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Microstrip Patch Antenna in WiMAX, ISM and L-band for Sub-6 GHz Application. Review

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Abstract

In rapid deployments of next generation wireless communication system, the demand for high speed data, capacity, high reliability, low latency and increased flexibility. Rigorous research in the field of 5G technology. Sub-6 GHz mid-band spectrum fetches the attention of the researchers due to its estimable ease of deployment in the existing infrastructure. 5G Sub-6 GHz band finds massive applications in fields of wireless communication. The Sub-6 GHz wireless bands are assigned for various applications. This article gives inclusive review of current state-of-art of antenna for 5G Sub-6 GHz technology. Different design techniques and methods of antenna to Sub-6 GHz are summarized in the literature, to overcome the antenna design challenges.

Keywords: WiMAX, ISM-band, L-band, Sub-6 GHz, and 5G

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Микрополосковая патч-антенна диапазонов WiMAX, ISM и L для применения в сетях стандарта Sub-6 GHz. Обзор

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Быстрое развитие беспроводных систем связи следующго поколения выдвигает требования по высокоскоростной передаче данных, пропускной способности, высокой надёжности, низким задержкам и повышенной гибкости. Основные исследования при этом сосредоточены в области технологии 5G. Средний диапазон частот до 6 ГГц привлекает внимание исследователей вследствие простоты его реализации на базе существующей инфраструктуры. Диапазон Sub-6 GHz (ниже 6 ГГц) стандарта 5G находит широкое применение в технике беспроводной связи. Полосы частот ниже 6 ГГц назначены для различных приложений. В статье дан обзор текущего состояния антенн для технологии 5G для диапазона ниже 6 ГГц. На основе литературных данных выполнено обобщение методов проектирования и применения антенн диапазона ниже 6 ГГц, направленное на преодоление известных проблем их проектирования.

Ключевые слова: WiMAX, ISM-диапазон, L-диапазон, диапазон ниже 6 GHz, 5G

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1. Introduction

In the modern era, the prominent increase of wireless devices, insufficient bandwidth and limited channel capacity has substantially promoted efforts to develop advanced standards for communication networks. Consequently, the development of next generation means much better channel capacity and higher data rates. As the demand for capacity in mobile broadband communications grows year after year, wireless carriers must be prepared to support a thousand-fold increase in total mobile traffic by 2020, necessitating researchers to seek greater capacity and new wireless spectrum beyond the 4G standard [1].

5G technologies not only provides greater reliability, higher data rates up to 20 Gbps and reduced power consumption to meet the massive increase in connected devices but also promises to increase the visions of emerging technologies such as virtual reality and smart cities [2]. According to wireless network statistics, global mobile traffic increased by around 70 % [3]. In 5G to increase the data rate, utilizing the frequency bands with wider channel bandwidth are been considered in future mobile communication [4]. The antennas are playing the vital role requiring cellular connectivity with high-speed and large quantity data transferring capabilities to demonstrate superior performance and are designed to meet the reliability needs of the applications,to satisfy the requirements. The antenna must adhere to specific standards approved by regulatory organizations like the European Telecommunications Standards Institute in order to operate across a given frequency range and the Federal Communications Commission of the United States [5].

While designing antennas certain parameters to be considered. Antenna parameters can be classified mainly into two categories. Radiation characteristics are critical for antenna design, system performance analysis, interference mitigation, antenna selection, and signal reception and transmission optimization. Electrical parameters give important information about an antenna's performance, impedance matching, efficiency, and noise characteristics, to ensure efficient power transmission, minimize signal reflections, improve signal quality, optimize system performance, reduce interference, and enhance the overall communication system effectiveness,the major focus in 5G technology are data throughput, forward error correction, access technology, latency, spectrum efficiency, and connection reliability. 5G is a global wireless network standard that succeeds 4G. The fifth-generation (5G) communication system is a promising technology that fulfils the increasing requirements of data rates and also enables its integration with various services [6]. The rapid increase of mobile data growth and the use of smart phones are creating unprecedented challenges for wireless service providers to overcome a global bandwidth shortage, to meet the future's fast expanding traffic demands, 5G systems should be able to provide considerable improvements in cell capacity and boost user data rates [7].

2. Towards Sub-6 GHz

The 5G network is not only limited to smart phones but it is also used in robots, agriculture, machines, smart cars, medical applications, and several other things. 5G able to provide immediate and real-time access to data. The time required for information process is comparatively faster than 4G. 5G technology covers the low, mid, and high bands. Low band covers less than 1 GHz, mid-bands covers 1 GHz to 6 GHz is considered as a Sub-6 GHz wireless bands. Finally, high bands are referred as millimeter wave (mm-Wave). Implementation of mm-wave devices is expensive as mm wave are high-frequency waves, they can only cover very short ranges, A Sub-6 GHz (mid band) is the main focus of researchers, the Sub-6 GHz, as it has a lower frequency range, is limited in terms of speed, in comparison of mm wave, but offers a longer range which makes it more suitable for real-world implementation. The Sub-6 GHz band is separated into various frequency bands, each with its own set of applications such as cellular networks, Wi-Fi, Bluetooth, and other wireless communication technologies. the most regularly utilised Sub-6 GHz frequency bands are, 700 MHz Band, frequencies in this band range from 698 MHz to 806 MHz and are widely utilised for cellular networks, including 4G LTE and 5G deployments. The 800 MHz band, which ranges from 824 MHz to 894 MHz, is widely utilized for cellular services in many parts of the world. 900 MHz Band, this band, which has frequencies spanning from 890 MHz to 960 MHz, is used for a variety of applications such as cellular networks, RFID, and industrial wireless systems. The 2.4 GHz band is commonly used for Wi-Fi, Bluetooth, and other short-range wireless communication technologies, with frequencies rang-

