A Review Of Microstrip Patch Antenna Design At 28 Ghz For 5G Applications System

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Abstract: The mobile technology is fast-developing nowadays owing to its large impact on social life. Accordingly, there is a need to study the progress of the antenna systems as they are considered as core devices for wireless technology. The modern antenna designs allow a single element to be employed in many systems. The microstrip patch antennas are essentially considered in the advancement of the latest communication mechanisms in contrast to the conventional type because they offer the advantage of being low profile along with simple or inexpensive manufacturing procedures. In the recent four decades, extensive research has been carried out on the antenna systems. Consequently, this review paper provides a comprehensive account of the former and subsequent research achievements of the microstrip patch antennas (MPAs) at 28 GHz for fifth generation (5G) application systems. The various types of systems considered for comparison include millimeter-wave, broadbanding techniques, dual/multi-band or reconfigurable structure, size-reduction, compact, low-profile, impedance bandwidth, high gain or linear and circular polarization applications.

Index Terms: 5G technology, microstrip patch antennas, mm- wave antenna and technology assessment.

1. INTRODUCTION

Wireless technology is currently one of the most analytical areas in the communication systems today. To handle the high traffic rate, scarcity of bandwidth and quality of millimeter wave frequency is evolved for 5G applications. The 5G technology employs high-frequency bands and wide signal bandwidth in order to increase the transmission bit rates, thereby providing better coverage with low battery consumption at low cost, that is the primary goal of the 5G [1]. For future communication systems with millimeter waves, the 2015 world radio communication conference identified the frequency allocation of 24 GHz to 86 GHz [2]. Microstrip antenna is essential to support mobile terminals of wireless communication systems due to its light, compact and integrated into the module circuit. Because the microstrip antenna is light, compact and integrated into the module circuit, it is essential to support the mobile terminal of wireless communication systems. Current trends lead to the development of an antenna which will transmit and receive the wideband characteristics and high gain that can be operated in a high frequency range. Thus, size reduction and bandwidth enhancement have become major design issues for sensible applications of microstrip antennas [3-5]. The purpose of this article is to review microstrip patch antennas technology and provide 28 GHz performance capabilities and design variability. The article then examines the latest developments in MPAs technology and presents the current state of the art in the various techniques to give readers a sense of the flexibility offered by MPAs and its potential benefits compared to traditional low-gain antennas. It is hoped that the information provided in the following sections will serve as a reference for especially new researchers entering the field of MPAs, providing a convenient summary of current achievements and listing benchmarks for comparing the performance of new MPAs. This article covers the achievable range of MPAs prototypes, low-profile, compact designs, broadband, MPAs with enhanced gain, reconfigurable designs, a linear and planar array survey and integrated MPAs.

2. MICROSTRIP PATCH ANTENNA

The antenna structure in Figure 1a consist of a very thin (0 t << λ0), where λ0 is the free-space wavelength), metallic strip (patch) placed a small fraction of a wavelength (h << λ0, usually 0.003λ0 ≤ h ≤ 0.05λ0) above a ground plane, [5]. The maximum radiation pattern of the patch is normal to the patch (broadside radiator). For a rectangular patch, L represents the length of the patch which usually λ0/3 < L < λ0/2, which controls the antenna frequency and W represents the patch width which is smaller than λ0 but it cannot be too small otherwise the antenna becomes a microstrip line but not a radiator [7]. The width controls the input resistance of the patch antenna. The ground plane is separated by a dielectric sheet (the substrate), as shown in Fig. 1b [6]. A patch antenna has a gain between 5 dB to 6 dB and exhibits 3 dB beamwidth between 70° and 90° [6]. The design parameters can be calculated by the following equations in [7-9]. The patch length determines the resonant frequency, and it is critical parameter in the design. The patch length L of the antenna is given as:

\[ L = \frac{c_0}{2f_{\text{center}}} \]  

(1)

Electrically the patch length is bigger than its physical length. Therefore, taking into account the normalized extension of the length, the length L is given as:

\[ L = \frac{c_0}{2f_{\text{center}}} - 2 \Delta L \]  

(2)

