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A Comprehensive Review on Multi-band Microstrip Patch Antenna Comprising 5G Wireless Communication

Devendra H. Patel[1] and G. D. Makwana[2]

[1] Ph.D. Scholar, Sankalchand Patel University, Visnagar, India and Electronics & Communication Engineering Department, Government Engineering College, Gandhinagar, India
[2]Electronics & Communication Engineering Department, Gujarat Technological University – Graduate School of Engineering and Technology, Ahmedabad, India

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Abstract: The rapid increase of mobile users, subscriber demands, and various enabling technologies of next-generation mobile and wireless communication systems such as 4G, 5G, WiMAX, and many more have triggered antenna researchers to develop new solutions. The evolving technologies such as mmWave, 5G require high gain and high capacity antennas. The rising demands for small size, low-cost, low-profile, and efficient multi-band antennas in a single system for various communication standards have also created many opportunities for researchers. The design and development of such multi-band and compact size antenna requires more attention towards other limitations like gain, directivity, bandwidth, high efficiency, various frequency bands, operating set-up, design complexity, etc. Microstrip antenna has characteristics like simple structure, small size, cost-effective and easy integration with Microwave Integrated Circuits. This review paper aims to overview the current research trends and presents the various approaches, design, and development techniques used by researchers in multi-band antennas comprising 5G wireless systems. This study will help the researchers to review and analyze the existing methodologies, design procedures, and future challenges.

Keywords: Microstrip Patch Antennas (MPA), Multi-band, Gain, Bandwidth, Substrate, Feeding Technique.

1. INTRODUCTION

Presently communication systems toggle between 2G, 3G, 4G, 5G, WLAN, WiMAX, Personal Communication System, Bluetooth, GPS, Zigbee, Digital Cellular System, and many more as per subscriber needs and network signal strength and this leads to antenna system design, which supports frequencies of many communication standards. Hence, the multiple antennas in a wireless communication system for different applications are replaced by Multi-band antennas offers benefits in reduction of cost and system complexity [1-2].

For leading edge communication technologies such as mm-wave, 5G, and beyond, antennas operating at multiple frequencies are of great importance in meeting subscriber requirements for high data rate and capacity [3-7]. Today, researchers find challenges in designing multi-band antenna for next-generation communication systems with high gain, low cost, high efficiency, small size, and high directivity which leads to more research opportunities in this field [4-5, 8-10].

In addition to this, the antenna design for next-generation wireless communication systems also focuses on Multiple-input multiple-output (MIMO) communication techniques because of its characteristics like interference suppression, increased diversity and high capacity [10-11]. As a result, the study of multi-user MIMO antenna design has recently been an interesting field of research.

The rapid growth in demand for smartphones users/subscribers for different wireless communication applications has brought the Microstrip Patch Antennas to the forefront due to its smaller size and low-profile characteristics. The great advantages of Microstrip patch antennas such as small size, easy fabrication, low weight, and low-profile have replaced conventional large size antennas in mobiles and wearable devices. Apart from having numerous advantages, Microstrip patch antennas

E-mail:pateldevendrah@gmail.com, gmakwana@gmail.com

have some disadvantages such as spurious feed radiation, low efficiency; poor scan performance, low power as well as narrow frequency band [4-5, 8-9, 12].

Core contributions of this study are as follows:
1. Classification of multi-band antenna operation techniques
2. Performance analysis of multi-band antenna on seven different parameters
3. Advancement in multi-band antenna design for wireless communication
4. General methodology to design a multi-band antenna
5. Discussion on current challenges in this field of study.

In this paper, various multi-band Microstrip patch antennas comprising 5G wireless communications are explored. In section 2, the basics of the Microstrip patch antenna with feeding techniques are discussed. Section 3 covers the recent research work review on multi-band Microstrip patch antenna along with their applications and performance comparative study of different antennas reviewed in the literature review. Section 4 concludes this review.

2. MICROSTRIP PATCH ANTENNAS (MPAS)

The MPA was first proposed in 1950s and it developed practically in 1970s [13]. It consists of the radiating patch, a dielectric substrate, and a ground plane [14-17].

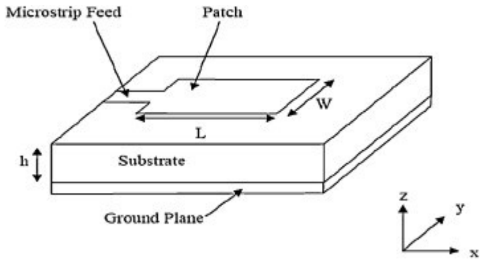


Figure 1. Microstrip Patch Antenna Structure [15]

In Figure 1, the basic structure of the Microstrip Patch Antenna is presented. The radiating patch printed on the dielectric substrate forces the EM waves to radiate at particular frequency. The patch can be of different shapes and size such as rectangular, circular, slotted, triangular, and many more [15-17].

The substrate and patch dimensions are chosen based on operating frequency and the properties of the dielectric substrate material used. The antenna physical parameters such as patch length & width, substrate length & width, feed location, feed length and others can be calculated using various mathematical equations given in [15-17, 20].

Each dielectric material is having its own properties, dielectric constants, and conduction properties, which affect the fringing waves in the patch antenna [15-18]. Some of the dielectric materials are Bakelite, FR4 Glass Epoxy, RO4003, Taconic TLC, Roger RT/Duroid etc., and they are chosen based on antenna application and cost [21-23].

Different feeding techniques, such as microstrip line, proximity coupled, inset feed, aperture coupled and coaxial probe feed have been used to feed the signal to the antenna that needs to be transmitted using EM waves [16-17, 19].