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ing from 2.4 GHz to 2.4835 GHz. In 5 GHz Band, frequencies range from 5.150 GHz to 5.925 GHz and are used for Wi-Fi networks, particularly in the 5 GHz Wi-Fi protocols (802.11a/n ac/ax). The 5.8 GHz band, which ranges from 5.725 GHz to 5.875 GHz, is extensively used for wireless communication systems such as Wi-Fi and point-to-point microwave communications. Bandwidth is the key parameter to enhancing capacity and data rates in wireless communication [8]. To achieve the higher data rates higher bandwidth is required [9]. WiMax has three allocated frequency bands. The low band (2.5–2.8 GHz), the middle band (3.2–3.8 GHz) and the upper band (5.2–5.8 GHz) [10], which lies in the Sub-6 GHz bands. The features of high data rate, higher mobility and multi-device connectivity, WiMAX technology is extensively used [11]. Industrial, scientific and medical (ISM) 5G Sub-6 GHz band, particularly at the frequency of 3.5 GHz. L-band refers to the operating frequency range of 1–2 GHz in the radio spectrum. The L band is one of the chief operating ranges used by various applications such as radars, global positioning systems (GPS). Researchers have proposed many kinds of antennas for WiMAX, 2.45 GHz ISM-band and 3.5 GHz 5G Sub-6 GHz band. Sub-6 GHz has ushered in a new era of connectivity and innovation, enabling cloud computing, smart traffic systems, AI services, automated industrial infrastructure, robotics, HD live streaming, virtual reality, augmented reality, space and astronomy, smart-home, and smart transportation [12]. Most antennas for lower 5G bands are either integrated with prior bands, in recent years, antennas have been studied extensively to solve the requirements that are associated with 5G antennas.

3. Antenna challenges specific to Sub-6 GHz WiMAX, ISM and L band

Practical design considerations specific to the target frequency bands and applications considerations are critical for the successful deployment and operation of wireless communication systems, some of these are.

3.1. Bandwidth enhancement

Microstrip patch antennas are typically narrowband due to their inherent physical and operational properties that includes, high-Q factor, dielectric loading, surface wave losses. A variety of techniques have been used to improve the bandwidth, such as cutting slots inside the patch [13], employing aperture coupled feeding network [14], building shorting walls [15], applying parasitic strips around the patch [16], hybrid-coupling method [17]. These approaches are effective for extending the bandwidth of microstrip patch antennas, but they introduce additional challenges in terms of miniaturization, gain, and radiation performance. Increasing substrate thickness, it introduces new issues in terms of the fringing fields at the edges of the microstrip patch are increased; it also can cause increased surface wave losses and can degrade the radiation pattern [18]. As per the Shannon capacity theorem the data rates are directly proportional to the bandwidth.

3.2. Interference and coexistence

Dealing with the possibility of interference from other users or systems operating in the same spectrum is an inherent part of operating in shared frequency bands, such as ISM bands. Techniques to reduce interference and enhance cohabitation with nearby systems should be considered during antenna design.

3.3. Integration and ompatibility

It is necessary to incorporate antennas into the overall design of the system in a seamless manner, taking into consideration aspects such as the form factor, the mounting options, and the compatibility with other components of the system, such as transceivers and radio frequency front devices.

3.4. Specific absorption rate

Specific absorption rate (SAR) is a measurement of the rate at which energy is absorbed by the human body when exposed to an electromagnetic field of radio frequency [19]. The human tissues convert the electromagnetic energy into heat which in turn causes the rise of temperature or thermal effects in the body. According to IEEE C95.1:2005, the safety limit to SAR has been set to ‘2’W/kg per 10 g of biological human tissue. The SAR values need to be very low as much as possible [20]. Electromagnetic radiations can have temporary as well as permanent effects on the health of human leading to most severe diseases in many cases [21]. Antenna positioning, shielding frequency selective networks techniques used to minimize the SAR value.

3.5. Miniaturization

Miniaturization of microstrip antennas is important by considering the reasons, demand for low-cost compact the electronic and radio-frequency portable devices [22], like Smartphones, tablets, and wearable technology, space constraints in many compact and lightweight applications, satellites, drones, IoT devices. It has the potential to increase their performance and usefulness; there are numerous methods to be considered in miniaturization. Use of a substrate with a high electric permittivity [23], is a most common technique, it having some limitations like decreases the bandwidth and the antenna radiation efficiency due to surface waves are excitation. Shorting wall [24], shorting pin [25], also plays an important role in miniaturization.

