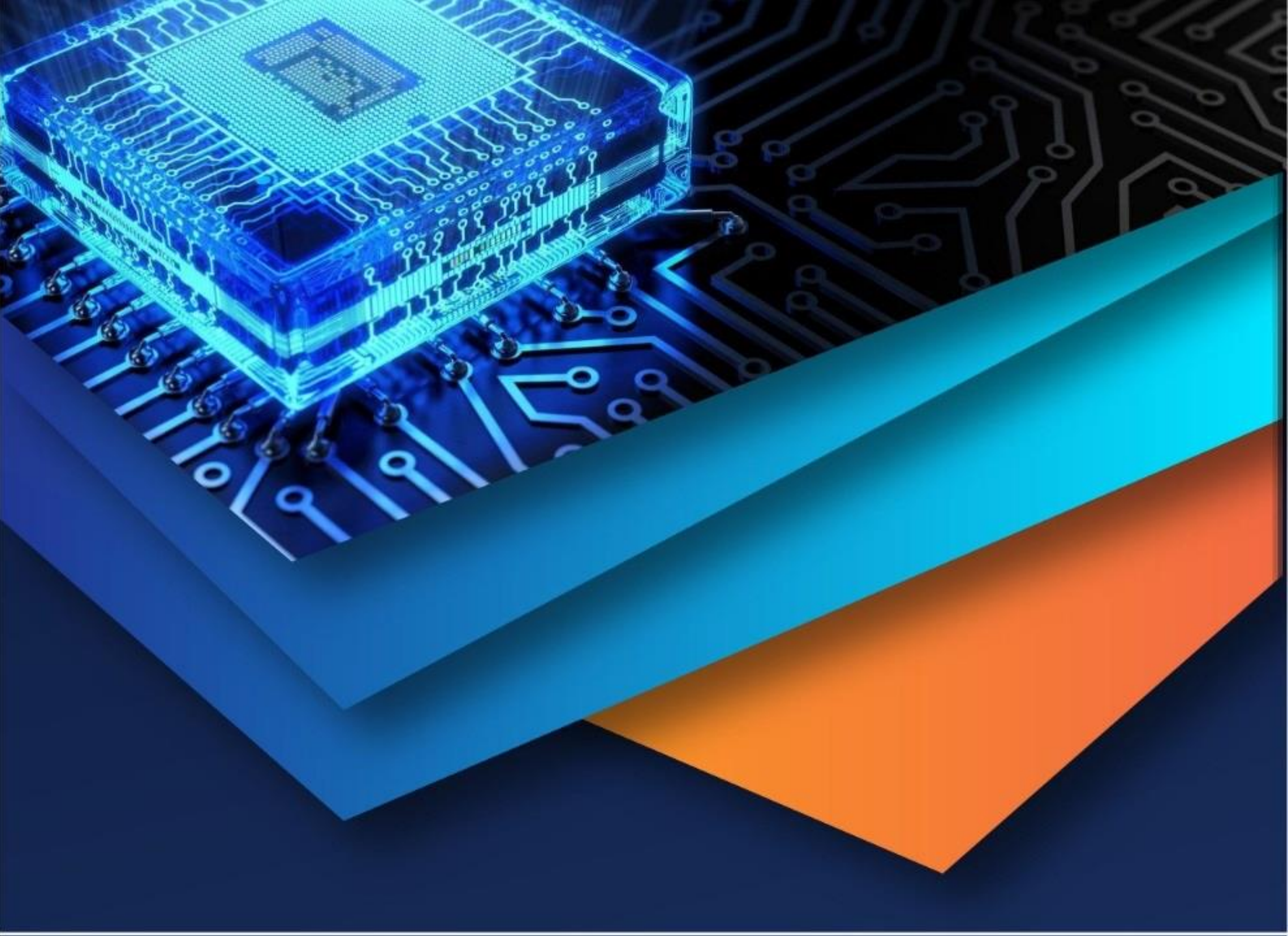

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