Analysis of Circularly Polarised Compact Microstrip Antenna For Broadband applications- a Review

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Abstract

Explosive growth of wireless communications, microwave sensors, bio-medical, radars demand multitude of new antenna designs over the past decade. Extensive use of antennas for GPS, Satellite phones, Navigation systems have been recently seen, that requires increased bandwidth, miniature size and circular polarization having better AR performance. Conventional microstrip antennas, in general have the attractive features of low profile, easy fabrication; but due to narrow bandwidth and relatively large size for UHF frequencies, enhancement in bandwidth and size reduction are becoming major design considerations for practical applications of microstrip antennas. Thus over the past several years significant progress have been reported in the design of microstrip antennas with broadband, compactness, circularly polarized and gain-enhanced operations.. However bandwidth improvement results into enlarge size; whereas the miniaturization reduces impedance bandwidth, gain and efficiency; the disadvantage of circularly polarized MSA is limited AR, impedance bandwidth. Hence there is a need of selection of appropriate techniques to achieve the desired characteristics. This paper is a review of various techniques applied for improving bandwidth and compactness of microstrip patches. These include various modified patch shapes, multiresonator (planar and multilayered) configurations, array configurations, size reduction techniques, photonic band gap structures. The paper analyzes different designs in terms of VSWR, AR, Impedance, Gain, Radiation pattern and suggests few optimum design techniques to achieve broadband and compactness. Also various results reported in the literature are discussed and compared.

Keywords: Axial ratio (AR), Voltage standing wave ratio (VSWR), Impedance, Miniaturization, Proximity coupled feed, Microstrip antenna (MSA), Circular Polarization (CP)

1. Introduction

In high performance aircrafts, spacecraft, satellites, missiles and other aerospace applications where size, weight, performance, ease of installation and aerodynamics profile are the constraints, a low or flat/conformal profile antenna may be required. Microstrip antenna are conformable to planar or non-planar surface, simple and inexpensive to manufacture, cost effective compatible with MMIC designs and when a particular patch shape and excitation modes are selected, they are very versatile in terms of resonant frequency, polarization, radiation patterns and impedance. In personal mobile communication systems, satellite mobile phones have been developed in the past few decades because of wide accessibility regardless of area restrictions. The physical size of satellite mobile phones became compact for portability, resulting in the need for antenna miniaturization while maintaining circular polarization (CP), large beamwidth, and high gain. Therefore appropriate selection of feeding technique, substrate material, polarization type, broadband technique, size reduction method has the crucial role for successful design of an antenna.

Feeding mechanism plays an important role for proper impedance matching. Microstrip patch antennas can be fed by a variety of methods. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes). These techniques are discussed in Section 2.

The selection of a substrate material is a balance between the required electrical, mechanical and environmental performance required by a design versus economic constraints. The various substrate materials available and their influence on patch antenna characteristics are discussed in section 3.

In a communication system that uses circularly polarized (CP) radiation the rotational orientations of the transmitter and the receiver antennas are unimportant in relation to the received signal strength. Therefore, CP is useful for a number of applications, such as radar, satellite, and navigational systems. Some of the single feed MSAs used are nearly square, corner chopped square, square or circle with a slot or patch with a notch etc. These techniques are discussed in detail in section 4.

However, circularly polarized antennas have a limitation that they have much smaller axial ratio bandwidth. Hence techniques for achieving wide band polarization characteristics, as well as wide band impedance characteristics are important. Various techniques used to increase the bandwidth of microstrip patch antennas may be classified as follows: (i) decreasing the Q-factor of the patch by increasing the substrate height and lowering the dielectric constant. (ii) use of multiple resonators located in one plane. (iii) use of multilayer configurations with multiple resonators stacked vertically. Some of these techniques are described in Section 5.

Various approaches have been used to achieve compactness – such as method of chip-resistor loading to make antenna broadband and compact, a method of loading a high-permittivity superstrate layer and a 1Ω chip-resistor, method of defective ground plane or method of making slots in the ground plane. These approaches reported in several papers, are discussed in Section 6.
Comparison of various results and concluding remarks are contained in the last section.