3.6. Multiband

Increase in demand of wireless systems and services operating at multiple frequencies, multiband antennas are designed to operate effectively in various frequency band. Interference between the different frequency bands, impedance matching and size of an antenna are the challenges [26], which can affect the performance of the antenna. Slot on radiation patch is simple technique for the multi-band operation; metamaterial-loaded antennas [27], slot stepped-impedance resonators [28], techniques help to perform at multiple bands.

3.7. Polarization

Polarization diversity can effectively improve the link quality for reducing multipath fading loss, increase the system capacity through reusing a frequency, and offer a useful polarization modulation for radio frequency identification.

3.8. Isolations

The ever-increasing demand for superior data rates, large channel capacity to provide multiple input multiple output (MIMO) technology is considered [29], the co-frequency and co-polarized antenna elements are arranged compactly, since some of their power can interact and cause interference to the nearby antennas that lowers their efficiency [30], which will degrade the performance of MIMO antennas, including dependable channel capacity, poor spatial correlation, and a high signal-to-interference-pulse-noise-ratio [31]. The terms port-to-port isolation and cross-polarization discrimination, are generally used to measure the antenna separation with its two polarizations, cross-coupling between their two signal ports degrading antenna diversity gain [32].

4. Techniques for enhancing antenna performance in the Sub-6 GHz WiMAX, ISM and L-band

To cover the Sub-6 GHz bands, antennas with multiband capability and a large frequency ratio are of great importance, along with maintaining low profile, a steady radiation pattern, good polarization purity, bandwidth, gain, efficiency, reduction in the mutual coupling, and compact size are challenging task [33]. The purpose of ongoing research is to address these challenges.

4.1. Multi elements

A thin monolithic antenna array has been proposed for on-body applications at the 5G Sub-6 GHz band as an evolution of the traditional comb-line array. The proposed layout offers better performance in terms of efficiency and gain as well as a miniaturized footprint. The antenna is robust against positioning over the body. Furthermore, the smallest 4 cm×4 cm×0.1 cm configuration proved to be conformable to curved surfaces, with almost invariable input impedance and gain [34]. These can be regarded as a simplified form of Krauss' grid, where the transmission lines connecting the top of the vertical radiating pieces are eliminated, resulting in advantages in terms of bandwidth and cross-polarization level [35]. Lightweight, interoperable, and easy-to-integrate antennas. 19.5 mm×26.5 mm 1x2 array patch. Working frequency is 3.5 GHz. return loss -12.54 dB, impedance bandwidth 66.5 MHz, VSWR 1.6, gain 5.5 dB [36]. Two orthogonal dipoles that are excited with a phase shift of 90º, to radiate both RHCP & LHCP polarizations, by using a 900 hybrid couple, by adding monopole fence the antenna shows a stable gain. Circular polarized dual-band antenna for WLAN/Wi-MAX application is reported in [37]. Square patch and square ring is arranged in the antenna patch. Transmission line feed strip should be arranged diagonally to achieve both RHCP & LHCP, the circularly polarized (CP) is somewhat depends upon the feeding angle and the feeding location is observed. 8-element dual-band MIMO dual-band

8-element MIMO antenna for 5G smartphone applications has been successfully investigated antenna operating in the 5G new radio band n77, antenna efficiencies better than 53 % [38]. Multi-element antennas, such as patches or dipoles, can be configured in multiple topologies on a single substrate, including linear arrays, planar arrays, and non-uniform arrangements. To enhance bandwidth [39], gain, directivity and radiation characteristics [40].

Patch antennas are popular for their simplicity and compactness, yet they possess certain limitations. Using multiple elements in patch antenna designs is a crucial strategy for enhancing antenna performance. By appropriately configuring multiple elements and optimizing them, these antennas satisfy the increasing demands of modern communication. Table 1 summarizes the various antennas desigm techniques and their enhancements in antenna performance.

Table 1

Analysis of the multiple elements in patch antenna to improve the performance

Ref	Method	Findings	Research Gap
34	Array	Miniaturized array has an efficiency 6 dB higher and an area 80 % smaller	Isolation, SAR
35	Array grid	Gain-bandwidth relationship:	Cross Polarization
36	Array	Simple to integrate	Bandwidth
37	Two orthogonal dipoles excited with a 900 phase shift	CP is somewhat depends upon the feeding angle and the feeding location	Cross Polarization
38	8-element MIMO	Good reflection coefficients, antenna efficiencies	Isolation

Summary of multielement research to increase patch antenna performance

Multielements in patch antennas provide improved bandwidth, spatial diversity, and enhanced gain.

