. Literature Review

Kai Da Xu, et al (2018). In this article, two novel microstrip patch antennas with multiple parasitic patches and shorting vias have been presented for the bandwidth enhancement. Based on the conventional triangular patch antenna, two more resonances can be obtained with the introduction of multiple parasitic patches, and consequently the antenna bandwidth can be broadened. The two shorting vias are inserted into the above proposed antenna to decrease the input impedance, resulting in further bandwidth enhancement of the antenna. A measured 10-dB impedance bandwidth of 17.4% from 5.5 to 6.55 GHz. When the parasitic patches are introduced in the structure of the proposed antenna, two extra resonances can be obtained, thus the bandwidth will be broadened effectively. The two shorting vias are added based on the above proposed antenna, consequently, the input impedance can be lowered at some frequency ranges and thus the bandwidth will be further broadened.

Naveen Jaglan, et al (2016). In this article, a circular monopole antenna for ultra wideband (UWB) applications with triple band notches is proposed. The proposed antenna rejects worldwide interoperability for microwave access WiMAX band (3.3GHz–3.8GHz), wireless local area network WLAN band (5.15GHz–5.825 GHz) and X-Band downlink satellite communication band (7.1 GHz–7.9GHz). The antenna utilises mushroom type and uniplanar Electromagnetic Band Gap (EBG) structures to achieve band-notched designs. The advantages of band-notched designs using EBG structures such as notch-frequency tuning, triple-notch antenna designs and stable radiation pattern are shown. The effect of variation of EBG structure parameters on which notched frequency depends is also investigated. Fabricated and measured results are in good agreement with simulated ones.

H. Errifi, et al (2015). In it The development in communication systems requires the development of low cost, minimal weight and low profile antenna that is capable of maintaining high performance over a wide spectrum of frequencies. To design and simulate a rectangular microstrip patch array antenna using HFSS software. Enhancement in gain, directivity and better return loss performance can be obtained by the use of RT-DURROID substrate because Low dielectric constant substrates are generally preferred for maximum radiation. It is convenient to say that 16×1 patch array antenna with series-corporate feed network provides better performance than
the other arrays, -15.28 dB return loss and 15.3dB directivity is achieved at 10.6GHz.

Anil K. Gautam, et al (2015), This paper represent antenna which uses an annular ring radiator which is encircled by a rhombus shaped strip and the defected ground plane. The ground plane is cambered shaped and cut out by rectangular-shape slot and thus forms a defected ground structure. To validate simulation results of the design a prototype is fabricated on the commercially available FR4 material to validate simulation results of the design a prototype is fabricated on the commercially available FR4 material. The proposed antenna can achieve wideband by etching an annular ring strip which is encircled by rhombus-shaped strip and by using defected cambered ground structure.

Devang V. Katrodiya, et al (2015), This paper gives the comparative analysis of improved performance of a 2×2 microstrip patch antenna array as compared to the single microstrip patch antenna for ISM band applications. This paper gives the comparative analysis of improved performance of a 2×2 microstrip patch antenna array as compared to the single microstrip patch antenna for ISM band applications. The series feed method when used for array, it has poor directive gain and more return loss but requires less area whereas corporate feed in array provides comparatively high radiation efficiency, low return loss but requires a larger area. In the array of the microstrip patch antenna, the increase in inter element spacing makes the main lobe in the radiation pattern narrower and increases the number of minor lobes and the position of the main beam can be steered by introducing a phase difference in the input to the array patch elements. The present paper gives the comparative analysis of the performance of the single microstrip patch antenna with a 2×2 microstrip patch antenna array. The feeding method used for the single microstrip patch antenna is coaxial feeding. These results shows that the antenna performance of the array is improved in terms of gain, directivity, HPBW, s-parameter, VSWR and the radiation efficiency for the resonating frequency of 2.44 GHz as compared to the single microstrip patch antenna.