2. Feeding mechanism

Feeding technique influences the input impedance and characteristics of the antenna, and is an important design parameter. In the case of a coaxial feed, increased probe length makes the input impedance more inductive, leading to the matching problem [1]. For the microstrip feed, an increase in the substrate thickness increases its width, which in turn increases the undesired feed radiation. One solution consists in adding a capacitance effect through the modification of the probe structure. Several designs have been reported such as L-shaped probes. An F-shaped probe feeding a rectangular patch has also been reported [2, 3] achieving 64% impedance bandwidth. Compact F-probe fed triangular patch antennas presented in [4] provides an impedance bandwidth of 67 %.

In comparison with the common microstrip feed technique form, the antenna structure discussed in [5], combines the advantages of CPW with the advantages of aperture coupled microstrip antenna, and simplifies the structure of the antenna by reducing the number of substrate level, from 3 to 1, consequently reducing the spurious radiation due to surface wave.

In order to achieve good circular polarization, location of coaxial feed position was optimized, on the arc by changing the feed position (X, Y) according to X=Xo Cos ϴ, Y=Xo Sin ϴ as reported in [6]. This feed optimization technique was found to be useful for rapid design of circular polarized stacked microstrip antennas.

High bandwidth of 38% has been achieved by using an aperture-coupled stacked-patch antenna as radiating element [7]. Utilizing an integrated branch line coupler and sequential rotation technique offers the selection of left and right handed circular polarization while axial ratios remain low.

The proximity feeding mechanism benefits from flexibility in manufacturing and matching. An important advantage of this feed when compared to coplanar feed is the reduction of radiation from transmission line-patch discontinuities. In case of microstrip-line inset-fed rectangular patch antenna, inset depth is the primary factor affecting the matching [9]. The comparison of various feed types is listed in table 1.

3. Choice of Substrate material

If air is used as a substrate for a microstrip antenna, then the antenna efficiency is high, the gain is maximized as is the impedance bandwidth, and also the surface wave loss is minimal. When a dielectric substrate is selected, one is interested in a material with the lowest tangent (tan δ), that maximizes the antenna efficiency (decreases the losses). The larger the dielectric constant the smaller the element size, but also the smaller the impedance, bandwidth and directivity and the surface wave loss increases. The use of the substrates with higher dielectric constants also tightens fabrication tolerances. A wide range of substrate materials is available for microstrip circuits, with relative permittivity ranging from 2 to 10 and various thicknesses available for each. Their application oriented properties are listed below.

Teflon (Polytetrafluoroethylene) has very desirable electrical qualities but is not recommended for many space applications.
Rexolite is a very good material for space applications. It is easily machined and its dielectric constant remains stable up to 100 GHz.
Noryl is suitable for many commercial microwave applications. It has a much lower loss than FR4 and is relatively cost effective, but it is soft and melts at a relatively low temperature which can create soldering complications.
FR4 is inexpensive and find use in many commercial applications below 1 GHz. The material can be used for some wireless applications, but great care must be taken to budget and minimize the losses.
Alumina has desirable microwave properties for applications which require a relatively high dielectric constant εr ~ 10.0 and low loss tangent. Its drawbacks are the difficulty involved in machining it and its brittleness. Alumina has good thermal conductivity and in some aerospace applications it more readily dissipates heat and remains cooler than other common microwave substrates.

4. Circular Polarization

Single-fed circularly polarized (CP) MSA can be realized more compactly by using less board space than the dual feed circularly polarized microstrip antennas. However, the single-fed CP antennas have their serious disadvantages of narrow impedance and AR bandwidth. The most used types of single-fed CP patches are the slotted patch, the notched patch, and the almost square patch. The 3 dB AR bandwidth of slotted patch and notched patch are commonly less than 1% and 3% respectively [12]. However, Ref. [10] reports 13% (2.5dB) AR bandwidth by using a probe-fed rectangular patch with an almost square parasitic element. Considering that patches on foam substrate is difficult to fabricate, the patches printed on a low dielectric substrate in [5], and 13.5% (3 dB) AR bandwidth has been achieved.

The antenna structure (fig.1) described in [13], has a hexagonal shaped feed element and a square shaped parasitic element, provide an axial ratio of 12 %.

