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A Review of Low Profile Single Layer Microstrip Antennas

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***Abstract*—The modern wireless systems call for integrating multiple applications. There are numerous techniques available to cater these demands. However the need for thin, light weight and compact wireless applications call for the design of low profile and single layer antennas with multiple features. Hence, this paper deliberates on the comprehensive review of compact, low profile, and single layer microstrip antennas suitable for fifth generation (5G) wireless applications, wireless local area network (WLAN), worldwide interoperability for microwave access (Wi-Max), and other state of the art wireless applications. The techniques discussed here consider the performance improvement of one or more parameters of the antenna. These parameters include the improvement of impedance (10dB return loss) bandwidth, gain, 3dB axial ratio (AR) bandwidth, improvement of isolation between the ports in multiple input multiple output (MIMO) antennas, and excitation of dual modes/dual polarization/circular polarization. Antennas with all such techniques and their advantages, applications & limitations have been discussed in detail. The studies presented here on single layer planar antennas offer a maximum impedance bandwidth of up to 68%, highest axial ratio bandwidth of 46%, and 11.6dBi gain for single element & 25.6dBi gain for arrays. Other significant findings covered are antennas with triple bands operation, arrays with less than -37.5dB mutual coupling and compact antennas with more than 60% reduction in physical area. In addition to the advantages and applications, their limitations and drawbacks are also discussed.**

***Index Terms*—Single layer, low profile, compact antennas, 5G, MIMO, dual polarized, circularly polarized.**

I. INTRODUCTION

It is well known from the last few decades that the microstrip antenna is being considered as the most prominent candidate for the wireless applications [1]. However, in its conventional form microstrip antenna poses some limitations including the poor impedance bandwidth and low gain. There are numerous techniques available to improve these basic limitations posed by the microstrip antennas. For example, to enhance the impedance bandwidth use of stacked/multi-layer configurations, thick substrates, changing the shape of the patch/probe, and/or use of suspended configurations (air-dielectric combinations) etc.

The 5G and other state of the art wireless systems call for antennas with multiple operating features [2]-[5]. This may be realized by combining two or more parameters of the antenna. The key parameters to be addressed are impedance bandwidth, gain, exciting dual and/or circular polarization (axial ratio bandwidth), use of antenna as a filter (filtenna), MIMO with good isolation between the ports, beam steering capabilities etc. With these considerations another important constraint or requirement is the need for the design of compact wireless systems which requires an antenna with minimum complexity. This has led to the evolution of low profile and single layer antenna geometries [3].

Section II covers the detailed discussion on gain and/or bandwidth enhancement techniques. Circular and dual polarization antennas are presented in Section III. Section IV covers antennas with beam scanning, multi beam, and beam controlling capabilities. Other innovative techniques for specific needs [4] are also discussed in this section. Finally, the concluding remarks are presented in Section V.

II. GAIN AND BANDWIDTH ENHANCEMENT TECHNIQUES

There are several techniques reported in literature which address the improvement of bandwidth and gain of single layer antennas. The common techniques adopted by the researchers for this purpose include the use of suspended (air-dielectric) configurations, defected ground structures (DGS), changing shape of the radiator, and use of innovative feeding techniques like capacitive feed [2], [3], [6]-[18], meander line feed, etc. It may be noted that use of air-dielectric combination reduces the effective permittivity of the substrate and hence the impedance bandwidth is improved. However, these configurations require large volume and hence pose limitations where size is the constraint. On the other hand DGS structures and changing the shape of the radiator patches improve the bandwidth by lowering their quality factor and/or improving the radiation efficiency. Other popular techniques such as changing the shape of the probe feed or modifying the feed section improves the bandwidth by matching the input impedance. However such geometries are complex in nature and difficult to analyze. Similarly, for enhancement of gain the most commonly adopted techniques are the use of arrays, EBG structures and metamaterials. It may be noted that metamaterial based antennas not only improve the gain but also help in

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improving in the design of compact antennas with high radiation efficiency. In following subsections all these antennas are discussed.

In 2000 authors of [12] reported the cavity backed & capacitively probe fed antenna. The antenna bandwidth is enhanced by etching the cavity beneath the substrate. An impedance bandwidth of 35.3% (VSWR<2) or 22.8% (VSWR<1.5) was reported. The cavity so etched lowers the effective dielectric constant and helps in improving the impedance bandwidth.

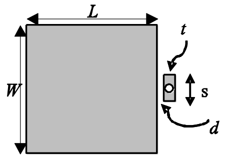
A new capacitive coupled feeding technique for exciting the main patch has been presented in [13], [14]. A small (compared to radiating patch dimensions) feed strip located along the one of the radiating edges is used for connecting the probe. The feed strip helps in tuning the unwanted access inductive reactance and thereby improves the bandwidth. The reported antenna parameters for this antenna are an impedance bandwidth of 27.9% with 8.9dBi gain. The antenna proposed here has an air gap of *x* mm from the ground plane

The antenna which uses the similar configuration as that of [13], [14] yet offers nearly twice the impedance bandwidth has been reported in [15], [16]. Here the feed strip dimensions and the amount of air gap to be used for optimum performance of the antenna have been demonstrated. Further, these authors have proposed an equation to calculate the value of air gap [16].