Ekke Vaishali R and P. L. Zade, (2014), The AMC structures are used to design low profile antenna with high gain, minimum size and larger band width required for communication system. The authors use FR4_ epoxy as dielectric substrate to design a 4 x 1 microstrip patch antenna array using HFSS simulation software. By
introducing vias gain does not get influenced, but cross polarization level is lowered by 5.35 dB. The observed return loss parameter with AMC shows resonance frequency at 2.604 GHz and 2.773 GHz.

Mike W. K. Lee, et al (2014), In this article, method for miniaturizing a chip antenna is presented in this communication. It uses a folded meander line and therefore the length is half. Also, two upper and lower loading patches are used to improve the performance of the chip antenna. The chip antenna has been miniaturized to 3.2x1.6x0.83 mm$^3$ at resonance measured frequencies of 2.45 GHz and 2.73 GHz with and without external matching, respectively. An economic fabrication method for the chip antenna is discussed. It uses an inexpensive multilayer PCB with two low-cost prepregs and a common laminate. Only two plated-through holes are needed for the whole design. Good agreement between the simulated and measured results is observed. Two capacitive loading patches have been used in our design to lower the resonant frequency. The upper loading patch also has the role as a blocking patch to solve the coupling problem existed between the upper and lower meander line parts. This is important when the meander line is folded. If the upper patch is not used, the coupling between the upper and lower meander lines would become significant.

Ferdows B.Zarrabi, et al (2014), This article represents a triple band Microstrip slot antenna with SRR shape ring. The prototype antenna is designed and fabricated for wireless communication like IEEE 802.11(g/b/a), WIMAX and GPRS application. In this paper presented a SRR structure which most famous in metamaterial and SIW structure before this. With presented structure we design a tripple band Microstrip antenna for wireless application with high gain and shown the effect of SRR structure and compare this with slotring antenna. The bandwidths are around 5.1% for 1.93GHz (1880-1980), 35.4 % for 2.75 GHz (2400-3100 MHz) and 28% for 5.7GHz (4900-6500MHz). It has enough gain and sufficient performance for wireless communication and here shows that ring and SRR parasitic elements are useful for antenna miniaturization and multi band design structure .The paper also shows the effect of parasitic elements on antenna gain and current distribution.

Mukesh Kumar Khandelwal, et al (2014), in this paper a circular shaped defect is embedded in the ground plane and antenna is stacked by a circular patch with air gap. Dual band characteristic is achieved at 2.55 GHz and 5.25 GHz with a
compactness of 36%. The proposed structure is stacked using a dielectric super state with air gap. The antenna resonates at two frequencies 2.55 GHz and 5.25 GHz with compactness of 36% and antenna is a suitable choice for WiMAX and WLAN applications. The circular patch is covered by a dielectric super state and compactness is improved to 38.3% with antenna resonating at 2.45 GHz and 5.10 GHz with gain of 6 dBi and 7.2 dBi, respectively.

Hassan Sajjad, et al (2014), The design of a rectangular microstrip line-fed patch antenna array with a centre frequency of 3.8 GHz for WiMAX and Unmanned Air Vehicle (UAV) applications. The antenna was fabricated using Rogers Duroid RT-5880 substrate with a dielectric constant _e of 2.2 and a thickness of 1.574 mm respectively. The array antennas were measured in the laboratory using Vector Network Analyser (VNA). The single microstrip antennas performance was then improved in terms of directivity and gain by comparing it with 1 × 2 and 2 × 2 array structures. The array antennas outperformed the single antenna in terms of directivity, and gain. However the side lobes level was too high (> −10 dB) to be used as conformal antennas. the performance of the array antenna met the desired requirement in terms of return loss. The simulation return loss was equal to −18.2 dB at the centre frequency of 3.8 GHz. The maximum directivity and gain achieved for 2 × 2 array antenna was 13.5 dB and 13.2 dB respectively.