\( \Delta L \) arises due to the effective dielectric constant, which is lower than the actual dielectric constant. This effective dielectric constant is used to account for the fringing effect.

\[ \frac{\Delta L}{h} = 0.412 \left( \varepsilon_{\text{eff}} + 0.3 \right) \left( \frac{W}{h} + 0.264 \right) \frac{1}{\left( \varepsilon_{\text{eff}} - 0.258 \right) \left( \frac{W}{h} + 0.8 \right)} \]  

(3)

The value of the effective dielectric constant is given below

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-1/2} \]  

(4)

The equation used to calculate the width is given as:
The dimensions are determined by the permittivity of the substrate. The electrical resistance characteristic of the patch also depends on the size and the permittivity of the patch antenna. The length \( L_g \) and width \( W_g \) of the ground plane are calculated using equations 6 & 7.

\[
W = \frac{c_0}{2f_0} \sqrt{\frac{2}{(1 + \varepsilon_r)}}
\]

\[
L = \frac{c_0}{2f_0} \sqrt{\frac{2}{(1 + \varepsilon_r)}} \tag{5}
\]

3. REVIEW OF MICROSTRIP PATCH ANTENNA DESIGN AT 28 GHZ FOR 5G APPLICATIONS

5G will bring mobility to millimeter-wave communications as the next-generation wireless network attempts to serve more people and even things with a major expansion of mobile services. The emerging of 5G technology is demanding antennas with features previously unseen on a user terminal, such as beamforming capability of the radiation pattern to perform spatial scanning [10–21]. This requirement raises numerous design challenges to achieve a reasonable trade-off between technological design issues and commercial criteria-low profile or inexpensive manufacturing methods. Many existing and emerging wireless applications, as well as many radar application, operate over wide frequency bands and thus require broadband antennas. Some researchers began to work to overcome the inherent disadvantage of the narrow bandwidth of impedance and produced interesting results based on the admired gain and bandwidth enhancement methods review previously. Table 2 and Table 3 displays the findings of various methods such as broadband designs, multiband designs, compact designs, circular polarization, increased directional design, reconfigurable designs, and array design, which are used to develop an antenna for mm-wave at 28/38/60 GHz band. Parameters including reflection coefficient, bandwidth, gain, materials used and techniques applied and for all the MPAs resonator models in addition to a few recently designed microstrip antennas were reported for the assessment. Also, the fabricates were segmented on the basis of the type of design for better perception of design for better perception.

Fig. 3. An example of double F-slot patch antenna \( f_c = 28/59.93, \text{Bw} = 4.028 \text{GHz}; \text{Gain} = 5.48 \text{dB}; R = -32.5 \text{dB} \) from [40]

A. LOW–PROFILE AND COMPACT DESIGNS

This section examines microstrip patch antennas designed at 28 GHz with either a low profile or a compact size and highlights the achievable bandwidth performance.

\[
L_g = 6h + L \tag{6}
\]

\[
W_g = 6h + w \tag{7}
\]
vias within the PCB with electrically small pitches. This enables the creation of a conductive, mesh-grid surface that is oriented vertically (along with z-axis) within the PCB by arranging the vias in a tightly-spaced periodic manner. The design patch antenna is implemented within a 10-layer PCB. Table 2 summarizes some published lower profile MPA designs at high frequency.

ii. Compact microstrip patch antennas.
Wireless communications have progressed very rapidly and many mobile devices are becoming smaller and smaller. Compact antennas are required to meet the miniaturization requirement. Many applications, especially for consumer wireless applications, require the integration of compact antennas in small packages such as handheld computer and smartphones or other portable developed using the three approaches: Q reduction, impedance matching and multiple resonances. It is known that the main factors affecting the bandwidth of a microstrip patch antenna are the shape of the radiator, the feeding scheme, the substrate and the arrangement of radiating and parasitic elements. Devices. For compact and broadband patch antenna design, a variety of broadband techniques have been Fig. 3 & Fig. 4 shows some examples of compact design with the techniques that accommodate the mini-SMP connector (PE44489) has a less complex plate through several views [28-31]. A list of various work is presented in Table 2 and Table3.