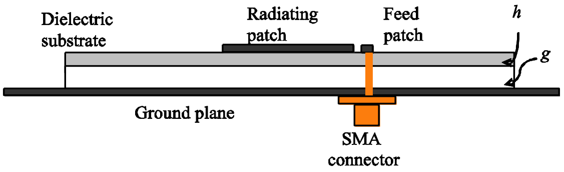
$$g \cong 0.16\lambda_c - h\sqrt{\varepsilon_r} \tag{1}$$

This work has reported an impedance bandwidth close to 50%. In addition to the study on basic geometry, other investigations carried out by these authors are the combination of different shapes of main patch and the feed strip i.e., rectangular radiating patch with one of the three different shapes of feed strip (rectangular, triangular, and circular). Similarly, one of the three different radiator shapes (rectangular, triangular, and semi-elliptical) is investigated with rectangular feed-strip. For all combinations investigated the performance of the antenna remains nearly same. The typical antenna geometry and its return loss characteristics are shown in Fig. 1 and Fig. 2, respectively.

In yet another work which is similar to [16] was presented by [17]. The only difference is that the rectangular patch was replaced with triangular geometries. Almost similar performance as that of [16] was reported. Authors of [18] have reported almost similar results and are presented in Table I.



(a) Top view



(b) Cross sectional view

Fig. 1. Basic geometry of the antenna with capacitive feed [16].

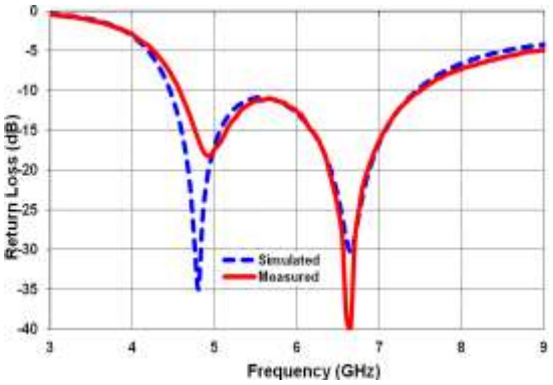


Fig. 2. S_{11} characteristics for the capacitive coupled antenna [16].

TABLE I: SURVEY ON WIDEBAND AND/OR HIGH GAIN ANTENNAS

Reference & Year of publication	Specifications and features of antenna geometry	Reported Results	Application(s)
[12], 2000	♦ Broadband cavity backed ♦ Capacitive coupled- probe fed ♦ Annular ring antenna	♦ 35.3% bandwidth (SWR<2) ♦ 22.8% bandwidth (SWR<1.5)	♦ UWB applications
[13], 2000 [14], 2003	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Rectangular MSA	♦ 27.9% bandwidth ♦ 8.6dBi peak gain	♦ UWB applications
[15], 2006 [16], 2007	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip	♦ 50.7% bandwidth ♦ 7.2dBi gain	♦ UWB applications
[17], 2008	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Triangular MSA	♦ 40.47% bandwidth ♦ 7.5dBi gain	♦ UWB applications
[17], 2010	♦ Array of rectangular patches ♦ Log periodic arrangement ♦ Proximity coupled microstrip feeding	♦ 4.59GHz bandwidth (2.26GHz-6.85GHz) (VSWR < 2.5) ♦ 2dB measured gain	♦ UWB applications
[18], 2011	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ U slotted H shaped MSA	♦ 46% impedance bandwidth ♦ 5. 4 dBi gain	♦ UWB applications
[19], 2018	♦ Pentagon shaped monopole antenna ♦ Compact design	♦ 8.73GHz impedance bandwidth ♦ 3.1dBi gain	♦ UWB applications
[20], 2018	♦ Low profile microstrip antenna with	♦ 71.92% impedance bandwidth (8.95GHz-19GHz)	♦ UWB applications