3. LITERATURE REVIEW AND COMPARATIVE PERFORMANCE ANALYSIS

To cover various frequency bands for different wireless communication applications in limited space and low cost requires modifications in shape and size of an antenna with proper optimization of performance parameters. This can be accomplished by using different techniques in antenna design, such as parasitic elements, fractals, slots, various feeding methods, arrays, reconfigurable design, defected ground structure (DGS), metamaterial antennas, and many more.

In this section, various antenna designs are reviewed. The classification of multi-band antenna operation techniques with examples is shown in Figures 2 and 3. Table-I and Table-II contain comparative analysis of reviewed literature based on various performance parameters and operation techniques. The advancements in multi-band antenna technology and its design methodology are also shown in Figures 4 and 5, respectively.

3.1 Literature Review

Sharma [24] presented a compact high gain multi-band antenna having radiating patch with glass-shape and a ground plane of rectangular shape. To support multiple wireless applications, the antenna resonance obtained at 1.71–1.88 GHz for DCS, 1.85–1.99 GHz for PCS and 2.402–2.480 GHz for Bluetooth by inserting stubs whereas at 3.30–3.80 GHz for WiMAX, 5.150–5.825 GHz for WLAN and 7.25–7.75 GHz for X-Band Downlink System by etching slots on the radiating patch. The measured bandwidth is 1.71–2.03, 2.39–2.50, 3.00–4.10, 4.90–5.81, and 7.00–7.90 GHz. It offers a radiation pattern which is considerably good.

Sathikbasha and Nagarajan [25] realized a rectangular shaped novel, defected ground structure (DGS) based efficient multi-band frequency reconfigurable antenna. Two symmetrically etched open ended U-shaped slots, short ended I-shaped slot and 3 PIN diodes are embedded in the ground plane for multi-band operation. The cross-polarization is reduced using two U shape slots. The characteristics of transmission lines were altered by DGS. The antenna resonates at 1.36, 1.8, 3.0, 3.9, 5.0, 6.2, 6.4, 7.4, 7.9, 8.2, 8.4, 8.6 GHz for 5 GHz Wi-Fi/WLAN, WiMAX, 3.1–10.6 GHz UWB system, satellite communication and fixed mobile systems applications.

Punith, Praveenkumar, Jugale, and Ahmed [26] proposed a compact multi-band MPA resonating at 23.9, 35.5 and 70.9 GHz for radio astronomy/satellites, radio location, and 5G mobile communications applications, respectively. It consumes less power as well.

Luo et al. [27] demonstrated a graphene-based dual-band millimeter-wave antenna operating at 28.1 GHz and 37.4 GHz with DC bias applied. The antenna is fabricated on the SiO2 covered high resistivity Si substrate and for the radiator functionality; a monolayer graphene is transferred onto the SiO2.

Araujo, Freitas, Prata, Casella and Capovilla [28] realized a thin and compact ultra-wideband microstrip antenna which resonates at 5G as well as 1575 MHz for GPS, 2.4 GHz for WLAN, 2.1 GHz for 3G, 2.6 GHz for Brazilian 4G, 900–1800–1900–2100 MHz for GSM wireless communication applications. The antenna offers good radiation control with 1.5 GHz or more bandwidth usage.

Alieldin et al. [29] presented a low-profile and compact triple-band dual-polarized antenna for sub-6 GHz 5G and 2G, 3G, & 4G applications as well. This dual polarized antenna comprising two orthogonal dipole antennas consists of elliptical & bowtie dipole and cat-ear shaped arms radiators for various frequency bands. It achieves the fractional bandwidth of 31.3%, 55.3%, and 14% at three independently controlled broad-bands 0.7-0.96 GHz, 1.7-3 GHz and 3.3-3.8 GHz, respectively. It also offers stable high polarization purity, radiation patterns, and dual-polarization capabilities.

Naji [30] demonstrated three compact multi-band coplanar waveguide (CPW) fed Microstrip patch antennas namely Spiral Fork-shaped Antenna (SFA), Mender Fork-shaped Antenna (MFA), and Double SFA (DSFA) which are constructed from the fork-shaped monopole antenna. The antennas cover 3.5/5.5 GHz WiMAX (3.3–3.7/5.25–5.85 GHz), 5.2/5.8 GHz WLAN (5.15–5.35/5.725–5.875 GHz) and C band of modern wireless communication systems. The MFA and DSFA give dual-band whereas the SFA gives tri-band characteristics. The antenna offers stable gain, good radiation characteristics and high-radiation efficiency.

Ikram, Trong, and Abbosh [31] proposed a compact and low-profile single-layered MIMO antenna with 4-element dual-band and wideband monopole tapered slot system operating at 2.45/5.2 GHz WLAN, 2.6 GHz 4G LTE and 24/28 GHz 5G bands. The antenna has a dual-function tapered-ground slot based decoupling mechanism that works as a decoupling structure ($\lambda_0/4$ long) and a tapered slot antenna ($3\lambda_0$ long) at 2.45 GHz and 28 GHz respectively. This approach can also be applied for future access points, Wi-Fi and wireless routers applications.