4.2. Mutual coupling reduction techniques

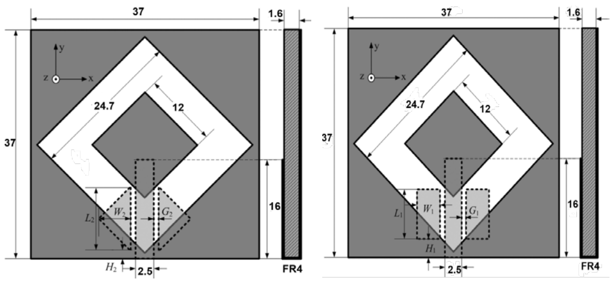
Generally, the decoupling methods used to suppress or weaken the currents between antenna elements, which can be realized by using metamaterials, defected ground structure (DGS) & slot/s. In other technique an additional coupling path is introduce to cancel out the coupling current between antenna elements, so high isolation will be possible using electromagnetic band gap (EBG), parasitic elements [41], decoupling networks [42] and neutralization lines [43].

4.2.1. Parasitic element

Parasitic elements in microstrip antennas positioned in such a way that they can interact with the electromagnetic fields generated by the active patch to modify the radiation pattern, impedance, and other characteristics of the antenna. To reduce mutual coupling, a parasitic element is loaded between the MIMO antenna elements [44]. By properly designing parasitic elements, the coupling between two two-element arrays was reduced. The the parasitic elements positioned on both sides of the driven patch for a symmetrical geometry and better mutual coupling reduction, with the same center spacing between two elements offered the isolation of more than 20 dB [45]. Letter presents in [46] dual-polarization wideband Sub-6 GHz suspended patch antenna for 5G base station, to operate in a 3.3−3.8 GHz band for 5G base stations application. The dual port antenna consist of a parasitic patch, two modified L-probe feeds, and a vertical metal wall. The parasitic patch contributes for enhancement of impedance bandwidth and isolation. The port isolation depends on the spacing between the metal wall and the capacitive driven main patch. To create ±45° slant dual polarization for diversity, the excitation of main patch by two modified L-probe feeds. The antenna provides $|S11|, |S22| < -10$ dB and $|S11|, |S22| < -15$ dB impedance bandwidths of 45 % and 36 %, respectively, with port isolation $|S21| < -30$ dB, has a gain of 8.95±0.25 dBi.

4.2.2. Decoupling network

A decoupling network connected to the antenna array, reactive components (like inductors and capacitors) can be used between closely spaced antenna ports to increase isolation between them. By interconnecting the feeding lines through lumped capacitors, the mutual coupling could be compensated [48].



a *b*

Figure 1 – Printed slot antennas for bandwidth enhancement, with parasitic patches: *a* – antenna with triangular parasitic patches; *b* – antenna with rectangular parasitic patches [47]

The π-shaped decoupling decoupling structure is placed between the feeding networks of the adjacent antenna elements to decrease the mutual coupling, widened bandwidth, without changing the size of the antenna array [49]. A decoupling network using connected couplers but without any lumped components is proposed in [50].

4.2.3. Defected ground structure

Defected ground structure is a modification in the ground plane to modify the electromagnetic behaviour of the antenna, to improve the radiation pattern, impedance matching, and other performance characteristics of the antenna [51]. DGS is one of the popular strategies to enhance the radiation characteristics of the microstrip patch antenna [52]. The reconfigurable rectangular microstrip monopole antenna for WLAN/WiMAX applications is implemented for resonant modes of 3.5 GHz and 5.2 GHz bands are achieved by employing inverted L-Shape slits in radiating patch and using defected ground structure, the proposed antenna exhibits high efficiency is implemented in [53]. A tri-band 4-port MIMO antenna, employing an innovative mutual coupling reduction technique that incorporates integrated parasitic strips and an inverted ground plane configuration, has attained a maximum isolation of ≤45 dB. The implementation of inverted ground planes does not affect the desired polarization characteristics as the number of antenna elements increases for MIMO applications [54]. To miniaturize a microstrip patch antenna, for this purpose, DGS has been employed to shift the resonance frequency from 5.7 GHz to 3 GHz, a miniaturization up to 50 %, with respect to the conventional microstrip antenna [55]. A slotted plus-shaped antenna with a DGS for 5G Sub-6 GHz/WiMAX applications is implemented in [56], for the popular band of WiMAX 3.3–4.2 GHz. The proposed antenna is fabricated on Rogers RT5880 substrate with defected ground structure technique is used and the rectangular slot on radiating patch for the enhancement of impedance matching and radiation performance, the T shaped stepped design to improve the current distribution. The antenna covers a wider bandwidth of 2.56 GHz and reflection coefficient of -52.06 dB. Authors also investigate the performance parameter of an antenna. Co-designed millimeter-wave (mm-wave) and Sub-6 GHz antenna system cover the bands of 0.79–0.96 GHz and 1.71–5 GHz, with band isolation is implemented in [57]. DGS technique is used to improve the isolation between the pair of the Sub-6 GHz antennas. A two corner capacitive coupling elements for matching purpose is used to maintain balance between bandwidth and isolation. The mm-wave array provides 90° scanning range with gain of up to 7.9 dBi at 28 GHz. The authors conclude with isolation and bandwidth are depends on the value of inductor and capacitor respectively of matching network. Miniature patch and slot microstrip antenna array to resonate at 5.8 GHz for IoT and ISM Band Applications is reported in [58]. A circular patch with and without DGS is proposed to reduce the cross-polarized radiation of a microstrip patch antenna, the cross polarization level with the DGS remains below -20 dB throughout in either plane. On the other hand, without DGS shows its value as high -16 dB [59].