	DGS ♦ Dual feed configuration ♦ Wide axial ratio bandwidth	♦ Mutual coupling below -37.5dB ♦ 2.1GHz axial ratio bandwidth (8.85GHz to11GHz) ♦ 6.9dBi peak gain	
[21], 2018	♦ Wideband compact monopole antenna ♦ Tree shaped patches with meander line feed ♦ Split ring resonators	♦ 0.115GHz-2.9GHz (2.785GHz] (185%) ♦ 2.35dBi gain ♦ 78.85% radiation efficiency	♦ RF front end
[22], 2019	♦ Vertex fed hexagonal antenna ♦ Low cross polarization ♦ FR4 substrate ♦ Reduced/defected ground (DGS)	♦ 600MHz bandwidth at 5GHz ♦ 3dB gain ♦ Suppressed higher order modes (10dB) ♦ 25dB cross polarization level	♦ WLAN (UNII-1)
[23], 2019	♦ Low profile wideband MSA ♦ Quasi periodic aperture ♦ Slot to CPW transition	♦ Return loss bandwidth:36.5% ♦ 3dB gain bandwidth:35.4% ♦ Peak gain:10.45dBi	♦ Broadband communication systems
[24], 2020	♦ Low profile antenna based on single layer meta-surface	♦ 2.13GHz bandwidth ♦ 14.2dB Gain	♦ Satellite communications in Ku band.
[25], 2020	♦ Compact wideband microstrip antenna ♦ Filtering performance ♦ Low profile and high gain, and high selectivity	♦ 20.1% (2.19GHz-2.68GHz) impedance bandwidth ♦ Gain more than 9.5dBi ♦ Radiation efficiency more than 88% ♦ SLL less than 14.5dB	♦ 5G systems
[26], 2020	♦ Single patch ♦ High gain patch antenna array ♦ Defected ground structure (DGS)	♦ For single patch 2.94GHz, for array 2.06GHz impedance bandwidth (27.99GHz-30.05GHz) ♦ Peak gain:7.05dBi (single) 15.07dB (array) ♦ 91.9% radiation efficiency at 28.5GHz	♦ 5G applications
[27], 2021	♦ Miniaturized patch antenna ♦ Coupled microstrip	♦ 60% reduction in area w.r.t. conventional patch ♦ 5.4dBi gain ♦ 180MHz bandwidth at 8.45GHz	♦ Integrated wireless systems
[28], 2021	♦ Line fed broadband MSA ♦ Teflon based thin substrate (0.508mm)	♦ Fractional bandwidths 3.71% (MPA1) and 6.12% (MPA2)	♦ General wireless applications
[29], 2021	♦ High gain MIMO antenna ♦ Dual band operation (2.4GHz & 5.8GHz) ♦ Enhanced isolation	♦ Return loss bandwidths 680MHz (2.12GHz-2.8GHz) and 1700MHz (4.95GHz-6.65GHz) ♦ Isolation: less than -15dB ♦ Peak gains: 6.4dBi and 4.8dBi	♦ WLAN

In 2018, compact monopole antenna with pentagon shape suitable for UWB and other wireless applications has been presented [19]. The proposed antenna offers 8.73GHz impedance bandwidth with 3.1dBi gain. In another effort by [20] a low profile antenna with defected ground (DGS) has been reported. The proposed antenna in this work has an operating range of 8.95GHz to 19GHz which is equal to 71.92% (impedance bandwidth). This antenna also offers an axial ratio bandwidth of 2.15GHz between the frequency ranges of 8.85GHz to11GHz.

A monopole antenna with broadband characteristics and suitable for wireless systems has been presented in [21]. The geometry presented here exhibits a huge bandwidth of 185% (0.115GHz to 2.95GHz), gain of 2.35dBi with an efficiency of 78.85%. The antenna proposed by these authors is suitable for integrating with RF front end circuitry.

Vertex fed hexagonal antenna that offers an impedance bandwidth of 600MHz at the operating frequency of 5GHz has been reported in [22]. The antenna was fabricated on low cost FR4 substrate with defected ground. This antenna suppresses higher order modes up to 10dB and exhibits low cross polarization levels of 25dB. W. Sun *et al*. [23] presented a low profile wideband microstrip antenna with a quasi periodic aperture. The aperture has four different sized rectangular shaped strips with an air gap. The slot to CPW transition is used for coupling and feeding the proposed antenna. It offers 36.5% return loss bandwidth, 10.45dBi peak gain. Additionally, it offers a 3dB gain bandwidth of 35.4%.

Meta-surface antenna with low profile has been demonstrated in [24]. In this configuration, a single layer meta-surface and a feed-line are deposited on FR-4 substrate. It offers a wide bandwidth of 2.13GHz and a peak gain of 14.2dBi. The proposed antenna is suitable for 5G applications. Another compact wideband antenna with high gain is demonstrated in [25]. This antenna offers filtering response with high selectivity. As it offers filtering performance the antenna may be used in RF front ends. The reported impedance bandwidth and gain are 20.1% and 9.5dBi respectively. The presented antenna has a radiation efficiency of 88% and a side lobe level below 14.5dB.

Patch antenna array with high gain of 15.07dBi with a bandwidth of 2.06GHz in the upper 5G band [26]. This geometry offers a good radiation efficiency of 91.9% at 28.5GHz. In [27], miniaturized antenna is presented. The miniaturization is achieved with the help of coupled microstrips. Nearly 60% reduction in patch area is achieved with respect to conventional patch antenna. This antenna offers 180MHz bandwidth with a peak gain of 5.4dBi.

A line fed wideband microstrip antenna printed on Teflon based thin substrate has been reported in [28]. It offers fractional bandwidths of 3.71% and 6.12%. A high gain MIMO antenna suitable for dual-band operation has been presented in [29]. The proposed antenna offers a good isolation of less than −15dB. It offers a bandwidth of 680MHz (2.12GHz to 2.8GHz) in the first band and 1700MHz (4.95GHz to 6.65GHz) in the second band. The corresponding gains are 6.4dBi and 4.8dBi for the first and second bands respectively.