Parchin et al. [32] realized a multi-band slot antenna array consists of double-element square-ring slot radiators located on the PCB corners for 4G and 5G smartphone. The antenna resonates at 2.6, 3.6, and 5.25 GHz with 2.6-2.7 GHz, 3.45-3.8 GHz, and 5.0-5.45 GHz for impedance-bandwidth of each radiator span, respectively. For −10 dB impedance bandwidth, the antenna covers 2.5–2.7 GHz, 3.45–3.8 GHz and 5.00–5.45 GHz for LTE 2600, LTE bands 42/43, and LTE band 46 respectively, whereas it covers 2.45–2.82, 3.35–4.00, and 4.93–5.73 GHz band for −6 dB impedance bandwidth. It provides good radiation pattern. It is also having good return-loss, better than 17 dB isolation and better efficiency.

Li, Sim, Luo, and Yang [33] demonstrated a multi-band ten-antenna array for massive MIMO applications with 10 T-shaped coupled-fed slot antenna elements provides dual resonant modes excitation operating at LTE bands 42/43 and 46 of the sub-6 GHz spectrum. Techniques of spatial and polarization diversity are used to improve isolation and to mitigate coupling effects. The antenna efficiencies achieved are higher than 42% and 62% in the low and high band, respectively.

Sarkar and Srivastava [34] presented a 4-element dual-band split-ring resonator (SRR)-loaded inverted L-monopole antenna for MIMO application. This SRR loading induced antenna resonates at 2.93 GHz and 5.68 GHz covering lower and upper WLAN band respectively. The antenna offers average gain of 4 dBi, directional radiation pattern and impedance bandwidth (IBW) of 35.21% & 6.86% at both resonating frequency, respectively. Apart from lower WLAN, antenna finds application in 4G, Wi-Fi, WiMAX and sub 6 GHz bands also.

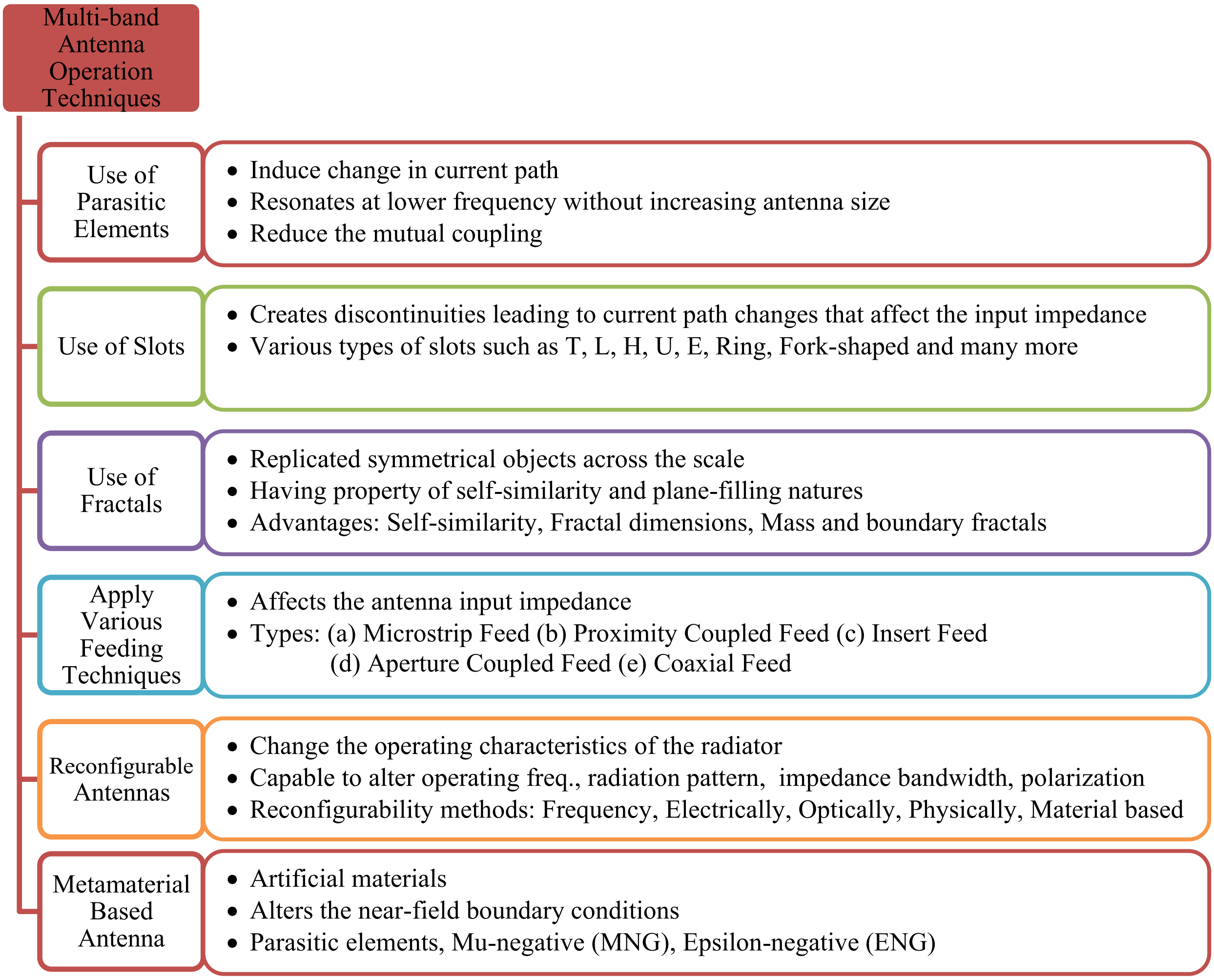


Figure 2. Classification of Multi-band Antenna Operation Techniques [3-4]

Reddy, Palla, and Kumar [35] proposed Multi-Layer Graphene (MLG) patch and flexible PDMS polymer substrate based triple band antenna. The antenna resonates at 2.4, 5, and 6.8 GHz. In all three bands with resonating centre frequencies, the antenna offers bandwidth of 2.58%, 1.5% and 4.5%, respectively. The bandwidth matching varies from 50 MHz to 100 MHz. The high conductivity of MLG results in a gain of 6.3 dBi at 6.8 GHz. Due to patch and substrate characteristics, antenna finds application in flexible, wearable and medical application.