In another design, a hybrid antenna comprised of a Dielectric Resonator Antenna (DRA) and four feed slots has been investigated in [14]. It has been seen that the antenna covers the range 1.13 to 1.63 GHz, the achieved gain is over 1.5 dBic and the axial ratio is less than 1 dB at bore sight. The half-power beamwidth is greater than 75◦, and the axial ratio beamwidth (AR ≤ 3 dB) is over 90◦.

In [16], two rectangular wire loops fed by dual ports with anti-phase had a 3dB axial ratio bandwidth of 22%. In [17], four L-probe feeds oriented to have the phase of 0^0, 90^0, 180^0, and 270^0 exciting a circular patch, and the 3-dB axial ratio bandwidth of 60%. However, such type of design would increase the complexity of the feed circuitry, resulting in a large footprint beneath the antenna. A wide band circularly polarized vertical patch antenna with compact microstrip to slot-line transition to supply dual feed with anti-phase is reported in [15]. The antenna has a wide axial ratio bandwidth (<3dB) of 30.7% and VSWR bandwidth (<-10dB) of 37.8%, gain of 8 dBi.

5. Broadband techniques

There are numerous and well-known methods to increase the bandwidth of antennas, however, the bandwidth and the size of an antenna are generally mutually conflicting properties, that is, improvement of one of the characteristics normally results in degradation of the other. Utilizing the shorting pins or shorting walls on the unequal arms of a U-shaped patch, U-slot patch, or L-probe feed patch antennas, wideband and dual-band impedance bandwidth have been achieved with electrically small size. Other techniques involves employing multilayer structures with parasitic patches of various geometries such as E, V and H shapes, which excites multiple resonant modes.

In another design [18], a slotted shape patch was investigated that employs contemporary techniques namely ,the L-probe feeding, inverted patch, and slotted patch techniques. The use of L probe feeding technique with a thick air-filled substrate provides the bandwidth enhancement, while the application of superstrate with inverted radiating patch offers a gain enhancement, and the use of parallel and series slots reduce the size of the patch. In addition, the antenna is relatively compact in comparison with the slotted antenna described in [20]. The antenna achieves a fractional bandwidth of 21.79% (1.84 to 2.29 GHz) at 10 dB return loss, gain of 9.5 dBi. The comparative results of various antenna configurations reported in past decade are listed in table 2.

Also, surface waves in MSA reduce bandwidth, gain, and efficiency of the antenna while increase the cross-polarization. The Photonic Band-Gap (PBG) structure is useful to suppress these surface waves. The attenuation of these surface waves improves the radiation pattern, gain and efficiency of the antenna because these surface waves propagate in free space several wavelengths which create the ripple in the desired radiation pattern [21].

6. Miniaturization techniques

In general, the size miniaturization of the normal MSA has been accomplished by loading, which can take various forms, namely, 1) Use of high dielectric constant substrates or superstrata; 2) Modification of the basic patch shapes; 3) Use of short circuits, shorting-pins or shorting-posts; and 4) A combination of the above techniques. Employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation. Modification of the basic patch shapes allows substantial size reduction; however, some of these shapes will cause the inefficient use of the available areas. In contrast, shorting posts, which were regarded as a more efficient technique, were used in different arrangements to reduce the overall dimensions of the MSA..

By parasitically coupling two shorted semi-disc patches with a single shorting-post each and employing Styrofoam substrate with low dielectric constant, an overall impedance bandwidth of 17.8% has been achieved to cover the frequency spectra of 1.862–2.225 GHz. The overall dimension of the antenna is 44.4mm (length) × 37.8mm (width) × 7mm (thickness), and it would be suitable for the IMT-2000 mobile handset application [22].

A substrate perturbation was one of the methods to achieve the goal of resonant frequency reduction, thereby making the antenna compact (shown in fig. 3). Around 11% reductions in resonant frequency has been achieved successfully [23].

Using rectangular-slot-loaded and V-slot-loaded proximity-coupled microstrip antenna [24], the peripheral area of the patch was reduced by 65% and 60% respectively. It has been found that V-slot-loaded proximity-coupled microstrip antenna has more impedance bandwidth than rectangular-slot-loaded proximity-coupled microstrip antenna.