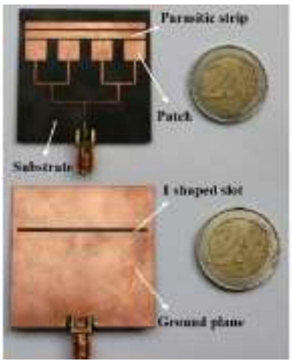


Fig. 3. A typical antenna with DGS structure [26].

A wide variety of antennas which offer large impedance bandwidth and/or high gain have been discussed. It may be noted from these studies that for enhancement of bandwidth air gap may be introduced. If volume is the design constraint then other techniques like changing the shape of patch, use of defected ground structures (DGS) may be considered for the bandwidth improvement. A typical DGS antenna's prototype is shown in Fig. 3. Whereas to increase the gain of an antenna meta-surface based geometries or antenna arrays will serve the purpose. These techniques are summarized in Table I.

III. DUAL AND CIRCULLARLY POLARIZED ANTENNAS

There are applications like wireless sensors, RFID tags, and tracking devices need circularly polarized (CP) antennas. The CP antenna also ensures low propagation and multipath losses [30]-[41]. This section covers low profile and single antenna geometries available in literature which address the excitation of dual and circular polarization. It must be noted that in addition to the excitation of dual/CP operation these antennas also reported good impedance bandwidth as well as good gain. The geometries have been designed to excite two closely spaced orthogonal modes so as to obtain the desired circular polarization [30]. The techniques used are cutting diagonal slots, use shorting pins, meta-surfaces, truncated corners etc. In contrast to the multi-layer geometries, the geometries covered in this paper are single layer based and have the advantages of large circular polarization (CP) or axial ratio (AR) bandwidth up to 36.4% [42]. In addition to this these antennas offer a maximum impedance bandwidth up to 68.42% [33] and a maximum gain of 25.6dB [35]. However, the large volume requirement due to an air-dielectric combination restricts the use of these antennas in the compact applications.

In [30], a capacitive coupled rectangular microstrip antenna (RMSA) is designed to operate as a circularly polarized antenna by placing a diagonal slot. Orientation of the slot (principal diagonal/ non-principal diagonal) decides the sense of polarization (RHCP/LHCP). The antenna offers an excellent bandwidth of nearly 50% and a 3B axial ratio (AR) bandwidth of 7.1%. In the year 2011, K Wei *et al*. [31] have presented a modified capacitive-coupled antenna with shirting pin. The proposed antenna here is low profile and has no air gap. However, the antenna offers an impedance bandwidth of 5.3% and AR bandwidth of 1.2%. In another work [32] reported on excitation of CP is a fractal antenna with a slot at the center as shown in Fig. 4 [32]. This antenna offers a tri-bands operation with impedance bandwidths are 8.7% (2.32GHz-2.52GHz), 2.4% (3.37GHz-3.45GHz, 5% (5.6GHz-5.9GHz) and corresponding AR bandwidths are 78MHz, 55MHz, and 174MHz respectively.

A reconfigurable antenna based on coplanar with capacitive-coupled feeding technique has beem presented in [33]. In this prposed geometry a PIN diode is used as a switch. When the diode is off, it offers an impedance bandwidth of 66.61% and when the switch is in the on condition (diode is on) its impedance bandwidth increases to 68.42%. Axial ration bandwidths reported are 4.42%, and 2.72% respectively. Another CP antenna that uses shorting is presented in [34]. This antenna is also a capacitive-coupled antenna with probe feed. It offers an impedance bandwidth of neary 50% and a good axial ratio bandwidth of about 19%.

An orthogonally polarized CP antena with varying frequency ratio is realized in [35]. The reported antenna is multi-funational which exhibits dual band, dual and orgonally polarized. It uses dual ports for excitation of input. An array was designed to achieve the high gain up to 25.6dB for an array size of 16×16 elements. Its axial ratio bandwidths are 2.84% and 1.57% respectively.

In 2019 a single layer dual polarized antenna with operating frequency of 2.4GHz suitable for full-duplex radia has been demonstrated [36]. This antenna has very good RF-isolation of 78dB between the transmitter and receiver ports. A prototype of the antenna is shown in Fig. 5 [36]. A self nulling dual mode MSA has been proposed to tackle the grating lobes and could able to reduce it below −20dB [37]. Further, a substantial peak gains of 16.25dB and 17.2dB have been achieved.

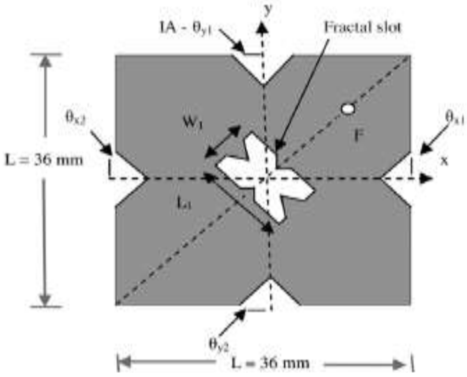


Fig. 4. Geometry of multi-bands CP antenna [32].