Anshika Khanna, et al (2014), The intended design has an impedance bandwidth of 85.42% around the resonant frequency of 1.844 GHz. This antenna can be simultaneously used for Bluetooth, WLAN and WiMAX applications. IE3D Zeland simulation software has been used for the simulation of the proposed design. a probe fed gap-coupled modified square fractal microstrip patch antenna has been designed to overcome the constraint of narrow bandwidth of the conventional patch antenna. This antenna has a VSWR of 1.029 and a return loss of _36.89 which are noticeable results. This antenna, with a gain of 3.31 dB and an antenna efficiency of 97.56%, is simultaneously applicable for Bluetooth (2.4e2.48 GHz), WLAN (2.4e2.484 GHz specified by IEEE 802.11 b/g standards), Mobile WiMAX (2.5e2.69 GHz specified by IEEE 802.16e standards), and WiMAX (3.4e3.69 GHz specified by IEEE 802.11a standards) applications.

Muzammil Jusoh, et al (2014), In this paper, a beam reconfiguration is achieved by using four p-i-n diode switches where the effect of switching technique on the
overall element performance is investigated numerically and experimentally. The proposed antenna has achieved excellent realized gain levels at all configuration scenarios with a minimum value of 7 dBi. The antenna design is based on the principles of the common Yagi–Uda antenna. The main driven circular patch is surrounded by several parasitic circular patches, and four p-i-n diode switches are used to short/open the parasitic patches to ground. The operating bandwidth ranges from 2.36 to 2.39 GHz.

R.Jothi Chitra, et al (2013), This paper represent microstrip patch antenna adopts the partial ground planes and Rogers Duroid 5880 substrate is used which is having low dielectric constant, thereby provides good bandwidth. Using Ansoft HFSS the simulated results are presented and evaluated with and without slit. With the use of E-slot and slit the proposed antenna excites dual resonance and achieves wide bandwidth. The proposed antenna also achieves good radiation performance and good impedance matching in lower and middle band of WiMAX. The antenna also satisfies the optimum value of return loss and VSWR in both lower and middle band. Due to its compact size it can be used in handheld and portable devices.

Ahmed Khidre, et al (2013), Two radiation beams off broadside are obtained by operating the patch antenna at the higher order TM 02 mode instead of the fundamental TM 01 mode, which radiates a broadside beam. Broadening the antenna bandwidth is achieved by using the U-slot technique. The antenna analysis is carried out with the aid of full wave simulation, and an antenna prototype is fabricated and measured for validation. The antenna operating frequency range is 5.18–5.8 GHz with VSWR less than 2, which corresponds to 11.8% impedance bandwidth. It exhibits two radiation beams, directed at 35° and -33° with 7.92 dBi and 5.94 dBi realized gain, respectively at 5.5 GHz. The antenna has 11.3% bandwidth (5.17–5.81 GHz) and exhibit dual radiation beams. The beams are directed around ± 35° at the center frequency, and both beams’ squint is less than 4° within the antenna bandwidth. The proposed design is a desirable candidate for stationary terminals of various indoor wireless communication networks.

Sika Shrestha, et al (2013), In this article, Among various antennas, microstrip patch antennas are widely used because of their low profile, lightweight, and planar structure. Conventional patch antennas are rectangular or circular in shape, but variations in their basic design are made for different purposes. This paper begins
with an explanation and discussion of different designs, put forward with an aim of miniaturization, harmonic rejection, and reconfigurability. Finally, microstrip patch structured rectennas are evaluated and compared with an emphasis on the various methods adopted to obtain a compact rectenna, harmonic rejection functionality, and frequency and polarization selectivity. The development of rectennas for wireless power transmission and space solar power transmission has achieved great success in implementing specific functions and applications, such as RFID tagging systems, sensor batteries or capacitors, WLANs, WiMax, and cognitive radio systems, and also in medical applications. Among various antennas used in rectenna, microstrip patch antenna is chosen for the evaluation and comparison because of its simplicity and easy fabrication. Various forms of microstrip patch antenna different from the conventional shape are analyzed with the explanation of the modification made in the design to obtain reduced size, harmonic rejection functionality, and reconfigurability in polarization and frequency.