**Fig. 5.** An example of (a) Top view of the dual band PIFA antenna with ground plane on the bottom side of the substrate, (b) PIFA antenna with modified U shape slot, and (c) Cross-sectional view of the dual band PIFA antenna: fc = 28 /38 GHz, BW = 3.34/1.395 Gain = 3.75/5.06 dB; from [82]

**Fig. 6.** An example of Single stacked-patch element: (a) 3D schematic structure and (b) crosssectional configuration. From [68]

### B. WIDEBAND DESIGNS
Many existing and emerging wireless applications operate on broad bands and therefore require broadband antennas. In this section, the achievable bandwidth of MPAs of various techniques that enhance bandwidth are presented. Since the bandwidth of the MPAs is inversely related to its dielectric constant, wideband performance is best achieved by MPAs with low values of εr. Some works relating to broadband, multiband antennas, circular polarization, increased directional designs, reconfigurable designs, an array design are presented in this section.

**Fig. 7.** An example of 16 element antenna cooperate array fc = 28.5/35, BW = 0.112/1.2121; Gain = 14.82/10.09; R = -21.7/26dB from [44]

**Fig. 8.** An example of Printed Patch Antenna Array: (a) structure of a single element antenna and (b) series five elements antenna array fc = 28, BW = 1; Gain = 13.8dB/; R = -17 dB from [43]

**Fig. 9.** An example of planar switchable 3-D-coverage phased array antenna configurations on the printed circuit board: fc = 28 GHz, Gain = 8 dB; BW = 2 GHz from [61]
### TABLE 1
COMPARATIVES ANALYSIS OF DIFFERENT FEED MECHANISM FOR 5G APPLICATIONS SYSTEM AT 28 GHZ