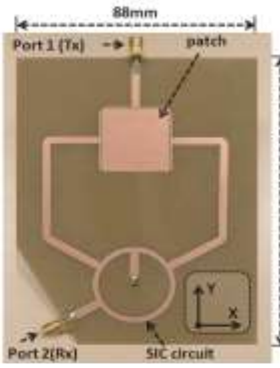


Fig. 5. Fabricated prototype of dual port antenna [36].

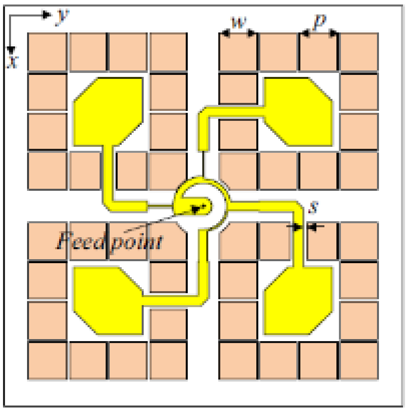


Fig. 6. A wideband 2x2 CP antenna geometry [42]

The work reported by [38] uses meta-surface to get high bandwidth and truncated corner for the excitation of circular polarization. The authors of this paper have reported 10dB return loss of 23.4% and an inband AR bandwidth of 16.8%. Futhermore the antenna has good radiation efficiency of more than 95% with stable radiation patterns and 11dBi flat gain. Authors S. S. Jehangir *et al*. [39] have presented Yagi like MIMO antenna suitable for Wi-Max applocations that offers an absolute bandwidth of 620MHz in the frequency range of 3.26GHz to 3.88GHz with 4dBi gain and more than 7dB front to back ratio (FBR). An antenna suitable for 5G wireless device to device systems has been reported by [40]. The proposed antenna is dual polarized and produces the end fire radiation patterns. It offers an impedance bandwidth of 28.6% (14GHz to 32GHz) for both horizontal and vertical polarizations. Corresponding gains are 10.5dBi and 11.6dBi respectively.

A filtering antenna capable of producing dual polarization based on “substrate integrated waveguide (SIW)” has been demonstrated by [41]. A new differential feed was used to couple the square radiating patch mounted on SIW. Authors have validated the results with two electromagnetic software CST and HFSS. A widebandwidth of 11% and 8dBi gain were reported for their proposed antenna. In [42] authors have proposed an antenna suitable for C-band wireless applocations. The proposed geometry of 2x2 antenna array is shown in Fig. 6 [42]. It uses sequential phase to offer the circular polarization. The reported AR badwidth is an impressive one and is equal to 36.4%. Further it offers an impedance badwidth of 42.9% and gain of 9.5 to 11.5 dBi.

In [43] authors have proposed planar suspended tennis-ball shaped radiator patch that offers impressive results. These are 100 MHz bandwidth (860MHz to 960MHz), 12.31% AR bandwidth, and 6.18dBi gain. The proposed antenna is designed for the UHF-RFID. In [44] authors have claimed that their proposed design is capable of filterning the signal (filtenna) and offres circular polarization operation. A low profile antenna suitable for WLAN applications was proposed by W. Wang *et al*. [45]. This antenna exhibits dual circular polarization. The geometry is SIW cavity backed and does the function of filtenna. These authors have reported an axial ratio bandwidth of 12% and 7dBi gain. The antenna has out of band rejection ratio of over −13dB. In yet another work reported in [46] is a broadband circularly polarized antenna with single layer metasurface. Antennas main parameters obtained are 25.1% impedance bandwidth, 13.8% axial ratio bandwidth, and 8dBi gain.

All configuartions discussed here have been summarized and the results reported by concerned researchers are listed in Table II. As mentioned earlier, in addition to the dual mode/CP operation, these antennas offer good bandwidth and gain.

TABLE II: DUAL AND CIRCULARLY POLARIZED ANTENNAS

Ref. & Year of publication	**Specifications and features of antenna geometry**	**Reported Results**	**Application(s)**
[30]-2009	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Rectangular MSA with diagonal slot	♦ 50% Impedance bandwidth ♦ 7.1% axial ratio bandwidth ♦ Both LHCP & RHCP can be excited based on slot orientation	♦ UWB applications
[31]-2011	♦ New coplanar capacitively coupled feed ♦ Fed through parallel short-ended strip ♦ Rectangular MSA with diagonal slot	♦ 1.2% axial ratio bandwidth ♦ 5.3% impedance bandwidth	♦ GPS and Satellite
[32], 2014	♦ Koch fractal boundary MSA ♦ Tri-band and circularly polarized operation	♦ First band: 8.7% (2.32GHz-2.52GHz) impedance bandwidth ♦ Second band:2.4% (3.37GHz-3.45GHz) ♦ Third band:5% (5.6GHz-5.9GHz) ♦ Corresponding axial ratio bandwidths: 78MHz, 55MHz, and 174MHz	♦ WLAN and Wi-Max
[33]-2016	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Reconfigurable hexagonal MSA with slit	♦ 66.61% bandwidth for Switch OFF ♦ 68.42% bandwidth for Switch ON ♦ 6.5dBi gain for Switch OFF ♦ 6.9dBi gain for Switch ON	♦ UWB applications
[34]-2017	♦ Capacitive coupled ♦ Circularly polarized antenna ♦ Shorting pin	♦ 49.79% Impedance bandwidth ♦ 19.05% axial ratio bandwidth	♦ UWB applications
[35], 2018	♦ Dual port, dual band ♦ Orthogonal-circularly polarized array ♦ Array with low frequency ratio (1.05) ♦ 8x8 and 16x16 array	♦ 4.81% and 6.75% return loss bandwidths ♦ 2.84% and 1.57% axial ratio bandwidths ♦ 18.6dB and 19.4dB isolations ♦ 25.1dB and 25.6B peak gains	♦ Satellite communication