Reza Karimian, et al (2013), In this paper the antenna structure consists of both open ended and short-ended slots connected by a metal “via” to a microstrip line. A quad-band F-shaped slot antenna, suitable for MIMO applications, is presented. The proposed antenna operates at the following frequency bands: 2.28–2.66, 3.35–3.65, 5.07–5.3, and 5.75–5.85 GHz. The antenna elements are orthogonal to each other, and a cross slot is cut in the ground plane. Current density and parametric study show that the proposed antenna allows independent adjustment or tuning of each frequency of interest within certain limits. The measured -parameters and radiation patterns show that the antenna can be used for MIMO applications.

Liang Xu, et al (2013), In this article a novel triple-frequency fork-shaped antenna for WLAN/WiMAX applications is proposed and investigated in this paper. The presented antenna is simply composed of three radiating elements viz. Stub1, Stub2, Stub3. By adjusting the lengths of the three stubs, three desired resonant frequencies can be achieved and adjusted independently. Experimental results show that the antenna impedance bandwidths for S11 ≤ -10 dB are 2.4{2.65 GHz, 3.3{4.05 GHz, and 5{5.98 GHz, covering the 2.4/5.2/5.8 GHz WLAN bands and 2.5/3.5/5.5 GHz WiMAX bands. Furthermore, nearly omni-directional radiation patterns over the operating bands have been obtained.
M. A. Soliman, et al (2013), In this paper, 4G smart planar dual-band phased array antenna suitable for fourth generation (4G) Long Term Evolution (LTE) at 3.5 GHz and also Wireless Local Area Network (WLAN) at 5 GHz systems is developed. The proposed planar array antenna is built using a microstrip rectangular U-slotted patch antenna element. Single element and linear sub-arrays with 1 x 2 and 1 x 4 dimensions of this element are designed, fabricated, and measured by the same authors. Separate feeding technique is used for each element of the smart planar array antenna; such that full beam-shaping can be achieved by steering the pattern main-loop to different angles in both azimuth and elevation directions with different amplitudes. Beam steering up to ±22 degrees can be achieved in both azimuth and elevation direction at 60 degree phase shift without the presence of any grating lobes. At this value of phase shift, the gain is 22.62 dBi without changing in the mutual coupling. This is also suitable for 4G Multiple-Input Multiple-Output (MIMO) wireless mobile applications with reduced power consumption. Design simulation and optimization processes are carried out with the aid of the Agilent Advanced Design System (ADS) electromagnetic simulator that uses the full-wave Method of Moment (MoM) numerical technique.

Stuti Srivastava, et al (2013), this paper represents the increase in bandwidth of a microstrip antenna using a duo triangle shaped probe-fed patch. The main aim of the paper is to obtain a wideband microstrip antenna with reduced size. The dual bandwidth of 7.68% and 36.56% covering the range from 1.745-1.884GHz and 2.229-3.226 GHz has been achieved with maximum radiating efficiency of about 90%. Structure. These are compatible with MMIC designs and are mechanically robust when mounted on rigid surfaces. Using PCB technology here, it is easy to install an antenna with embedded circuit board for any system. Microstrip Patch antennas are well suited in satellite, missile and aircraft application, radars, biomedical applications and reflector feeds. Also compatible for embedded antennas in handheld wireless devices such as cellular phones and pagers etc. Practically we must have finite ground plane and it can be obtained such as the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness. The thickness of the substrate is h=1.6mm (with operating frequency, f₀= 2.72 GHz). A dual wide band probe fed duo-triangle-shaped patch antenna is simulated & designed on substrate of dielectric constant 4.4 and operating on the
frequency below 3 GHz.