4.2.4. Electromagnetic band gap

Electromagnetic band gap structures are type of metamaterials that can be utilized to improve the microstrip patch antenna characteristics [60]. EBG structure can either transmit electromagnetic waves or block electromagnetic waves of a certain frequency [61]. To reduce mutual coupling between radiating elements, the uniplanar compact electromagnetic band gap (UC-EBG) structures placed on top of the antenna layer, which reduces element separation and mutual coupling between patch antennas that helps to increase antenna directivity [62]. EBG structures can resonate at lower frequencies depending upon the shape and dimension of unit cells, therefore are capable of antenna miniaturization [63].

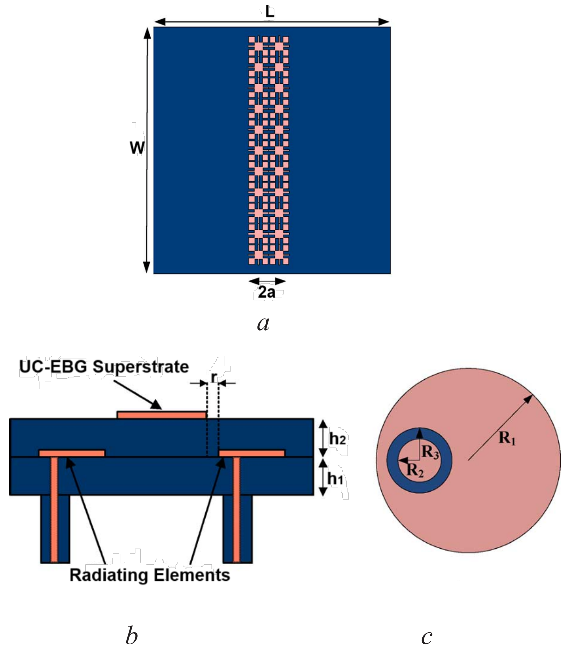


Figure 2 – Electromagnetic band gap. Superstrate based antenna for mutual coupling reduction: *a* – top view; *b* – side view; *c* – radiating element [62]

4.2.5. Neutralisation line

Neutralization line (NL) is designed such that, the current by NL is out of phase with the coupling current so these currents cancel each other. By addition of NL on the MIMO antenna can be helpful in achieving miniaturisation and compactness [64]. A printed dual-antenna decoupled by three NLs operating at the GSM1800, GSM1900, UMTS, LTE2300, LTE2500, and 2.4-GHz WLAN bands, the measured mutual coupling between the two antenna elements is lower than -15 dB, diversity gains of nearly 10 dB [65].

When working with multi-element patch antennas, you need to know how to lower mutual coupling. By making sure that the elements work separately, these techniques improve the antenna's gain, bandwidth, and efficiency, making it work better in communication systems. There are different techniques to lower the mutual coupling between the elements; their findings and gaps are listed in Table 2.

Table 2

Analysis of the techniques used to reduce mutual coupling in patch antenna

Ref	Method	Findings	Research gap
44	Parasitic element	A dual-band MIMO antenna ECC <0.001	Isolation improvement
45	Parasitic element	Two MIMO antennas, isolation of more than 20 dB	Bandwidth
48	Decoupling network	Through lumped capacitors, feeding lines can be connected to compensate mutual coupling	Gain
49	Decoupling network	Co-polarization isolation of the antenna array was improved by 24 dB isolation at 3.6 GHz	Bandwidth
50	Decoupling network	Coupling reduced to below -58 dB	Return loss
53	DGS	Rogers RT5880 substrate, reflection coefficient of -52.06 dB	Gain
54	Parasitic strips	Corner capacitive coupling elements for matching purpose, 201 MHz bandwidth WiMAX band	Bandwidth
56	DGS	Designed on a Rogers RT5880for WiMAX band, bandwidth of 2.56 GHz, DGS is used for improvement of radiation properties	Gain
58	DGS, array	Operating at 5.8 GHz (ISM band), size @ 30 %.	Gain
62	EBG	Minimize element separation and mutual coupling, Mutual coupling between patch antennas can indeed affect their directivity	Bandwidth
65	Neutralization lines	Operates at 2.4 GHz band with bandwidth of 1.3 GHz, mutual coupling is lower than 15 dB	Gain ECC

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Summary of various strategies to reduce mutual coupling

• By deliberately placing an electromagnetic field around the antenna, parasitic elements can manipulate the radiation pattern, resulting in enhanced directivity.

• Decoupling networks ensure appropriate impedance matching by isolating each element, hence preserving the impedance characteristics of each element.