<table>
<thead>
<tr>
<th>MPAs Configuration</th>
<th>Fc (GHz)</th>
<th>Material for design</th>
<th>εr</th>
<th>Area (mm²)</th>
<th>BW (GHz)</th>
<th>Gain (dBi)</th>
<th>Return loss (dB)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-band printed slot antenna.</td>
<td>28/38</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>8 x 7.5</td>
<td>N/A</td>
<td>4.2/6.9</td>
<td>-40</td>
<td>[22]</td>
</tr>
<tr>
<td>Dual-polarized patch array</td>
<td>28.5</td>
<td>FR4 substrate</td>
<td>2.2</td>
<td>11.6 x 11.6</td>
<td>1.5-2</td>
<td>10</td>
<td>-20</td>
<td>[23]</td>
</tr>
<tr>
<td>A Grid Array Antenna Low-profile</td>
<td>28</td>
<td>FR4 substrate</td>
<td>2.2</td>
<td>15 x 15</td>
<td>2.2</td>
<td>12.66</td>
<td>N/A</td>
<td>[24]</td>
</tr>
<tr>
<td>Mesh-Grid Antenna Array Low-profile</td>
<td>28</td>
<td>10- layer FR4 PCB</td>
<td>4.2</td>
<td>N/A</td>
<td>&gt;3</td>
<td>10.9</td>
<td>N/A</td>
<td>[25]</td>
</tr>
<tr>
<td>Low-profile Wide Scanning Angle Phased Array</td>
<td>28</td>
<td>10-layer FR4 substrate</td>
<td>4.2</td>
<td>N/A</td>
<td>0.5</td>
<td>N/A</td>
<td>&lt;10</td>
<td>[26]</td>
</tr>
<tr>
<td>A Compact Millimeter-wave Slot Antenna Array (4 x 4)</td>
<td>28</td>
<td>Single layer PCB</td>
<td>4.2</td>
<td>29.9 x 28.7</td>
<td>0.7</td>
<td>13</td>
<td>N/A</td>
<td>[27]</td>
</tr>
<tr>
<td>Compact Antipodal Tapered Slot Antenna (ATSA)</td>
<td>28.5</td>
<td>Rogers substrate (5880)</td>
<td>2.2</td>
<td>25 x 30</td>
<td>1.42</td>
<td>12.2</td>
<td>N/A</td>
<td>[28]</td>
</tr>
<tr>
<td>A Switched Beam Planar Array</td>
<td>28</td>
<td>Rogers substrate (5880)</td>
<td>2.2</td>
<td>N/A</td>
<td>1</td>
<td>12</td>
<td>&lt;10</td>
<td>[29]</td>
</tr>
<tr>
<td>Conformal Tapered Slot Antenna Array</td>
<td>28</td>
<td>FR4 substrate</td>
<td>2.2</td>
<td>65 x 130</td>
<td>14.8</td>
<td>&gt;20</td>
<td>N/A</td>
<td>[30]</td>
</tr>
<tr>
<td>Circular-Shaped DD patch Antenna Arrays</td>
<td>28</td>
<td>Dense Dielectric (DD)</td>
<td>N/A</td>
<td>3.2 x 3.3 x 2.2</td>
<td>N/A</td>
<td>16</td>
<td>&lt;10</td>
<td>[31]</td>
</tr>
<tr>
<td>Microstrip Antenna Array 64-Elements</td>
<td>28</td>
<td>Rogers substrate (5880)</td>
<td>2.2</td>
<td>2</td>
<td>12</td>
<td>N/A</td>
<td>[32]</td>
<td></td>
</tr>
<tr>
<td>Dense dielectric patch array antenna.</td>
<td>28</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>N/A</td>
<td>2.4</td>
<td>12.48</td>
<td>-29</td>
<td>[33]</td>
</tr>
<tr>
<td>Magneto Electric Dipole Leaky-wave Antenna</td>
<td>28</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>N/A</td>
<td>N/A</td>
<td>16.55</td>
<td>-25</td>
<td>[34]</td>
</tr>
<tr>
<td>Planar antenna</td>
<td>28</td>
<td>PET</td>
<td>3.2</td>
<td>N/A</td>
<td>N/A</td>
<td>8.2</td>
<td>-18</td>
<td>[35]</td>
</tr>
<tr>
<td>Pharaonic Ankh-key Broadband Antenna</td>
<td>28</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>7.5 x 7.5</td>
<td>N/A</td>
<td>8.4</td>
<td>-20.2</td>
<td>[36]</td>
</tr>
<tr>
<td>New Gridded Parasitic Patch Stacked Microstrip Antenna.</td>
<td>60</td>
<td>Taconic TLY</td>
<td>2.2</td>
<td>N/A</td>
<td>15.6</td>
<td>8.6</td>
<td>-10</td>
<td>[37]</td>
</tr>
<tr>
<td>Patch antenna array</td>
<td>28/60</td>
<td>Liquid Crystal Polymer</td>
<td>2.9</td>
<td>55 x 70</td>
<td>N/A</td>
<td>16.7/17.1</td>
<td>-20/-20</td>
<td>[38]</td>
</tr>
<tr>
<td>Single Band Antenna Low-profile</td>
<td>59.93</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>8 x 8</td>
<td>4.028</td>
<td>5.48</td>
<td>-40</td>
<td>[39]</td>
</tr>
<tr>
<td>Double F Slot Patch antenna Low-profile</td>
<td>58.10</td>
<td>Silicon</td>
<td>11.9</td>
<td>0.984 x 0.62</td>
<td>N/A</td>
<td>5.99</td>
<td>-32.5</td>
<td>[40]</td>
</tr>
<tr>
<td>Microstrip Antenna Array</td>
<td>28</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>2.5 x 2.25</td>
<td>8</td>
<td>-40</td>
<td>[41]</td>
<td></td>
</tr>
<tr>
<td>Dual Band Antenna Low-profile</td>
<td>28.25/38</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>4.9 x 7.6</td>
<td>1.5 - 2</td>
<td>5.5/4.5</td>
<td>-40</td>
<td>[42]</td>
</tr>
<tr>
<td>Printed Patch Antenna Array.</td>
<td>28</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>30.25 x 9.5</td>
<td>N/A</td>
<td>13.8</td>
<td>-17</td>
<td>[43]</td>
</tr>
<tr>
<td>16 Element Array of Microstrip Patch Antenna</td>
<td>28.5/33</td>
<td>RT Duroid</td>
<td>2.2</td>
<td>34.265 x 34.265</td>
<td>0.1126/1.2121</td>
<td>14.82/10.09</td>
<td>-21.7/-26</td>
<td>[44]</td>
</tr>
</tbody>
</table>