[36], 2019	♦ Dual polarized, 2.4GHz, ♦ Compact square microstrip antenna	♦ 78dB peak isolation between DC isolated Tx-Rx ports ♦ 70dB isolation bandwidth of 25MHz ♦ 50MHz 10dB return loss bandwidth	♦ Full duplex radio ♦ Active antenna applications
[37], 2020	♦ Dual mode (TM11and TM21) microstrip antenna	♦ -20dB grating lobe reduction ♦ 16.25 and 17.2dB single mode and dual mode gains	♦ Grating lobe reduction
[38], 2020	♦ Meta-surface based wideband antenna ♦ Circularly polarized MIMO antenna	♦ Impedance bandwidth: 23.4% (24.5GHz-31GHz) ♦ Axial ratio bandwidth: 16.8% (25GHz-29.6GHz) ♦ 11.6dBi gain ♦ Radiation efficiency: More than 95%	♦ 5G smart devices and sensors
[39], 2020	♦ Compact four ports orthogonally polarized antenna ♦ Yagi like MIMO antenna	♦ 620MHz (3.26GHz-3.88GHz) bandwidth ♦ 4dBi gain ♦ More than 7dB front to back ratio	♦ Wi-Max
[40], 2020	♦ Wideband end fire array ♦ Dual polarized	♦ 28.6% (24GHz-32GHz) bandwidth ♦ HP gain: 10.5dBi; VP gain:11.6dBi ♦ Port isolation 18.85dBi	♦ 5G Wireless systems
[41], 2020	♦ Differential fed dual polarized ♦ High gain filtering antenna ♦ SIW technology with defected ground structure (DGS)	♦ 11% bandwidth ♦ 8dBi gain	♦ 5G Wireless systems
[42], 2020	♦ Wideband circularly polarized array ♦ Sequential phase feed	♦ Impedance bandwidth:42.9% (4.4GHz-6.8GHz) ♦ 36.4% axial ratio bandwidth ♦ 9.5 to 11.5dBi	♦ C-band applications
[43], 2020	♦ Circularly polarized, ♦ Capacitively fed, ♦ Planar suspended antenna ♦ Tennis ball shaped radiator	♦ 860MHz-960MHz (Center Frequency: 910 MHz) ♦ 6.18dBi gain ♦ 14.13% return loss bandwidth ♦ 12.31% axial ratio bandwidth	♦ UHF RFID
[44], 2021	♦ Low profile circularly polarized antenna	♦ Operational bandwidth and axial ratio bandwidth: 4.1% ♦ 8.3dBi peak gain ♦ Out of band suppression: more than 20dB	♦ WLAN (2.4GHz)
[45], 2021	♦ Dual circularly polarized ♦ SIW cavity packed patch Filtenna ♦ Wide axial ratio bandwidth	♦ Axial ratio bandwidth: 12% ♦ Gain: 7.dBi ♦ Out of band rejection over -13dB	♦ --
[46], 2021	♦ Meta-surface antenna ♦ Circularly polarized	♦ 25.1% impedance bandwidth ♦ 13.8% axial ratio bandwidth ♦ 8dBi gain	♦ --

IV. BEAM CONTROLLING TECHNIQUES & OTHER SPECIFIC APPLICATION

The spurious radiations from the feed strip as well as a probe pin at high frequency end of operations are significant and these interfere with the radiations of the main patch that causes asymmetry in radiation patterns. This issue has been addressed by [47]. The improvement in patterns is expected due to the cancellation of surface waves by modifying the shape of the geometry edges.

In another work, author of [48] reported the design that offers a dual frequency operation. The geometries for the same are shown in Fig. 7. It is interesting to note that when air gap is reduced to zero the antenna offers dual band/frequency operation. In this case the feed strip is tapered for better impedance matching and to have dual frequency operation. It has the frequency ratio variation from 1.48 to 1.71. In [49], dual band operation was obtained from the capacitive-coupled antenna. It involves no air gap but uses a thick substrate with thickness of 3.12mm. This antenna offers two bands with the frequency range of 1.8GHz to 2GHz as the first band of operation and 2.25GHz to 2.5GHz as its second band.

A very high gain antenna based on Butler matrix has been demonstrated in [50]. This antenna is specially designed for base stations as it offers a gain of up to 14dBi. Its frequency of operation is 28GHz. The fabricated prototype of 8×8 antenna array is shown in Fig. 8 [50].

