CHAPTER 2

REVIEW OF THE PAST WORK

The development of microstrip antenna technology began in 1970's. Historical development of the experimental and theoretical studies on microstrip antenna during the last few decades is explained in this chapter. The relevant research works in the field are reviewed with emphasis given to bandwidth enhancement techniques.
2.1 Development of microstrip antennas

The concept of microstrip antennas was conceived by Deschamp's [13] in 1953. In 1955, Gluton and Bassinot [14] patented a flat aerial that can be used in the UHF region. Lewin [15] studied the radiation from discontinuities in strip line. However, serious attention was given to this element only in the early 1970's. The first microstrip radiator was constructed by Byron [17] in the early 1970's. It was a strip radiator of several wave lengths long and half wave length wide and fed at periodic intervals using coaxial connectors. Howell [18] in 1972, designed basic rectangular and circular microstrip patches. Munson [19] in 1974 demonstrated a new classes of microstrip wrap around antenna suitable for missiles using microstrip radiator and microstrip feed networks on the same substrate.


Mathematical modeling of microstrip antenna was first proposed by Munson [19] and Derneryd [23-24] by applying transmission line analogy. This gives an approximate explanation of the radiation mechanism and provides the expressions for the radiation fields, radiation resistance, and input impedance. Radiation mechanism of an open circuited termination was studied by James and Wilson [25]. They observed that the terminal plane region is the dominant radiating aperture.

Agarwall and Bailey [26] suggested the wire grid model for the evaluation of microstrip antenna characteristics. Here the radiating structure is modeled as a fine grid of wire segments. This technique is useful for the design of microstrip antennas of different geometries.

Long et al. [27-28] measured the driving point impedance of a printed circuit antenna consisting of a circular disc separated by a dielectric from a ground plane.

Ker [29] investigated the rectangular and circular patches with a central diagonal slot. He obtained polarized radiation with a very good axial ratio. The bandwidth obtained was nearly 2%.

Newman et al. [30-31] proposed the method of moments for the analysis of microstrip antennas. They used Richmond's reaction method in connection with the method of moments for the calculation of unknown surface currents flowing on the walls forming the microstrip patch, ground plane and magnetic walls.

A more accurate mathematical cavity model was suggested by Lo et al. [32-34] for the analysis of microstrip antennas. In this model, the upper patch and the section of the ground plane are located below it, is joined by a magnetic wall under the edge of the patch. The antenna parameters for different geometries with arbitrary feed points can be calculated using this model. The effects of radiation and other losses are introduced in terms of either an artificially increased substrate loss tangent [34] or by employing the impedance boundary conditions.

Caver and Coffey [35-37] proposed the modal expansion model, which is similar to cavity model. The patch is considered as a thin cavity with leaky magnetic walls. The impedance boundary conditions are imposed on the four walls and the stored and radiated energy were calculated in terms of complex wall admittances.

Hammer et al. [38] developed an aperture model for radiation field calculations of the microstrip antenna. This method accounts radiation from all the edges of the patch and gives the radiation fields and radiation resistance of any mode in the microstrip resonator antenna.

Mosig and Gardiol [39] developed a vector potential approach and applied the numerical technique to evaluate the fields produced by microstrip antennas of any shape.

Microstrip disc has been analyzed by Derneryd [40] by calculating the radiation conductance, antenna efficiency and quality factor associated with circular disc antenna.

Alexopolus et al. [41] developed a dyadic Green's function technique for the calculation of the field radiated by a Hertzian dipole printed on a grounded substrate.
The circular microstrip antenna was rigorously treated by Butler [42]. He solved the problem of central fed circular microstrip antenna by treating patch as a radiating annular slot, in which the radius of the outer ring is very large. Butler and Yung [43] analyzed the rectangular microstrip antenna employing this method.

Mink [44] developed a circular microstrip antenna, which operates at a low frequency compared to a circular patch antenna of the same size.

Electric probe measurements on microstrip were proposed by J.S Dahelle and A.L. Cullen [45]. By this method the field of microstrip is determined using a field probe.