• In order to suppress or enable particular frequencies to propagate, DGS create bandgaps. An antenna's operational bandwidth can be increased with the help of frequency selectivity by reducing the presence of undesirable resonances and harmonics.

• EBG structures work by introducing controlled variations in the ground plane or substrate of patch antennas, leading to improvements in mutual coupling reduction, surface wave suppression.

4.3. Slot technique

The distribution of the electric current on the patch surface is affected by the presence of slots in the patch, that alter the current path and the patch's effective length and width, that changing its resonant frequency and impedance properties, to improve the bandwidth & other parameters. The shape and size of the slot is important parameters that affect the antenna performance. There are a number of ways that have been described to increase the impedance bandwidth of printed slot antennas. The antenna bandwidth is increased by creating many fractal-shaped slots in the main slot's corners in order to achieve multiresonance behaviour [66]. A wide-slot antenna with a fractal-shaped slot is proposed, increased bandwidth is 2.4 GHz at operating frequencies around 4 GHz, also achieved a 2-dB gain [67]. Some slot antennas have a finite bandwidth that is insufficient for more applications [68]. An open slot antenna with nonsymmetric ground is used to minimise the size and to increase the bandwidth [69]. Enhancement of gain and bandwidth in a microstrip patch antenna is achieved through the incorporation of a rectangular slot in the patch and the deposition of nanomaterials in the slot area, intended for WLAN applications. The enhancement in antenna performance results from the incorporation of capacitance between the two distinct nanomaterials [70]. Several slot shapes, in addition to square, rectangular, circular, and regular forms, which includes; binomial-curved [71]. Isosceles triangular slot [72]. Ring slot [73], have been designed to boost the bandwidth. Paper [74] presents a compact slotted patch hybrid-mode antenna for Sub-6 GHz Communication, for the microbase stations in the band 3.0–5.0 GHz with centre frequency 4.0 GHz. The proposed antenna is composed of a slotted rectangular patch, a feeding dipole, and a balun. To achieve a compact size from $0.90\lambda_0 \times 0.78\lambda_0$ to $0.48\lambda_0 \times 0.31\lambda_0$. A sequentially excitation of the three modes is used, as a patch slot and dipole share the same radiator that helps to reduce the size. The author uses the dimensions controlling techniques of strips and slots to change the field distribution of a patch antenna that helps to improve the bandwidth enhancement. The antenna provides the impedance bandwidth of 53.797 %, radiation efficiency at 4.6 GHz maximum of 90.00 %, an average antenna gain of 8.00 dBi. In [75], author implemented miniaturized dual-frequency linear polarization diversity antenna in L and WiMAX bands for IoT applications. Slot loading technique is used in patches to reduce side lobe levels which help in stabilizing the radiation patterns, the feed points are place mutually perpendicular to each other at an equal distance to achieve the better isolation and pure orthogonality. The antenna provides impedance bandwidth 200 MHz at 1.575 GHz. WiMAX band 3.4–3.6 GHz centered at 3.5 GHz. The measured return loss is -30 dB and -24 dB for lower and upper bands respt. The maximum gain in boresight direction is 3.15 dBic, and the peak gain for WiMAX band is 4.3 dBi. A square concentric slot-based octaband shared radiating aperture for both Sub-6 GHz as well as mm-wave bands antenna is presented in [76] for 1.05–1.23 GHz, 1.4–1.55 GHz, 1.9–2.3 GHz, 2.3–2.7 GHz, 3.1–3.7 GHz, 4.04–4.511 GHz, 4.83–5.2 GHz, and 5.66–6.151 GHz of Sub-6 GHz the band and the mm wave band covers 27.4–28.4 GHz for IoT application. The proposed antenna is with the bandwidth about 1 GHz. Length of the feed line plays important role in input impedance matching.

4.4. Materials

Material advancements make patch antennas more efficient, compact, and versatile. These materials have distinct magnetic properties, such as high magnetic permeability, low electrical conductivity, and the ability to operate at high frequencies, in which size and performance are critical factors. Shorting pins improve the electrical and structural properties of patch antennas, making them more efficient, compact, and capable of handling multiple

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frequencies. The findings & gaps are summarized in Table 3.

Table 3

Analysis of slot, strips and metamaterial approaches employed to enhance the performance of patch antennas

Ref	Method	Findings	Research gap
66	Slots	Slots are added in the corners of the main slot improvement in bandwidth is observed	
70	Slots	Isolations 21 dB, operating frequency bands of 2.73–3.12 GHz and 4.324.68 GHz with the peak gains of 4 dBi, efficiencies 80 % with ECC <0.004	Gain
74	Strips & slots	Bandwidth of 2.36 GHz, operating frequency band of 3.0–5.0 GHz. strips and slots to modify patch antenna field distribution to enhance bandwidth	Impedance matching
80	Metamaterial	MIMO antenna operates in 5.68–6.05 GHz with a peak gain of 7.98 dBi	Bandwidth

Summary slot, strips and metamaterial approaches employed to enhance the performance of patch antennas

• Slots introduce alternative resonance modes and alter the current distribution along the patch antenna, resulting in an increase in bandwidth, are utilised to manipulate and regulate the emission pattern of patch antennas.