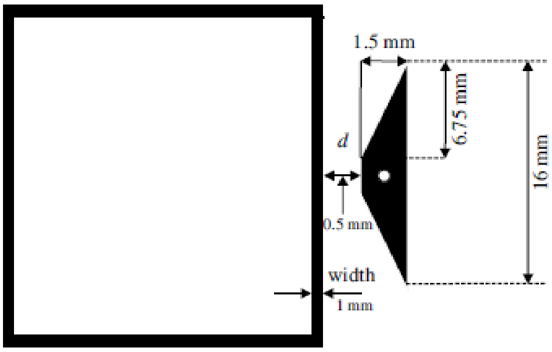


Fig. 7. Ring antenna for dual frequency operations [47].

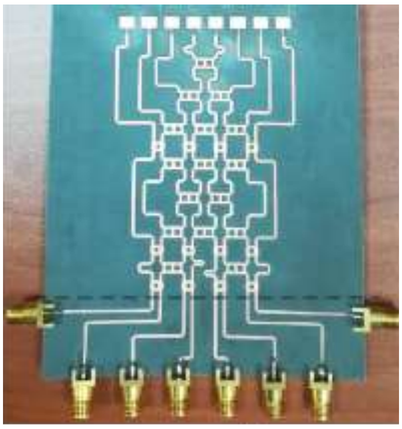


Fig. 8. A prototype of 8×8 array multi-beam antenna [50].

In [51] a reflect-array antenna for efficient beam scanning has been reported. This geometry offers an AR bandwidth of 46% and beam scanning of 70°. It offers 1dB and 3dB gain-bandwidths of 24.5% and 46.15% respectively. Typical scanned beams at various frequencies are shown in Fig. 9. In yet another work a reflect-array antenna for which the operating range is between 27.2GHz and 51.1GHz was presented [52]. The HP and VP gains are 25dBi and 25.8dBi respectively. Further, all beam steering antennas [50]-[56] with their characteristics and reported results are highlighted in Table III. Authors of [57] and [58] have presented single layer electronic band gap (EBG) structured antennas suitable for improving the gain of the antenna. A comprehensive study on EBG and metamaterial based antennas are covered in [59], [60]. However, single layer based metamaterial antennas [61]-[64] are summarized in Table III. These antennas have been designed to operate in ISM, LTE, Bluetooth, and Terahertz applications.

The antennas reported here not only serve the special functions like obtaining patterns symmetry, beam scanning but also focus on other parameters of the antenna. For example [47] focuses on the improvement in radiation patterns symmetry but also offers an impedance bandwidth of 50%. Antennas with these features are highlighted in the Table III.

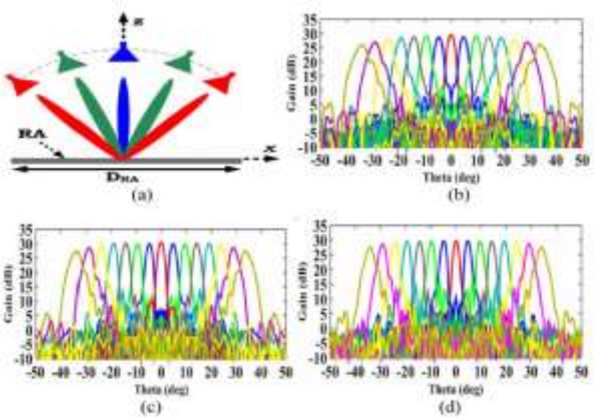


Fig. 9. (a) Beam scanning technique with typical scanned beams at (b) 17GHz (c) 19GHz and (d) 21GHz [51].