Yang, Sun, and Li [36] presented a wideband compact monopole antenna with deca-band WLAN, 4G, and 5G mobile phone wireless applications. A small C-shape PCB structure consists a monopole antenna and a coupling strip and an inductor. The antenna provides three-wide operating bandwidths which cover 685–1012 MHz, 1596–2837 MHz, and 3288–3613 MHz bands. The antenna offers good gains and radiation efficiencies of 1.4 dBi–2.5 dBi and 38%–47% in all three bands, respectively.

Boukarkar, Lin, Jiang, and Yu [37] realized low profile and small size miniaturized single-feed multi-band patch antennas. By loading short metalized vias at one edge of the patch, the size reduction is accomplished, while etching inverted several U-shapes provides multi-band operation. The peak gains and efficiencies are ranging from 1.43–3.06 dBi and 42–74%, respectively. The radiation pattern is stable, symmetrical and directional. The antenna is having widely tuned highly isolated frequency band combinations.

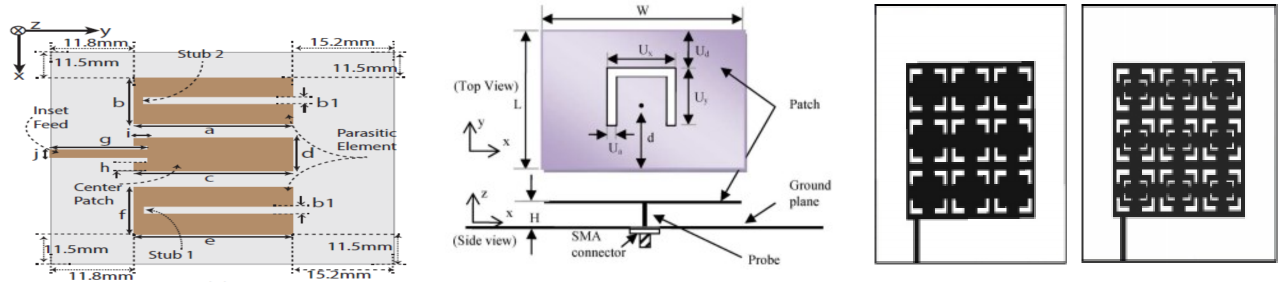
Baiet al. [38] demonstrated two triple-band independently tunable slot antennas resonating at 800, 1500, and 2000 MHz bands. The varactor diodes are used in the design provide independent tuning across three bands with 300 MHz or more tuning ranges at each band. The antennas offer diversity due to its design configuration.

Desai, Patel, Upadhyaya, Kaushal, and Dhasarathan [39] proposed a compact dual branch multi-band slotted antenna consisting varied branch lengths inverted U and E shape slots on the patch and a full ground plane structure. This multi-band antenna resonates at 750–790 MHz, 1.41–1.45 GHz, 2.10–2.14 GHz, 3.44–3.51 GHz, 3.80–3.87 GHz, 5.17– 5.20 GHz, and 5.97–6.38 GHz for Digital broadcasting, wireless medical telemetry, Universal Mobile Telecommunication Service (UMTS), WiMAX/sub-6 GHz 5G, Sub-6 GHz 5G, WLAN and fixed satellite communication applications bands respectively. It provides Omni-directional radiation pattern, over 1.1 dBi gain, and 78% efficiency.

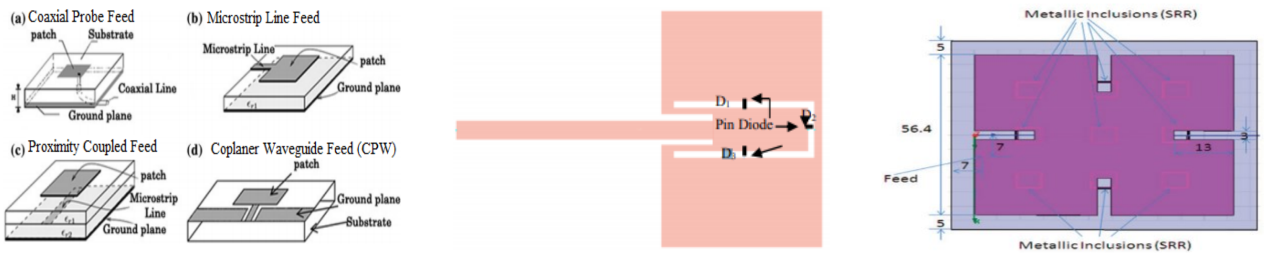
Desai, Patel, Upadhyaya, Kaushal, and Dhasarathan [40] realized a compact, small size and low-profile slotted multi-frequency bands antenna having offset feed comprising a vertical and horizontally coupled slot in the patch and a complete ground plane. It resonates at 1.52–1.60 GHz, 2.97–3.02 GHz, 3.73–3.84 GHz, 4.42–4.52 GHz, and 4.83-4.96 GHz. The antenna finds application GPS, Radio Frequency Identification and Detection, healthcare, mobile communication, logistics, manufacturing, Amateur Fixed Mobile, transportation, radio communications, TransferJet USB Aviation etc. It offers symmetrical omni- & bi-directional radiation patterns and 1.07 to 3.92 dBi gain.