• Metamaterials provide various benefits for patch antennas reducing their size. However, they may have restricted tunability in comparison to traditional antennas due to their fixed features that are not easily adjustable.

5. Additional methods and corresponding efforts to enhance patch antenna performance

A dual-band wideband CP microstrip antenna is proposed for Sub-6 GHz application the antenna consists of an a non-centered L-shaped radiator and two circular strips at left and right corners on the lower ground, to achieve the right-handed circular polarization for Wi-Fi (2.4–2.48 GHz) and n77 (3.3–4.2 GHz) band to achieve the characteristics of high frequency circular polarization and broaden the axial ratio bandwidth. Two circular strips added to the ground and an asymmetric feed structure provide a 90° phase difference to achieve the high frequency circular polarization. Adjusting the dimensions and center position of the two circular strips used for the impedance matching and broaden bandwidth of the antenna [82]. A bidirectional, circularly polarized antenna with a miniaturized design in WLAN 2.4/3.65-GHz, WiMAX 2.3/2.5-GHz. The antenna consists of a hexagonal slot, a hexagonal patch, ten meander tips, and rectangular corner notches to achieve broad impedance and axial ratio bandwidth. The antenna has a −10-dB impedance bandwidth of 89.7 % (1.60–4.20 GHz) and a 3-dB axial ratio bandwidth of 70.5 % (1.80–3.76 GHz). The peak realized gain in the boresight direction is 3.65 dBi [83].

Xiaojun Tang et. al. [84]. Introduced bandwidth enhancement of a compact dual-polarized antenna for Sub-6G Hz 5G CPE, achieved better bandwidth than the cross-dipole antennas implemented in [85]. Crossed-dipoles generally exhibit narrow impedance bandwidth. To enlarge it, sometimes diamond-shaped metal dipoles are adopted [86], the ultra-wideband dual-polarized antenna for fifth generation (5G) compact antenna is investigated and designed for bandwidth enhancement by using a double-loop-dipole structure consisting pairs of perpendicularly cross-feeding structures the radiators serve as +45°/−45° polarization. The radiating structure consist of two baluns are used to excite the radiators at the top by connecting to the small semicircle loop for improvement of frequency bandwidth, the antenna consists of octagonal loop and coupled small semicircle loop etched on the top and bottom of the substrate, and the co-planar-slot feeding concept which helps to the improves the impedance matching. Antenna has a wide bandwidth of 86 % from 2.2 to 5.5 GHz with the VSWR less than 1.8, high polarization isolation of 25 dB, and stable radiation patterns over the desired frequencies of 2.3–5.2 GHz. It is best suited in impedance bandwidth improvement for Sub-6 GHz 5G applications.

Planar four-port dual circularly-polarized MIMO antenna for Sub-6 GHz Band for 3.4–3.8 GHz is implemented on the FR-4 substrate. An open slot ground plane integrated with two rectangular arms for realizing circular polarization. Opposite facing with equal amplitude and 90º phase difference in two rectangular arms to obtain the CP. To improve the 3-dB axial ratio beamwidth I-shaped strip is used [87]. A four-port MIMO array antenna system to operate within a frequency range of 3.2–5.75 GHz to serve in 5G new radio Sub-6 GHz n77/n78/n79 and 5 GHz WLAN with high isolation between ports is introduced, uses four methods of reducing mutual coupling and compare the performances of each method, the best method is EBG because it has high isolation due to extra capacitance in the circuit [88].

Zhong Yu et al. in [89], implemented MIMO antenna with the use of decoupling mechanism, with polarization diversity for Sub-6 GHz band, consisting a pair of RHCP and LHCP. Element decoupling and position concept is used for antenna isolation, axial ratio bandwidth and for compactness, in an orthogonal connection of I and II-shaped metal strips, which realizes the circular polarization characteristics. Inter-element isolation is less than −16 dB, impedance bandwidth of 520 MHz is achieved for 3.45 GHz & envelope correlation coefficient (ECC) less than 0.07.

Insha Ishteyaq et al. [90] 8-element and orthogonally polarized annular slot element is presented for Sub-6 GHz 5G application on epoxy FR-4 substrate, to achieve the isolation between the feeding ports is by placing the antenna with split ring resonators perpendicular to the annular slots, the current density flow pattern focused to reduce the mutual coupling between the elements that helps to the improved isolation of 21 dB, in the operating frequency bands of 2.73–3.12 GHz and 4.324.68 GHz with the peak gains of 4 dBi, efficiencies around 80 % with ECC <0.004.

The antenna proposed for wireless applications in the ISM 2.5 GHz/WiMax 3.5 GHz/WLAN 5.2 GHz/ISM 5.8 GHz frequency bands for mobile communication, specifically for 4G LTE and Sub-6 GHz 5G spectrum, use the RT duroid 5870 substrate. The slots are strategically utilised to incorporate a combination of modal behaviour, effectively capturing numerous relevant frequency ranges with accurate radiation alignment.is reported in [91]. To achieve multiband antennas various techniques described in [92]. Parasitic elements patch antenna with proximity-coupled V-slotted rectangular patch implemented in [93], proposed antenna used the loading method of multiple shapes slots on the patch with slant by 45° is cut at the central region improves matching at each excited frequency and consequently improves the operating bandwidth.