TABLE III: APPLICATION SPECIFIC ANTENNAS

Ref. & Year of publication	Specifications and features of antenna geometry	Reported Results	Application(s)
[47]-2008	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Edge modified rectangular MSA	♦ Symmetry in radiation patterns ♦ 50% impedance bandwidth	♦ Feed antennas for Circularly symmetrical reflectors
[48]- 2011	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Dual ring antennas with tapered feed	♦ Two frequency operation ♦ 2.4GHz and 3.71GHz ♦ Frequency ratio can be varied from 1.48 to 1.71	♦ General multiband wireless applications
[49]-2013	♦ Coplanar capacitively coupled feed ♦ Fed through small feed strip ♦ Thick substrate & without air gap	♦ First band: 1.8GHz-2GHz ♦ Second band: 2.25GHz-2.5GHz ♦ 8dBi gain	♦ General multiband wireless applications
[50], 2020	♦ Compact multi-beam array antenna ♦ 8x8 Butler matrix	♦ 9 to 14dBi gains (P1 to P8) ♦ 28GHz operating frequency ♦ 2.5dB average insertion loss with 10^0 phase error	♦ 5G base station
[51], 2020	♦ Circularly polarized reflect array ♦ Efficient beam scanning	♦ 1dB gain-bandwidth:24.5% ♦ 3dB gain-bandwidth:46.15% ♦ 3dB axial ratio bandwidth: 46% ♦ 70^0 degree beam scanning	♦ --
[52], 2020	♦ Broadband dual polarized reflect array antenna ♦ Independently controllable 1 bit dual beams	♦ Impedance bandwidth: 27.2GHz-51.1GHz ♦ -30dB cross polarization ♦ Less than -14dB side lobe level ♦ HP gain: 25dBi; VP gain:25.8dBi	♦ MIMO
[53], 2017	♦ Single layer, W-band beam-steering antenna ♦ 16x32series fed RHCP phased array ♦ 4-bit phase shifter	♦ Operational frequency: 85.4GHz (W-band) Broadside patterns: co & cross polarization separation: 18dB ♦ Beam steering: $\pm 30^0$	♦ Cubesat
[54], 2017	♦ Low profile linearly polarized antenna array ♦ Rectangular pin-fed patch antenna with wideband characteristics ♦ U-slot on single layer substrate	♦ Reflection coefficient magnitude is less than 0.4 in 12% relative bandwidth ♦ 40% conical beam steering sector	♦ --
[55], 2019	♦ SIW variable phase shifter for beam steering antenna ♦ 3dB coupler and a 90^0 phase phase transition	♦ 2GHz (better than -10dB) bandwidth centered at 17GHz ♦ 10.7dBi gain ♦ Beam steering from -25^0 to 25^0.	♦ Ku band applications
[56], 2020	♦ Single layer mm wave antenna with tilted beam characteristics ♦ Compact size 15x14.6 mm^2	♦ 5.6% bandwidth (27.75GHz-29.35GHz) ♦ 28.5GHz operating frequency ♦ 45^0 tilted beam ♦ 8.75dBi gain	♦ 5G
[57], 2018	♦ Single EBG layer based high gain antenna ♦ 5x5 planar array	♦ 11.1dBi gain at 2.45GHz ♦ 22dB front to back (F/B)ratio	♦ Telemetry applications
[58], 2021	♦ 3x3 EBG array	♦ 8.95dBi gain at 5.2GHz	♦ Wi-Max

	♦ Split ring resonator ♦ FR-4 with 70x70x1.6 mm^3	♦ 680MHz (5.83GHz-5.15GHz) bandwidth ♦ 31% aperture efficiency ♦ HPBW: E-plane-86.6^0, H-plane-66.8^0	
[61], 2018	♦ A compact metamaterial antenna ♦ Geometry size::42x32 mm^2	♦ Operating bands: 0.60~0.64 GHz, 2.67~3.40 GHz and, 3.61~3.67 GHz ♦ 3.81dBi peak gain	♦ LTE ♦ Bluetooth ♦ Wi-Max
[62], 2019	♦ Metamaterial based rectangular microstrip antenna ♦ Geometry size: 180x212x10 μm^3 ♦ Quartz substrate	♦ Operating frequency: 1.02THz ♦ 4.12% operational bandwidth ♦ 5.75dBi peak gain	♦ Terahertz applications
[63], 2019	♦ Enhanced gain Fabry-Perot antenna ♦ 6x6 array ♦ Single layer metamaterial antenna	♦ 15.5% (13.1GHz-15.3GHz) impedance bandwidth ♦ 8.2dB gain ♦ 3dB gain bandwidth:17.1% ♦	♦ --
[64], 2019	♦ Compact dual band antenna ♦ Metamaterial SRR ♦ Hexagonal SRR with dimensions 30x30x0.8 mm^3	♦ Operational bands with bandwidth: 180MHz (2.42GHz-2.60GHz) & 2400MHz (3.44GHz-5.84GHz)	♦ ISM ♦ Wi-Max ♦ WLAN

V. CONCLUSION

This paper presented the review of low profile and single layer antennas published by several researchers to cater the demands of 5G, RFID, WLAN, Wi-Max, UWB, and other state of the art wireless applications. Results of such antennas have been discussed. It is observed that for bandwidth enhancement most of the researchers have introduced finite air gap. The purpose of introducing air-gap helps in the reduction of effective dielectric constant and thereby increase in the bandwidth is achieved. However, the use of air gap increases the space/volume requirements for the overall antenna geometry which limits its use in the compact applications. In addition to this use of thick substrate, defected ground structures, use of meta-surface etc. have been adopted for enhancing the bandwidth. The basic limitation in using the thick substrate is the excitation of surface waves which has impact on the reduction of gain and efficiency of the antenna. Defected ground structures help in impedance matching but their analysis is cumbersome. On the other hand meta-materials based antennas resolve these issues very effectively i.e. high gain, reasonably good bandwidth & efficiency can be achieved even with compact geometries. Issue of addressing the excitation of dual and circular polarization has been also examined in detail. A few geometries which serve the specific applications like improvement in the symmetry of the radiation patterns and beam scanning using reflect-arrays have been discussed. The studies on single layer antennas presented here demonstrate a maximum beam scanning of up to 70^0.The other findings include 40% conical beam steering, -30dB cross polarization, and 22dB front-to-back (F/B) ratio. Finally, it must be noted that based on the studies presented here the single layer antennas are not only simple to design but also they help in designing compact wireless systems.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Both authors have analyzed the complete paper and approved the final copy.

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