S. N. H. Sa'don [41] presented a Graphene based single and 4-element defected ground structure array antennas which is excited by coplanar waveguide and operating at 15 GHz. The DGS in the array provides improved gain and radiation. The antenna offers 48.64% impedance bandwidth, 2.87 dBi gain, and 67.44%, efficiency, whereas the array antenna offers 72.98% efficiency, 48.98% impedance bandwidth and 8.41 dBi gain. It also provides beam width of 21.2° with 0° to 39.05° scanning beam capability.

Sivia and Bhatia [42] demonstrated a multi-band fractal based rectangular MSA operating from 1 to 10 GHz with return loss of -15.39 dB, -16.48 dB, -10.02 dB, -17.29 dB, -13.15 dB, -23.41 dB, -10.22 dB, -11.28 dB, -17.02 dB, -10.94 dB, -15.15 dB and -15.48 dB at 1.86 GHz, 2.33 GHz, 3.67 GHz, 4.57 GHz, 5.08 GHz, 6.06 GHz, 7.03 GHz, 7.75 GHz, 8.08 GHz, 8.84 GHz, 9.56 GHz and 10 GHz resonating frequencies respectively. The antenna doesn't affect the regular patch antenna parameters and it is useful for the ultra wideband (UWB) applications.



(A) U Shaped Parasitic Element [44]   (B) U-Shaped Slot [46]   (C) Fractal - 1st and 2nd iteration [42]



(D) Feeding Techniques [19]   (E) Reconfigurable Antenna [45]   (F) Metamaterial Antenna [43]

Figure 3. Design Examples of Multi-band Antenna Operation Techniques: (A) Parasitic Elements (B) Slots (C) Fractals (D) Feeding Techniques (E) Reconfigurable Antennas (F) Metamaterial Based Antenna

Patel and Kosta [43] presented multiband metamaterial loaded meandered square MPA operating at 0.6–2.2 GHz range with 670, 1185, 1293, 1747, 1909, 1999, 2063, and 2134 MHz center frequencies. The use of metamaterial in antenna design enhances the gain, and it is increased by 59%.

Asif et al. [44] realized compact and 2-rectangular U-shaped parasitic elements based antenna resonates at 2.6, 6.0, and 8.5 GHz, useful in WiMAX, vehicular LAN, and weather radars application. The parasitic elements can be used for controlling resonance frequencies and 2nd and 3rd mode excitation. The antenna provides the bandwidth of 50MHz, 22.8 MHz, and 30 MHz, and the gain of 6.2 dBi, 4.52 dBi, and 6.9 dBi for each resonant frequency, respectively.

Yeole and Khot [45] demonstrated a low profile; lightweight U-shape slotted reconfigurable patch antenna. The use of pin diodes provide tuning at 2.6, 4.5, 8.4, 8.8, and 9.8 GHz, which provides Wi-Fi, Wi-Max, UWB, and 3G applications using a single patch.

Lee, Yang, and Kishk [46] proposed a wide band patch antenna for dual and multi-band application with L-probe feeding and U-slots on the patch structure. The antenna operates for 4.95-5.20, 5.74-6.00, and 6.41-7.24 GHz bands with gain of about 8 dBi.

Farooq and Rather [47] presented a compact dual band antenna resonates at 33.5 GHz (Ka band) and 62.5 GHz (V band) for Millimeter wave (MMW) communication applications. Two symmetrical slots in the design at optimum position give resonance at higher frequency. The antenna offers -16.6 dB & -15.03 dB return loss and 4.93 dB & 3.67 dB peak gain at both the resonating frequencies, respectively. To enhance gain and bandwidth, a dual element antenna array design of the proposed antenna is also demonstrated.

3.2 Comparative Analysis

A comparative analysis of the various multi-band antennas, multi-band antenna operation techniques and focus of study of literature reviewed in section 3.1 is as follows:

TABLE I. PERFORMANCE COMPARATIVE ANALYSIS OF MULTI-BAND ANTENNAS

Ref.	Technique Used	Antenna Dimensions (in mm)	Substrate Material Used	Cut-off Frequency/Bands	Gain	Feeding Technique Used	Radiation Pattern
[24]	Inserting L-shaped stubs, slots on the patch	18 × 16	Rogers RT/duroid 5880	1.71-1.88, 1.85-1.99, 2.402-2.480, 3.30-3.80, 5.150-5.825, & 7.25-7.75 GHz	7.80 dB	Microstrip-line	Bi-directional
[25]	Frequency reconfigurable antenna with defected ground	37 × 47	Flame Retardant (FR-4)	1.36, 1.8, 3.0, 3.9, 5.0, 6.2, 6.4, 7.4, 7.9, 8.2, 8.4, and 8.6 GHz	10.13 dB	Microstrip-line	Quasi omni-/Omni- /Bi-directional
[26]	Microstrip patch antenna	6.1949 × 7.2514	FR-4	23.9, 35.5, and 70.9 GHz	4.435, 3.6602 and 5.6402 dB	Microstrip-line	Directional
[27]	Monolayer Grapheme onto the SiO_2	9 × 9	Si	28.1 GHz and 37.4 GHz	-5.13 dB and -2.97 dB	Coplanar Wave-guide	Bi-directional
[28]	Microstrip patch antenna	78 × 45	Rogers RT/duroid 5880	1.575, 1.8,2.1, 2.4, 2.6, and 26 GHz	2.8, 3.1, 3.6, 4.2, 4.7, and 2.4 dBi	Microstrip-line	Bi-directional
[29]	Two-orthogonal dipole, Elliptical & bowtie dipole, cat-ear shaped arms	0.35 × 0.35 (λ_L)	FR-4	0.7-0.96, 1.7-2.7, and 3.3-3.8 GHz	5.5-8 dBi	Coaxial	Directional