Wanchen Yang, et al (2013), In this letter, a new edge-fed patch antenna element using artificial magnetic conductor structures (AMCs) is proposed. The AMCs are employed as the antenna magnetic ground plane for bandwidth enhancement and radiation gain improvement of patch antenna. Meanwhile, the ground plane below the feed line is raised, the height of substrate is reduced, so the feed line width would be narrow to avoid the spurious radiation. In addition, it has been particularly found that the height and number of the AMCs have a specific impact on performances of antenna with AMCs. On the basis of antenna element design, a 2x2 array with AMC techniques is also proposed. Compared to the dual-thickness-substrate antenna and cavity-backed antenna in the previous literature, the antenna element and array with the AMCs have wider bandwidth and higher-gain performances. The simulated and measured results both demonstrate significant improvements. The antenna element exhibits 11.76% bandwidth and high gain of 9.36 dBi; the 2x2 array achieves 20.45% impedance bandwidth and high gain of 15.95 dBi. To further demonstrate the validity of the proposed strategies, a 2 2 antenna array is also designed. The simulated and measured results indicate that the proposed antenna and 2x2 antenna array exhibit better performances, including wider bandwidth, higher gain, and lower cross polarization.

Pooja Prakash, et al (2013), In this paper a polarization-insensitive dual-band artificial magnetic conductor (AMC) structure is designed and experimentally verified. It consists of a planar array of annular ring-slot loaded rectangular patches. Details of the proposed structure and origin of the two bands is discussed. Through simulations and measurements, it is shown that the structure is insensitive to polarization of the incident wave. The tuning of the higher AMC band is demonstrated by varying the capacitance of the annular slot through its width variation. The designed AMC is used as a reflector for a wideband monopole patch antenna. It is shown experimentally at the antenna frequencies in the AMC band that the gain of the antenna improves by almost 10 dB and front-to-back ratio is improved by 15 dB. a simple structure for significantly improving the gain of a single-monopole patch antenna that otherwise is low. Coplanar waveguide (CPW) is used to excite the patch to minimize the radiation from feedline.
Sangkil Kim, et al (2012), In this letter, a novel electromagnetic band-gap structure (EBG) with single-ring resonators is inkjet-printed on the commercially available photo paper using conductive nano-silver ink. The printed EBG array is placed above a copper sheet, forming an artificial magnetic conductor (AMC) reflector at the designed frequency range (2.4 2.5 GHz). A microstrip monopole antenna is backed with the designed AMC reflector and is tested in free space and in contact with a human phantom. The antenna gain of a conventional microstrip monopole on human phantom is as low as 9 dBi. The gain of the proposed AMC backed monopole, measured on a human phantom is 0.95 dBi. The measurements demonstrate superior performance of the proposed monopole with EBG array compared to a conventional microstrip monopole antenna when they are considered for wearable applications. microstrip monopole antenna, backed with an inkjet-printed EBG array and a metallic copper sheet, is proposed. The combination of an EBG array and a metal layer effectively forms an artificial magnetic conductor (AMC) reflector at the designed frequency band of 2.4 2.5GHz, and consequently isolates the radio system from the human body effect, alleviating the common on-body antenna performance degradation. The proposed antenna with the integrated AMC reflector has very low profile (0.025×2.45 ) and improved gain. Free-space and on-phantom measurements for S11, radiation pattern, and gain were conducted to verify the antenna’s performance. The measured 10-dB bandwidth covers the whole frequency range of the IEEE 802.15 standard. At the same time, the reported gain increase of 8.44 dBi for the antenna on phantom indicates that the monopole antenna with EBG array is a very good candidate for wearable electronics applications.