Shen [46] analyzed the elliptical microstrip patch and proved that the radiation pattern from this antenna is circularly polarized in a narrow band when eccentricity of the ellipse is small.

R.Chadha and K.C Gupta [47] developed Green’s function of circular sector and annular sector shaped segments in microwave planar circuits and microstrip antennas.

Lo and Richard [48] applied the perturbation model approach to the design of circularly polarized antenna. Critical dimensions needed to produce circularly polarization from nearly circular patches were determined by trial and error method.

Newman and Tulyathan [49] analyzed microstrip patch antennas of different shapes using moment method. The patch is modeled by surface currents and dielectric by volume polarization current.

Schaubert et al. [50] was reported a method for controlling the operating frequency and polarization of microstrip antennas. The control is achieved by placing shorting posts within the antenna boundary.

A full wave analysis of a circular disc conductor on printed substrate backed by ground plane was presented by Araki and Itoh [51].

Chew and Kong [52] analyzed the problem of circular microstrip disc antenna excited by a probe on thin and thick substrate. Here the unknown current was solved by vector Hankel Transform.

Itoh and Mentzel [53] suggested a method for analyzing the characteristics of open microstrip disk antenna. This method provides a number of unique and convenient features in analytical and numerical phase.

Kuester et al. [54] suggested a thin substrate approximation applied to microstrip antennas. The formulae suggested by them were found to be useful in simplifying the expression for the antenna parameters considerably.

Microstrip antenna covered with a dielectric layer was proposed by Bahl et al. [55]. They suggested an appropriate correction for the calculation of resonant frequency of a microstrip antenna coated with protective dielectric layer.

2.2 Broadband Microstrip Antennas

The narrow bandwidth available from microstrip patch antenna is recognized as the most significant factor limiting the applications of this class of antennas. Some of the researchers world wide are working towards overcoming this inherent disadvantage.

Hall et al. [56] reported the concept of multilayer substrate antennas to achieve broader bandwidth. These antennas constructed on alumina substrates which gave a bandwidth of 16 times that of a standard patch antenna with an increase in overall height.

C. Wood [57] suggested the use of circular and spiral microstrip lines as compact wide band circularly polarized microstrip antennas.

C.Wood [58] suggested a method for doubling the bandwidth of microstrip patch antennas by locating capacitively excited λ/4 short circuit parasitic elements at their radiating edges.

Derneryd and Karlsson [59] have made a broad band microstrip antenna by using thicker substrates of low dielectric constant.

Pandharipande and Verma [60] suggested a new feeding scheme for the excitation of patch array which gave broader bandwidth. The feeding network consists of a strip line power divider using hybrid rings and the coupling from strip line to feed point is achieved by thin metal probe.
Poddar et al. [61] has obtained an increase in bandwidth of microstrip antenna constructing the patch antenna on a stepped wedge shaped dielectric substrate.

Das and Chaterjee [62] reported a conical microstrip antenna with much larger bandwidth than that of an identical circular patch antenna. The conical patch antenna is obtained by modifying the circular patch antenna by slightly depressing the patch configuration conically into the substrate.

Sabban [63] reported a stacked two layer microstrip antenna with an increase in bandwidth of 15%. This antenna has been used as an element for 64 element Ku band array.

Long S A et al. [64] described that cylindrical dielectric cavity resonator can effectively be used as an antenna.

Bhatnagar et al. [65] proposed a stacked configuration of triangular microstrip antennas to obtain larger bandwidth.

Girish Kumar and K. C. Gupta [66] described two configurations for bandwidth enhancement of microstrip patch antennas. One of these configurations uses two additional resonators which are gap coupled to the non radiating edges of rectangular patch, whereas in the second case four additional resonators are gap coupled to the four radiating edges of a rectangular patch.

Hori and Nakagima [67] designed a broadband circularly polarized microstrip antenna for public radio communication system.

A microstrip antenna with double bandwidth has proposed by Prior and Hall [68], by the addition of a short circuited ring to a microstrip disc antenna.