Ref.	Technique Used	Antenna Dimensions (in mm)	Substrate Material Used	Cut-off Frequency/Bands	Gain	Feeding Technique Used	Radiation Pattern
[30]	MFA, SFA, and DSFA	21 × 21	FR-4	3.33-3.78, 4.96-6.20, and 6.84-7.50 GHz	2.61 dB	Microstrip-line	Omni-directional
[31]	Tapered slot based decoupling in the ground Plane (Defected Ground Structure)	104 × 104	Rogers RT/duroid 5880	2.45/5.2 GHz, 2.6 GHz, and 24/28 GHz	4 dBi and 11 dBi	Microstrip-line	Omni-directional and Directional
[32]	Double element square ring slot	150 × 75	FR-4	3.45–3.8 GHz, and 5–5.45 GHz	2.5–2.8 dBi	Microstrip-line	Omni-directional
[33]	T-shaped coupled-fed slot by an L-shaped feeding strip	150 × 80	FR-4	3.4–3.8 GHz, and 5.15–5.925 GHz	7-8 dBi	Microstrip-line	Directional
[34]	4-element SRR-loaded inverted L-elements	40 × 40	FR-4	2.60, 3.30, and 5.70 GHz	4 dBi	Microstrip-line	Directional
[35]	Flexible antenna using Multi-layer grapheme and polymer patch	88 × 96	Polydimethylsiloxane (PDMS)	2.4, 5 and 6.8 GHz	6.3 dBi	Microstrip-line	Uni-directional
[36]	Staircase-shaped coupled ground strip, and an inductor	120 × 60	FR-4	685-1012, 1596-2837, and 3288-3613 MHz	1.4–2.5 dBi	Coaxial	Omni-directional
[37]	Single-feed, one patch edge shorted, inverted U-shapes etched	40 × 40	F4B (Teflon woven glass fabric copper-clad laminates)	3.04, 3.83,4.83, and 5.76 GHz	1.43-3.06 dBi and 1.43–2.39 dBi	Coplanar Wave-guide (CPW)	Directional
[38]	3-slots tuned by varactor diode	100 × 50	FR-4	800, 1500, and 2000 MHz	Between -2.1 dBi & -6.5 dBi	Microstrip-line	Omni-directional
[39]	Inverted E & U shaped stubs, T shaped feed	30 × 30	FR-4	0.77, 1.43, 2.13, 3.48, 3.84, 5.17, and 6 GHz	1.1, 1.3, 1.1, 1.6, 1.7, 1.8, & 2.2 dBi	Microstrip-line	Omni-directional
[40]	Meandered slotted antenna with offset feed	36 × 30	FR-4	1.57, 2.90, 3.82, 4.50, and 5 GHz	2.65, 3.84, 1.07, 1.93, 3.92 dBi	Microstrip-line	Omni- / Bi-directional
[41]	Graphene antenna with rectangular slot with chamfer	11.8 × 12.2	Kapton polyimide film	15 GHz	2.87 and 8.41 dBi	Coplanar Wave-guide (CPW)	Omni-directional / Bi-directional

Ref.	Technique Used	Antenna Dimensions (in mm)	Substrate Material Used	Cut-off Frequency/Bands	Gain	Feeding Technique Used	Radiation Pattern
[42]	L-slot fractal based	54.36 × 46.72	FR-4	1.86, 2.33, 3.67, 4.57, 5.08, 6.06, 7.03, 7.75, 8.08, 8.84, 9.56 and 10 GHz	-	Microstrip-line	Directional
[43]	Meandered meta-material	66.4 × 66.4	Dielectric, Diamond	670, 1185, 1293, 1747, 1909, 1999, 2063, and 2134 MHz	1.31 dBi	Coaxial	Omni-directional / Bi-directional
[44]	Rectangular U-Shaped Parasitic Elements	54 × 59.5	Rogers TMM4	2.6, 6.0, and 8.5 GHz	6.2, 4.52, and 6.9 dBi	Inset Feed	-
[45]	U-shape slot, reconfigurable	61 × 38	FR-4	2.6, 4.5, 8.4, 8.8, and 9.8 GHz	-	Inset microstrip line feed	-
[46]	U-slot	18 × 22	Air	5.0, 5.8 and 6.55 GHz	8 dBi	Coaxial (L-probe)	Directional
[47]	Two symmetrical slots	4.30 × 10.08	FR-4	33.5 GHz and 62.53 GHz	4.93 and 3.67 dB	Inset Feed	Directional

TABLE II. MULTI-BAND ANTENNA OPERATION TECHNIQUES COMPARISON

Ref.	Multi-band Antenna Operation Techniques					
	Use of Parasitic elements	Use of Slots	Use of Fractals	Apply various Feeding techniques	Reconfigurable antennas	Metamaterial based antenna
[24]		√		√		
[25]		√		√	√	
[26]				√		
[27]		√		√		
[28]				√		
[29]				√		
[30]		√		√		
[31]		√		√		
[32]		√		√		
[33]		√		√		
[34]		√		√		√
[35]		√		√		
[36]	√			√		
[37]		√		√		
[38]		√		√	√	
[39]		√		√		
[40]		√		√		
[41]		√		√		

Ref.	Multi-band Antenna Operation Techniques					
	Use of Parasitic elements	Use of Slots	Use of Fractals	Apply various Feeding techniques	Reconfigurable antennas	Metamaterial based antenna
[42]		√	√	√		
[43]		√		√		√
[44]	√	√		√		
[45]		√		√	√	
[46]		√		√		
[47]		√		√		

Table-I and II present the various methods and design procedures used by researchers in designing multi-band antenna. This comparative study will help researchers to focus on current research gaps and to develop new or improved methodologies & designing procedures in the field of multi-band antenna design.