R. lothi Chitra, et al (2012), this paper represent antenna comprising two rectangular planar patch elements each embedded with two L shaped slots. For the proposed antenna, the -10 dB return loss is achieved and it reach about -35 dB which covers some of the bandwidth specification of WLAN and WiMAX standards. Due the advantages such a slow cost, small size, low weight and capability to integrate in applications such as mobile phones and laptops the microstrip antennas are used.

M.F.Jamlos et al (2011), The antenna’s is fed from an aperture coupled structure while its radiating element is designed based on configuration of radial line slot array. An aperture coupled structure allowed the feeding line to be incorporated with
Radio Frequency switches for the proposed antenna to capable beaming the radiation with divisive and single-sided radiation pattern. The 4 aperture slots leaned at 45° angle of aperture-coupled structure with circular arrangement of radiating surface contributed to the significant effects in dropping the size of the proposed antenna. The antenna can afford a divisive pattern which is wider value of HPBW covering from -85° to 85° compared to -80° to 80° of single-sided radiation pattern. The proposed antenna which considered as a small antenna would be significantly appropriate for appliance of WiMAX and radar technology.

Jorge R. Costa, et al (2011), In this paper covering several wireless communication services from 2.4 to 4.8 GHz, that is especially designed to enhance MIMO system capacity. The array topology provides both spatial and polarization diversity. Despite very close packing of the array elements, these exhibit very low mutual coupling and low cross-polarization, greatly favoring MIMO diversity gain. The proposed CXETS antenna array, with its very low coupling between the closely packed array elements and with its pure linear polarization characteristics, is shown to clearly enhance the known benefits from using space and polarization diversity in MIMO systems, when compared to commonly used antennas, like the array of patches. The large operating bandwidth from 2.4 to 4.8 GHz with stable radiation characteristics allows using the CXETS array for multisystem access points covering services like WiFi, WiMax, LTE and UWB.

Vinod Kumar Singh, et al (2011), This paper presents the dual wideband microstrip antenna which is designed using stacking configuration to give a better bandwidth as compared to single layer substrate design. The designed slotted stacked patch antenna can operate in the Wimax,(2.2-3.4 GHz) WLAN (2.40–2.48GHz), and UMTS II (2.50–2.69GHz) frequency band giving a maximum bandwidth of 37.95%. The feeding technique used in the design is the coaxial probe feed and the impedance matching and radiation characteristics of the structure are investigated using MOM based IE3D. The proposed stacked microstrip patch antenna achieves a good bandwidth of 37.95% at 10 dB return loss covering the range from 2.27 GHz to 3.33 GHz. making it suitable for WIMAX and WLAN applications.

R. L. Li, et al (2009), A triple-band unidirectional coplanar antenna is developed for WLAN/WiMax wireless applications. The triple-band planar antenna consists of a
top-loaded dipole for the 2.4-GHz band, two longer dipoles for 3.5-GHz band, and 2 shorter dipoles for the 5GHz band. The triple-band antenna is printed on a coplanar substrate. The antenna achieves a similar directional radiation pattern at all of the three frequency bands with gains of 7.5 dBi for the lowest band, 8.5 dBi for the middle band, and 9-10 dBi for the highest band.

J. L. Masa-Campos and F. Gonzalez-Fernandez (2009), In this paper a low profile double-layer polarizer structure is presented for planar patch antennas to obtain circular polarization in 3.5 GHz WiMAX band (3.4-3.6 GHz = 5.7% bandwidth). Each polarizer layer is composed of 45° tilted metallic strips on a printed circuit. A bandwidth widening is obtained due to a significant reduction of the distance between polarizer and patches. An array prototype has been manufactured, and an optimum broadband dual linear/circular polarization behavior has been achieved, although some undesired effects have been detected: high coupling and radiation asymmetry.