A compact broadband dual frequency slot-loaded rectangular microstrip antenna with meandering slots in the ground plane (fig. 4) has been reported in [25].The result states size reduction of 0.6% and 30% for the two resonant frequencies with enhanced bandwidths of 12.2% and 4.5% respectively, when compared to standard rectangular microstrip antenna without slots (conventional antenna). An increase in bandwidth is more significant for the lower frequency.

The merits and demerits of various size reduction techniques are listed in table 3.

7. Concluding Remarks

Various techniques for improving bandwidth and compactness have been reviewed. It is pointed out that for successful design of antenna, appropriate selection of feeding technique, substrate material, good polarization , broadband technique, size reduction method are important.

Among several feeding techniques available, different shape probe feeds such as L-shaped [2], F-shaped [3], C-shaped have achieved better impedance matching with high bandwidth. Also Proximity coupled microstrip antennas are suitable both for microwave and millimeter wave antenna elements due to various advantages like reduction of radiation loss from feeding network, improvement of impedance bandwidth etc.

The impedance bandwidth can be broadened by making use of stacked patch concept while the AR bandwidth can be enhanced by using substrates with high and low permittivity for driven and parasitic patches respectively [11].

Between the two different methods of constructing multiresonator coupled patch configurations, the two-layer configuration with vertically-stacked patches provide higher bandwidth, requires smaller area and does not suffer much from pattern degradation with frequency.

It was observed from various studies that Slot loaded patch has greater advantages in terms of reduced size and bandwidth (table 3).

References

[1] Ramesh Garg, Prakash Bhartia, Inder Bahl, Apisak Ittipiboon, Microstrip Antenna Design Handbook, Artech House, Boston, London, 2001.

[2] C.L. MA. K.M. Luk. K.f. Lee. Wideband triangular patch antenna, IEEE Roc. Microwave Antennas and Propagation. Vo1.146, pp. 167-168, 1999.

[3] B.L. Ooi, C.L. Lee. P.S. Kooi, “A novel F-probe-fed broadband parch antenna.” Microwave opt. Technol. Letters, Vol.30, pp. 355-356, 2001.

[4] Anne Claire LEPAGE, Xavier BEGAUD, Gilles LE RAY, Ala SHARAIHA “F-Probe Fed Broadband Triangular Patch Antennas Mounted on a Finite Ground Plane”, IEEE Trans. Antennas Propagat, 2004.

[5] K. Hettak, G.Y. Delisle and M.G. Stubbs, “A novel variant of dual polarized CPW fed patch antenna for broadband wireless communications”, IEEE Trans. Antennas Propagat., 2000.

[6] Nasimuddin, Karu P. Esselle and A. K. Verma, “Wideband Circularly Polarized Stacked Microstrip Antennas”, IEEE Trans. Antennas Propagat. 2007.

[7] Sebastian Methfessel, Lorenz-Peter Schmidt, “Design and Measurement of a Wideband Aperture-Coupled and Polarization-Agile Stacked-Patch Antenna-Array for Monopulse Radar Applications”, 2008.

[8] Ye Jianfeng, Pang Weizheng, “Optimized Design of Circularly Polarized Wideband Stacked Microstrip Antenna With Single-Fed ”, ICMMT Proceedings, 2008.

[9] Zhang Ronghui, Tang Xiaohong, Wang Ling, and Zhang Xianjing, “Study of Microstrip-Line Inset-Fed and Two-Layer Electromagnetically Coupled Rectangular Patch Antennas”, IEEE Trans. Antennas Propagat, 2005.

[10] N. Herscovici, Z. Sipus, and D. Bonefaci,“ Circularly polarized single-fed wideband microstrip patch, ” IEEE Trans. Antennas Propagat, vol. 51, no .6, pp. 1277- 1280, 2003.

[11] Q.Lee, T. Talty, and K. F. Lee, “Circular Polarization characteristics of stacked microstrip antennas”, Electronics Letters, vol.26, pp.2109-2110, 1990.