Reduction in degradation of signals due to fading or multipath interferences and orientation of transmitting and reception antenna needed circular polarized antennas for satellite systems because the circularly polarized antennas are more protected to faradays rotation effect caused in ionosphere. A design of a dual circular polarized crossed-dipole antenna for L-band applications (1.1–1.6 GHz) with antenna gain and polarization purity is implemented in [94]. Patch antenna performance can be improved through a variety of methods, each focusing on a specific aspect. Each effort contributes to the development of high-performance antennas suitable for modern communication systems. These methods help to address issues such as compactness, efficiency, and multiband operation. Table 4 contains a concise summary.

Table 4

Analysis of additional methods and corresponding efforts to enhance patch antenna performance

Ref.	Method	Findings	Research Gap
83	Circular strips are utilized for circular polarization	Asymmetric feed arrangement creates a 90° phase difference, bandwidth of 1.1 GHz	Bandwidth
86	A double-loop-dipole structure, cross-feeding structures for Sub-6 GHz of 5G applications	Bandwidth of 3.3 GHz	Gain
90	Split Ring Resonators	The current density flow pattern is designed to minimize mutual coupling and provide an isolation of 21 dB within the frequency ranges of 2.73–3.12 GHz and 4.32–4.68 GHz, with peak gains of 4 dBi	Bandwidth

Summary of research findings from other techniques improve the performance of patch antenna

• Strips, which function similarly to tuning stubs, are frequently utilised. Strips can increase the bandwidth of the patch antenna and aid in achieving impedance matching.

• Cross-feeding structures improve patch antenna performance by controlling radiation characteristics, permitting multiband operation, and reducing mutual coupling.

• SRRs help shrink patch antennas. The antenna structurecan be lowered in size without sacrificing performance.

Table 5

Comprehensive investigation of several techniques, including their benefits and constraints

Method	Advantages	Limitations
DGS	• The antenna's operational bandwidth is increased, impedance matching and frequency coverage are enhanced and undesired resonances and harmonics are suppressed. • The performance of the array is improved in terms of the control of the radiation pattern and the efficiency – Makes it possible to construct antenna arrays that are economical and compact.	• Difficulties associated with frequency sensitivity. • In certain instances, there is a limited improvement of the bandwidth; sensitivity to the characteristics of the substrate and fabrication tolerances.
Metamaterial	• The antenna's operational bandwidth is increased; impedance matching and frequency coverage are enhanced. • Multi-band operation is made possible. • Improves antenna performance in settings with high surface wave propagation. • Increases antenna efficiency and allows for better control of radiation patterns.	• Construction can be difficult and expensive, and there is a possibility of limited bandwidth augmentation under some circumstances. • Complex design and optimization are necessary.
Parasitic element	• Gain enhancement – Beam shaping – Bandwidth adjustment. • Mutual coupling reduction.	• Requires precise positioning and sizing of elements. • Sensitivity to surrounding environment. • Additional complexity in design and tuning.
Decoupling network	Enhances the isolation of antennas and decreases the mutual coupling between elements, resulting in improved radiation efficiency and pattern shaping.	• Different frequency bands may affect decoupling network effectiveness. • Integrating the decoupling network with antenna elements while retaining compactness and structural integrity is difficult in miniaturised systems.
EBG	Reduces mutual coupling – Improves radiation pattern control – Enhances bandwidth – Size reduction.	• The design complexity of a system can be influenced by its sensitivity to fabrication tolerances. • Can result in extra losses and impedance mismatches.
Slots	The enhancement of the bandwidth, the improvement of the radiation properties. Reduction of surface waves, and the compact design.	• Optimization that is difficult to understand. • Improvement in bandwidth that is limited in some circumstances. • Sensitivity to fabrication tolerances.

Summary of the pros and cons of the approaches taken to enhance the patch antenna's performance

To successfully improve the performance of patch antennas for ISM, L and WiMAX band applications, need to know the benefits and drawbacks of each method for the frequency bands you are interested in. It is possible to achieve significant enhancements to antenna performance, by carefully choosing and integrating diverse approaches. To get the best possible performance from these methods in real-world applications across multiple frequency bands, however, problems like complicated fabrication, narrowband operation, and sensitivity to changes in the substrate must be carefully addressed.

Conclusion

This article addresses antenna performance and challenges in the Sub-6 GHz band of 5G. Identifies the microstrip antenna requirements for applications operating in the WiMAX, ISM, and L-band Sub-6 GHz bands. Authors pays particular importance on mutual coupling, wideband, radiation characteristics, and high-speed processing capability. There is a need for more compact antennas that have a high gain and wideband. Emphasizes the significant necessity of multiple input and output antennas.

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