3.3 Advancement in Multi-band Antenna Design for Wireless Communication

Today, most of the multi-band antennas are complex in structure, and their analysis relied on computational electromagnetic methods such as FDTD, FEM, and MoM. The rapid advancement in multi-band antenna with new capabilities for future wireless communication is attributed to innovative technologies such as Reconfigurable, Metamaterial and Diversity antennas.

In general, multi-band antennas require coverage of several frequency bands and broad bandwidth for different wireless applications. In order to satisfy the advanced systems requirements used in modern wireless communication, different multi-band and tunable/switchable/reconfigurable antennas have been proposed and investigated by researchers in the past years. Hence, the small size and low profile multi-band antenna research is entering into the reconfigurable and metamaterial-based advanced antenna design and development, as shown in Figure 4.

3.4 Multi-band Antenna Design Methodology

Since, there is a rapid reduction in dimensions of the wireless communication devices, a small size, compact and light-weight Microstrip patch antenna needs to be designed. Presently the researchers are working on new shapes and different substrate with various dielectric constants for improving the performance of the multi-band antenna.

Figure 5 illustrates the design steps for the multi-band MPA to achieve the needed radiation characteristics and capabilities. Design Steps of multiband antenna are as follows:

1. Selection of operating frequencies for the particular application
2. Design and Modeling of antenna with physical and performance parameter optimization
3. Simulate, Fabricate and test the modeled antenna
4. Analyze and review the designed antenna.