[12] Xue Ruifeng, Zhong Sunshi, “Survey and progress in circular polarization technology of microstrip antennas”, Chinese journal of radio science, vol.17, pp. 331- 336, 2002.

[13] Takanori NORO, Yasuhiro KAZAMA, Masaharu TAKAHASHI and Koichi Ito, “A Study on the Mechanism of Wideband Characteristics for Single-Fed Stacked Circularly Polarization Patch Antenna”, IEEE Trans. Antennas and Propagat. 2007.

[14] Gabriel Massie, Mathieu Caillet, Michel Cl´enet, Y.M.M. Antar, “A Wideband Circularly Polarized Rectangular Dielectric Resonator Antenna”, IEEE Trans. Antennas and Propagat. 2010.

[15] Ze-Hai Wu and Edward K. N Yung, “Wide Band Circularly Polarized Vertical Patch Antenna”, IEEE Trans. Antennas and Propagat. 2007.

[16] M.Sumi, K.Hirasawa, and S.Song. “Two Rectangular Loops Fed in Series for Broadband Circular Polarization and Impedance Matching,” IEEE Trans. Antennas Propagat. Vol.52, No.2. pp. 551-554., 2004.

[17] L.Bian, Y.X.Guo, L.C.Ong, and X.Q.Shi. “Wideband Circularly-Polarized Patch Antenna”. IEEE Trans. Antennas Propagat. Vol.54, No.9. pp. 2682-2686., 2006.

[18] Mohammad Tariqul Islam, Mohammed Nazmus Shakib, Norbahiah Misran, “Broadband Microstrip Patch Antenna”, ISSN 1450-216X ,Vol.27 No.2 , pp.174-180, 2009.

[19] Yan Shan Boo, Nasimuddin, Z. N. Chen, and A. Alphones, “Broadband Circularly Polarized Microstrip Antenna for RFID Reader Applications”, IEEE Transactions on Antennas and Propagation, 2009.

[20] Tariqul Islam M., Misran N., Ng K.G., “A 4×1 L-probe fed Inverted Hybrid E-H Microstrip Patch Antenna Array for 3G Application”, American Journal of Applied Sciences.

[21] Raj Kumar and V. A. Deshmukh, “On the Design of Compact Broadband Gap–Coupled Microstrip Patch Antenna with PBG”, APMC Proceedings, 2005.

[22] Y. J. Wang and C. K. Lee, “Compact and Broadband MSA for the 3G IMT-2000 Handsets applying Styrofoam and Shorting -Posts”, Progress In Electromagnetics Research, PIER 47, 75–85, 2004.

[23] R. R. Wakodkar and Bhaskar Gupta, “Compact Microstrip Antenna Design Using Substrate Perturbations”, IEEE Region 10 Colloquium and the Third ICIIS, Kharagpur, INDIA, 2008.

[24] Jibendu Sekhar Roy, Milind Thomas, “Compact and Broadband Microstrip Antennas for Next Generation High-Speed Wireless Communication Using HIPERLAN/2”, International Journal of Microwave Science and Technology, Volume 2007, Article ID 75320.

[25] Usha Kiran K., R. M. Vani, Ravi R. M. and P. V. Hunagund, “Slot-loaded Rectangular Microstrip Antenna with Meandering Slots in the Ground Plane for Compact Broadband Dual-frequency Operation”, 2006.

[26] Nasimuddin, Z. N. Chen and Xianming Qing, “Single Fed Circularly Polarized Microstrip Antenna with C-Slot”, IEEE Trans. Antennas Propagat, 2008.

[27] X.H. Tang, K.L. Lau, Q. Xue and Y.L. Long, “Miniature circularly polarised patch antenna”, ELECTRONICS LETTERS Vol. 46 No. 6, 2010.