BW = Bandwidth; N/A = Not Available, Fc = Centre Frequency, εr = Dielectric Constant
TABLE 2
COMPARATIVE ANALYSIS OF DIFFERENT FEED MECHANISM FOR 5G APPLICATIONS SYSTEM AT 28 GHZ

<table>
<thead>
<tr>
<th>Fc</th>
<th>Configuration</th>
<th>$\varepsilon_r$</th>
<th>Technique Applied</th>
<th>BW@ (−10dB) (GHz)</th>
<th>Gain (dBi)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>2 x 2 U- shaped Patch Array Antenna</td>
<td>2.2</td>
<td>Inserted slot</td>
<td>3.35</td>
<td>12</td>
<td>[45]</td>
</tr>
<tr>
<td>28</td>
<td>U- shaped MSA</td>
<td>3.36</td>
<td>Inserted slot</td>
<td>N/A</td>
<td>4.15</td>
<td>[46]</td>
</tr>
<tr>
<td>28</td>
<td>Broadside Array MSA</td>
<td>2.2</td>
<td>Series-fed</td>
<td>0.5</td>
<td>15.4</td>
<td>[47]</td>
</tr>
<tr>
<td>28/32</td>
<td>4 x 1 - Elements Patch Array</td>
<td>4.35</td>
<td>Inserted slot</td>
<td>N/A</td>
<td>11.2</td>
<td>[48]</td>
</tr>
<tr>
<td>28</td>
<td>32- Elements Patch Array</td>
<td>2.2</td>
<td>Inserted slot</td>
<td>1.12</td>
<td>21.1</td>
<td>[49]</td>
</tr>
<tr>
<td>28</td>
<td>8-Elements Helix Phase Array Antenna</td>
<td>1</td>
<td>Inserted slot</td>
<td>7</td>
<td>5</td>
<td>[50]</td>
</tr>
<tr>
<td>28</td>
<td>A Compact Parasitic Element MSA</td>
<td>4.4</td>
<td>Coplanar slot</td>
<td>1.55</td>
<td>6.7289</td>
<td>[51]</td>
</tr>
<tr>
<td>28</td>
<td>Swarm Intelligence Algorithm MSA</td>
<td>2.2</td>
<td>PSACO</td>
<td>0.35</td>
<td>10.49</td>
<td>[197]</td>
</tr>
<tr>
<td>28</td>
<td>Patch Phase Array Antenna</td>
<td>2.2</td>
<td>Inserted</td>
<td>1.4</td>
<td>8.64</td>
<td>[52]</td>
</tr>
<tr>
<td>28</td>
<td>PIFA with Low-profile</td>
<td>2.2</td>
<td>Slot &amp; shorting strips</td>
<td>1.5</td>
<td>4.5</td>
<td>[53]</td>
</tr>
<tr>
<td>28</td>
<td>Empty Substrate Integrated Waveguide-fed Square MSA</td>
<td>3.55</td>
<td>Aperture-couple</td>
<td>2.9</td>
<td>11.6</td>
<td>[54]</td>
</tr>
<tr>
<td>28</td>
<td>4×2 Element Microstrip Antenna Array Patch</td>
<td>2.2</td>
<td>Probe feed</td>
<td>0.84</td>
<td>16.1</td>
<td>[55]</td>
</tr>
<tr>
<td>28</td>
<td>A Compact Elliptical</td>
<td>4.4</td>
<td>Inserted slot</td>
<td>4.6</td>
<td>N/A</td>
<td>[56]</td>
</tr>
<tr>
<td>28.2</td>
<td>A Compact MPA Slot</td>
<td>3</td>
<td>Inserted slot</td>
<td>1.38</td>
<td>9.0</td>
<td>[57]</td>
</tr>
<tr>
<td>28/38</td>
<td>A Compact T- shape Slot</td>
<td>2.2</td>
<td>Inserted slot</td>
<td>N/A</td>
<td>9.33/9.57</td>
<td>[58]</td>
</tr>
<tr>
<td>28 &amp; 38</td>
<td>Rectangular MSA</td>
<td>2.2</td>
<td>Inserted slot</td>
<td>N/A</td>
<td>7.23 &amp; 3.69</td>
<td>[59]</td>
</tr>
<tr>
<td>28</td>
<td>Multilayer Yagi</td>
<td>3.48</td>
<td>Inserted slot</td>
<td>6.9</td>
<td>15.51</td>
<td>[60]</td>
</tr>
<tr>
<td>28</td>
<td>Planar Switchable 3-D-Coverage Phased Array Antenna</td>
<td></td>
<td></td>
<td>2</td>
<td>N/A</td>
<td>[61]</td>
</tr>
</tbody>
</table>