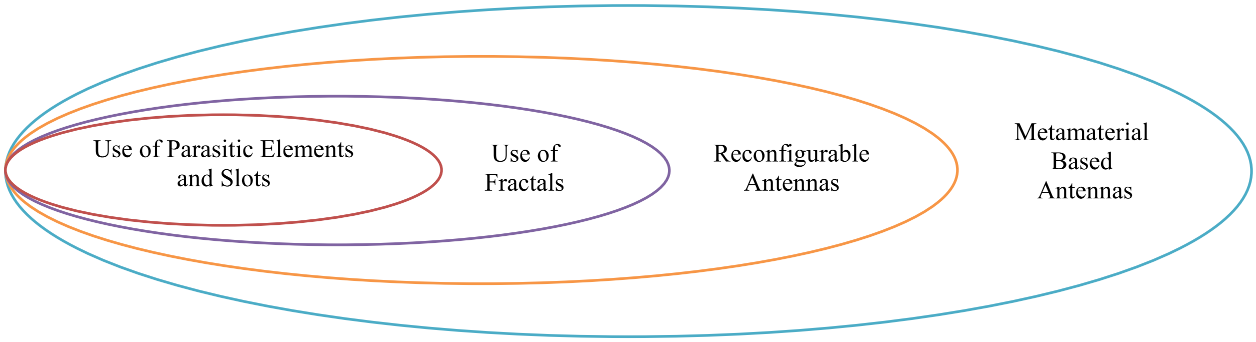


Figure 4. Advancement in Multi-band Antenna Design Technology

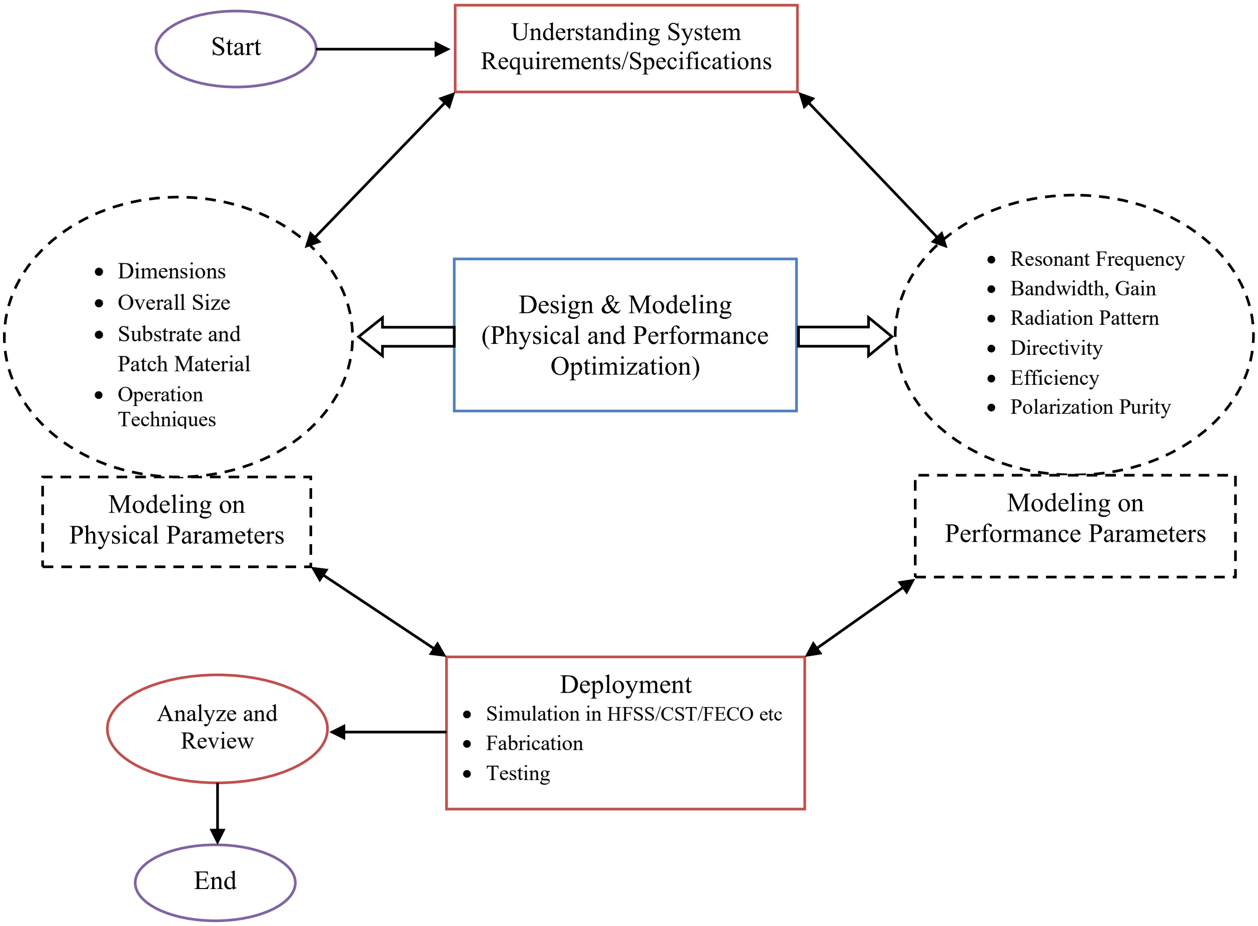


Figure 5. Multi-band Antenna Design Methodology

4. DISCUSSION AND CONCLUSION

This review paper has presented a comprehensive review of the multi-band antenna design techniques for various wireless applications. There are some unique design issues in multi-band antennas, like performance improvement, reduction in the mutual coupling between elements, optimization of antenna parameters, bandwidth enhancement, compact and low profile design, and many more. The multi-band antenna should provide good radiation characteristics, including frequency response, gain, bandwidth, efficiency, compact size, radiation pattern, impedance, isolation, VSWR, directivity, and return loss according to the application, and that can also be adapted with changing system requirements/specifications and operating environmental conditions.

The following points are observed from the literature which helps researchers in the designing of multi-band antennas with different operating standards. This also motivates researchers to work on improving the present scenarios.

1. The demand for wireless communication devices that operate at several standards or applications is increasing day-to-day. Due to this, the demand for multi-band antenna design rapidly increasing to incorporate and integrate it in different wireless communication devices like mobile phones, wearable, and portable devices etc.

2. Etching slots of various shapes on radiating patch and ground is a popular technique for designing multi-band antenna. But there is a need for frequency reconfigurable antennas, array antennas, metamaterial-based antennas, diversity antennas to compensate for some limitations like frequency shift from the origin, low efficiency and gain, poor return loss, and poor polarization purity, etc.

3. Existing design methodology could be re-engineered by selecting the best substrate, applying proper

feeding technique, and use of slots and fractals to improve performance and coupling effects between elements as per the application needs.

4. The focus of study in this field is essentially following a concentric process where the study initially started with slots and parasitic elements based antenna, and the current focus is on the smart reconfigurable and metamaterial-based antenna.

5. The biggest challenge in designing small size, compact, and low profile multi-band antennas is to improve the antenna performance parameters like frequency response, isolation, gain, return loss S_{11}, directivity, VSWR, and efficiency.

6. The multiband antenna designing is not limited upto achieving only desired functionality and performance but it also comprises incorporation and integration of it into system with desired functionality.

This study presents the state-of-the-art research work on multiband Microstrip Patch Antennas design. The above limitations of multiband antenna design for future communication technologies can be overcome with antenna performance enhancement. The antenna performance can be enhanced by various techniques like proper substrate choice, corrugation, multi-element design, use of various mutual coupling reduction techniques and use of different multiband antenna operation techniques etc. These methods create remarkable effects on the physical and electrical properties of an antenna which improves the overall performance of the antenna in terms of compactness, compatible, speed, multi-band applications supports and quality of service etc as per customer expectations. The study also discusses potential breakthroughs on designing antenna for multi-frequency operation with better performance, such as fractals, frequency reconfigurable and metamaterial based antennas which help researchers for further advancement in the multiband microstrip patch antenna design.

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Devendra H. Patel received B.E. (Electronics & Communication Engineering) degree from Saurashtra University Rajkot, M.E. (Electronics & Communication Engineering - Communication Systems Engineering) degree from Gujarat University Ahmedabad and pursuing Ph.D. from Sankalchand Patel University, Visnagar. His research interests include Antenna Design and Development, VLSI Design, Embedded Systems and Image Processing.

G.D.Makwana received B.E. (Electronics) degree from SVNIT Surat, M.E. (Telecommunication) degree from IISC Bangalore and Ph.D. (Electronics & Communication Engineering) from DA-IICT Gandhinagar. His research interests include Antenna Design and Development, RF and Microwave and Wireless Communication. He is serving as reviewers in 06 SCI and Scopus index International Journals and 3 reputed International Conferences. He is also serving as Editorial Board Member of International Journal of Electrical Electronics Communications and Computer Science Engineering, South Africa & Journal of Electronics and Communication.