Xiaoxiang He, et al (2009), in this article, a novel high-gain, dual-band antenna covering IEEE 802.11a/b/g bands is presented in this letter for wireless local area network (WLAN) applications. The antenna is composed of a forklike monopole, a rectangular ring, and a miniaturized rectangular patch. The backside radiation of the antenna is effectively reflected back by a rectangular metal, so maximum gain with the values of 6.2 and 10.4 dBi are achieved in the lower and higher frequency band, respectively. The return loss, radiation pattern, and the critical design parameters are also investigated in detail. Simulated and measured results verify that the presented antenna is a good solution for dual-band WLAN long-distance communication applications.

Joseph Costantine, et al (2009), In this paper the radiating elements in this antenna are composed of rectangular slots following a Chebyshev distribution of order 10 around a center rectangular slot, and an additional triangular slot. The new idea behind this design also includes the insertion of rectangular slots following a Chebyshev distribution around a central rectangular slot, in addition to a triangular slot inserted into the triangle, which has the same area as the rectangular patch using only one single feed, represented by a 50 SMA connector, where the position has been optimized.
Diego Caratelli, et al (2006), in this paper a wideband E-shaped microstrip patch antenna for wireless communications is presented. Zig-zag slots and perturbations of the L-shaped metallic patch are employed to excite two resonant modes and achieve a wide-band frequency behavior, featuring a fractional bandwidth of about 30%, and, at the same time, to meet the occupation volume requirements of mobile wireless local-area network enabled communication devices. A locally conformal finite-difference time-domain numerical procedure has been employed to analyze the radiating structure. Numerical results concerning the antenna parameters are in good agreement with experimental measurements.

Chi-Lun Mak, et al (2005), In this paper a technique employing the use of parallel feeds is applied to the recently proposed L-probe coupled patch antenna design. By employing only two L-probes, with proper separation, for feeding one single patch, a twin-L-probe coupled patch antenna is designed with both high-gain (10 dBi) and wide-band [25%, standing wave ratio (SWR) < 1.5] characteristics. In addition, the 1-dB-gain bandwidth is around 26%, which covers the impedance bandwidth. A high gain of 10 dBi is achieved across the wide operating band of 25% (SWR< 1.5) since the 1-dB-gain bandwidth is 26%. Antenna array can be designed using the proposed antenna element to further increase the gain, which is suitable for mobile communication applications such as base station antenna and other high-gain antenna designs.

Raul R. Ramirez et al (2000), in it an analysis is presented for a microstrip-feed proximity-coupled ring antenna and a four-element array. Interactions between the embedded microstrip feed and the radiating element(s) are rigorously included. Results demonstrate that circular polarization of both senses can be achieved with a ring antenna with proper design of two inner stubs located at angles of ±45 with respect to the feed line. Theory and experiment demonstrate an axial ratio 3-dB bandwidth of 1% and the voltage standing wave ratio (VSWR)<2 bandwidth of 6.1%. The axial ratio bandwidth is typical for a microstrip antenna with perturbations, while the VSWR bandwidth is larger than for the circular or rectangular patch with perturbations. A mutual coupling study between two elements shows that the axial ratio is less than 2 dB for interelement spacing greater than 0.55 eff, while the VSWR<2 for all spacings considered. A comparison between theory and experiment is provided for a 2x2 element array. The axial ratio and VSWR
bandwidths are both increased to 6.1% and 18% for a four-element array. A single- element antenna with two orthogonal feeds to provide both senses of polarization is demonstrated. The ring antenna is small (D/\lambda_0 =0. 325), the substrate thickness is thin (H/\lambda_0 ~ 0.035), and the microstrip feed produces a completely planar antenna system, which is compatible with microwave and millimeter integrated circuits (MICs), and monolithic microwave integrated circuits (MMICs). The mutual coupling effects on AR and VSWR between elements in a two-element array were presented. Dual polarization with one antenna element using two independent orthogonal feeds was also presented. The stub ring antenna element thus promises to be a viable candidate for circularly polarized array applications. The axial ratio and VSWR responses for the case of main beam scanning off broadside will be further investigated.