i. **Microstrip Patch Antennas Arrays**
An antenna array (often referred to as a phased array) is a set of two or more antennas. The antenna signals are combined or processed to improve the performance of a single antenna. The antenna array can be used: Increase the overall gain; provide reception of diversity and determine the direction of the incoming signals [11-14]. This section highlights the developments in linear and planar MPAs arrays, and also considers some of the challenges involved in their fabrication.

ii. **Linear Arrays**
Linear arrays are used for applications requiring fan-shaped radiation patterns (with a narrow beam in the plane parallel to the array axis, and a broad beam in the orthogonal plane). Some examples of linear arrays are shown in Figure 7 and Figure 8. The array can be fed with either a series or a corporate power-divider network. Table 4 shows a summary of the advantages and disadvantages of parallel-fed and series-fed arrays. Therefore, the selection of a series or corporate feed for the linear array depends on the requirements of the intended application. Although several studies have been published analyzing the performance of various linear MPAs array configurations, the number of arrays actually fabricated has been quite small because of the complexity. Table 2 and Table 3 lists the keys feature of some of these arrays. One reason for the limited number of arrays is in the fabrication process.

iii. **Planar Arrays**
The planar array is used to create radiation patterns from the pencil beam with moderate to high directivity. Figure 9 shows a 3D phased array antenna for 5G mobile terminals with a planar switchable coverage.

![Fig. 10. An example of increased directivity designs from [71]](image-url)
ii. Microstrip Patch Antennas Arrays

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ii. Linear Arrays

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Fig. 11. An example of single fed geometry for dual-frequency CP annular-ring antenna: (a) profile, (b) patch on the top and (c) a cross-slot ground plane. [77]

Fig. 12. An example of Circularly Polarized Planar Helix Phased Antenna Array: fc = 28 GHz, Gain = 7 dB; Bw= 5 GHz from [50]

Fig. 13. An example of High-gain low-profile circularly polarized slotted SIW Cavity Antenna (a) top view of the convertor, (b) top view of the slotted SIW cavity, and (c) side view; fc = 28 GHz, Gain = 16B; from [98]

Fig. 14: An example of Sequentially rotated CP subarray 2x2 CP subarray with sequential rotation: (a) Each element is a CP patch and (b) Each element is a LP patch from [97]

Fig. 15. An example of new modified 2 x 2 and 3 x 3 series-fed patch antenna arrays with beam-steering capability (a) Single two-port microstrip patch antenna, (b) Series-fed 2x2 patch antenna array, and (c) Series-fed 3x3 patch antenna array from [83].
Therefore, the selection of a series or corporate feed for the linear array depends on the requirements of the intended application. Although several studies have been published analyzing the performance of various linear MPAs array configurations, the number of arrays actually fabricated has been quite small because of the complexity. Table 2 and Table 3 lists the keys feature of some of these arrays. One reason for the limited number of arrays is in the fabrication process. By efficiently exciting and controlling chassis surface waves, 3-D coverage beam scan was carried out with a simple planar array. Three identical subarrays of slots were used to form three switchable beams to different regions, and in each region, one subarray operates as a phased array for beam steering. Some techniques are studies in [64-70] on phase array antenna.

iv. Increased Directivity Designs

The directivity can be increased by using multilayer dielectric covered layer structure and increasing patch dimensions, but bandwidth and directivity can be increased by using a parasitic patch and air gap between the ground plane and the feed patch as shown in Figure 10. The gain of 14 dB was 56% higher than the conventional rectangular patch antenna using a multilayer multi- dielectric antenna [71]. By using more dielectric substrates and appropriate air gap spacing in studies [72-74], directivity can be increased.