Table 1
Comparison of feeding methods

Charact.	Coaxial probe (nonplanar)	Gap Coupled (coplanar)	Inset feed (coplanar)	Proximity coupled (planar)	Aperture coupled (planar)	CPW feed (planar)
Spurious feed radiation	More	More	More	More	More	Less
Polarization purity	Poor	Poor	Poor	Poor	Excellent	Good
Fabrication on Ease	Solder reqd.	Easy	Easy	Alignment reqd.	Alignment reqd.	Alignment reqd.
Reliability	Poor	Better	Better	Good	Good	Good
Impedance matching	Easy	Easy	Easy	Easy	Easy	Easy

Table 2
Comparison of Various CP Compact Wideband MSA configurations

Antenna configuration	Antenna size	VSWR BW	3 dB AR BW	Gain, dBi	Frequency range
Compact stacked folded patch antenna with an L-probe feed [27](fig. 2)	90 mm x 90 mm	17.9 %	9 %	7.3	1.57–1.88 GHz
CP stacked microstrip antenna for RFID [19]	0.48 λo × 0.48λo × 0.0984λo	12 %	12 %	7.2	840-940 MHz
wideband circularly-polarized vertical patch antenna [15]	100 mm x 100 mm	37.8 %	30.7 %	8.0	1.16－1.70 GHz
"Almost square" CP stacked antenna [8]	25.6 mm x 19 mm x 7.6 mm	17.9 %	14.8 %	8.46 dB	4.57-5.43 GHz
Circularly polarized stacked patch antenna with C-type feed [6]	25 mm x 25 mm	21 %	13.5 %	10.0	4.83 to 5.96 GHz
Compact, aperture-coupled, circularly polarised, asymmetrical C-shaped slot [26] (fig.5)	60.0 mm x 60.0 mm x 12.34 mm	16 %	3.3 %	6.76	2.185–2.565 GHz

Table 3
Merits/demerits of Size reduction techniques

Size reduction techniques	Merits/demerits
High Permittivity Substrate	reduced BW, increased dielectric losses and cost
Folded Patch	increased volume, complex manufacturing process
Shorting Pin	problems with radiation pattern, feeding and manufacturing tolerances
Slot Loaded Ground Plane	problems with back radiation, less transmission power
Slot Loaded Patch	can produce wide range of designs, reduced size, available for single frequency, dual frequency, wideband

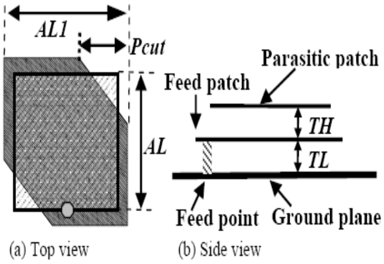
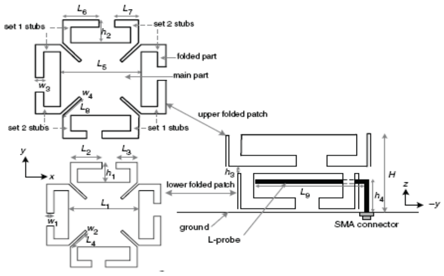
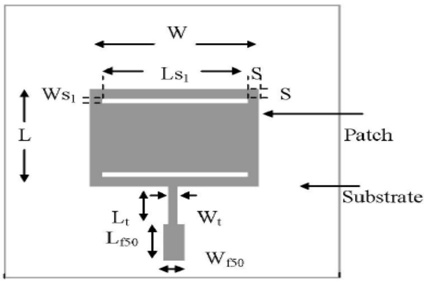


Fig. 1 Hexagonal shaped feed element [13]



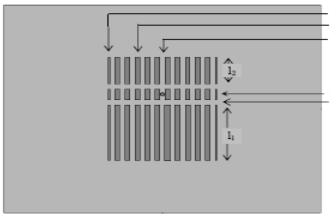
Cross Section view

Fig. 2 Folded patch antenna with L-probe feed[27]



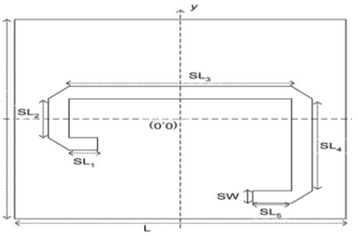
Top view

Fig. 4 Slot-loaded MSA with meandered ground plane [25]



Top view

Fig. 3 Compact MSA using Substrate slot Perturbations [23]



Top view

Fig. 5 Asymmetrical C-shaped patch radiator [26]