v. Circular-Polarization Designs

Microstrip patch antennas can be designed to radiate circular polarization, like other low-gain antenna elements, such as crossed dipole. For individual MPAs elements, different configurations have been proposed for circular polarization using single or multiple feeds. Single-point feed designs are relatively easy to implement, but typically lead to relatively narrow axial bandwidths. Multiple-fed designs attain wider bandwidths, but are more complicated to implement. Some of these circular polarization configurations and their axial performance are examined in this section. Fig. 11 shows examples of single-point -fed antenna geometry comprising two annular-rings surrounding a small circular patch on top with an unequal lateral cross-slot ground plane. The circularly-polarized frequency ratio of the two resonant modes is tunable to a small value. Elements are rotated in space and fed by phase changes. Due to symmetry, radiation from higher order mode tends to be reduced, this unique array has the ability to generate excellent circular polarization (CP) over a relatively broad bandwidth and result in good cross-polarization as shown in Fig. 11 – Fig. 13.

vi. Reconfigurable Designs

With increased spectrum use due to increased consumer demand for wireless high-speed communications, the use of reconfigurable or adaptive antennas is considered to be one method for improving spectrum use. This section examines MPAs with capabilities for beam-steering, frequency tuning or polarization agility.

a. Microstrip Patch Antenna with Beam-Steering Capability

The ability to control the radiation pattern beam peak finds many uses in different applications that require tracking or mitigation of interference. Beam patterns can be controlled either by physical antenna movement or by electronic control of certain parameters in the antenna. An example of the ability to steer the beam is shown in Fig. 15. The patches are continuously and symmetrically connected in the designs using high-impedance microstrip lines in the 2-D format. In the first design, 3-D-beam-scanning range of ± 25° and good radiation and impedance characteristics were attained by using only one phase shifter. In the second, a new mechanism is introduced to reduce the number of feed ports and related phase shifters (from default number 2 N to reduced number N+1 in the serial feed (here N = 3), and the cost, complexity, and size of the design can be significantly reduced. Good scanning performance of ± 20 °, acceptable sidelobe level and a gain of 15.6 dB is achieved [83]. Some related work is studied in [84-86].

b. Frequency-Tunable with Microstrip Patch Antenna

Antenna with electronic frequency tuning capabilities can be used in applications requiring frequency hopping, for spectrum reuse or to change the operating frequency from a remote location. Several publications have shown that the resonant frequency of MPAs can be adjusted by properly loading them with different slots, stubs or metal caps. Like microstrip patches, electronic frequency tuning should then be possible by incorporating variable capacitors or diode switches. Fig. 16 shows an example of a tunable filter antenna. The antenna is fed by a microstrip line based on a three-line coupled resonator (TLCR) with a bandpass filter. The filter reconfiguration allows the monopole antenna to operate with a PIN diode in either a broadband or a narrow-band state. In both operating states, radiation patterns with low cross-polarization levels are achieved [94]. Some related work is studied in [99-107].
iv. CONCLUSION

In engineering, the discipline of the antenna has enjoyed an extremely fruitful period during the past several decades. Responsible for its accomplishment has been the technical advances in certain novel antennas, for instance, millimeter-wave antenna, broadband, dual/multi-band or reconfigurable structure, size-reduction, compact, low-profile, impedance bandwidth, high gain or linear and circular polarization applications., and the like. An enormous influence in the victory of radiating elements has been the innovations in 5G technology. Even though a confident level of maturity has been accomplished, there are several problems to be worked out. The innovative miniaturized footprint suitable for 5G applications system along with enhanced performance characteristics is until now a most challenging problem. However, the microstrip patch antenna can be designed to be integrated with much architecture to develop patterns for the current and future 5G applications system. Utilizing novel materials and new fabrication techniques for the antennas represent another approach to offer multiple prospects for the system performance. This will make the MPAs at mm-wave an even more viable alternative to the conventional low-gain resonant antenna.

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