C.K. Aanandan and K.G Nair [69] developed a compact broad band microstrip antenna configuration. The system uses number of parasitic elements which are gap coupled to a driven patch element. By using this technique they acquire an impedance bandwidth of 6% without deteriorating the radiating characteristics.

Bhatnagar et al. [70] has obtained a large bandwidth in triangular microstrip antennas using two parasitic resonators directly coupled to the non radiating edges and a third one gap coupled to the radiating edge.

T. Huynh and K.F. Lee [71] has described a coaxially fed single-layer wideband microstrip antenna in the form of rectangular patch with a U-shaped slot. The antenna attained an impedance bandwidth of 10 - 40%.

L. Gaireffret et al. [72] proposed an efficient method for bandwidth enhancement by coupling a CPW line fed slot to a microstrip antenna. This antenna has a large bandwidth with high gain and low cores polarization levels.

S.D Targonski et al. [73] presented a wide band aperture coupled stacked patch microstrip antenna. This has the capability of operating over a bandwidth in excess of 50%.

M.Deepu Kumar et al. [74] developed dual port microstrip antenna geometry for dual frequency operation. This antenna has wide impedance bandwidth and excellent isolation between ports.

Kin-Lu and Wen-Hsiu Hsu [75] designed a broad band triangular microstrip antenna with a U-shaped slot. It consists of a foam substrate of thickness ~0.08λ0, a slotted triangular microstrip antenna.

Kin-Lu Wong and Jian-Yi Wu [76] designed a circularly polarized square microstrip antenna fed along a diagonal with a pair of suitable chip resistors. This antenna provided a wide bandwidth for circular polarization about two times that of a similar design with a pair of shorting pins.

K.P Ray and G. Kumar [77] presented the experimental investigations on a hybrid circular microstrip antenna. The geometry constitutes circular patches with different radii with a small gap between them. Shorting strips of different widths are used to adjust the coupling between the central fed patch and two parasitic patches, yielding dual band, triple band and broad band operations.

K.M Luk et al. [78] designed a proximity fed stacked circular disc antenna with an impedance bandwidth of 26% and gain of 8dBi. The essential feature of this design is the presence of four linear slots in the bottom patch of the stacked arrangement.

Chih-Yu Huang et al. [79] presented a compact rectangular microstrip antenna enhanced gain and wider bandwidth. The compact antenna is obtained by
loading a high permittivity superstrate layer and a 1Ω chip resistor. This design has an operating bandwidth of six times that of conventional patch antenna.

Y.Kim et al. [80] designed a wide band microstrip antenna with dual frequency dual polarization operation. A parasitic element is stacked above the fed element for widening the bandwidth. The measured bandwidth at 15dB return loss at dual frequencies are 9.02 and 12.4 & respectively.

C.L Mak, et al. [81] designed a proximity coupled U-slot microstrip antenna with an impedance bandwidth of 20%. The antenna has an average gain of 7.5 dBi and cross-polarization of about ~20dB.

A novel broad band probe fed rectangular microstrip antenna with a pair of toothbrush shaped slots embedded close to the non radiating edges of the patch is presented by Jia-Yi Sze and Kin-Lu Wong [82]. An antenna bandwidth as large as ~2.6 times that of a conventional rectangular microstrip has been obtained.

Shyh-Ting Fang et al. [83] presented a broad band antenna by embedding a pair of properly–bent narrow slots in an equilateral triangular microstrip patch, broadband operation of microstrip antenna can be achieved with an inset microstrip line feed, and the proposed design has an impedance bandwidth as large as ~ 3 times that of a corresponding simple triangular microstrip antenna.

K.M. Luk et al. [84] investigated an L-shaped probe fed broadband rectangular microstrip. It consists of a foam layer with a thickness of around 10% of the wavelength is used as the supporting substrate. The proposed antenna has an impedance bandwidth of 35% and an average gain of 7.5 dBi.

K.M. Luk et al. [85] designed a rectangular U-slot patch antenna proximity fed by an L-shaped probe using a foam layer of thickness of ~7 % of the wavelength as supporting substrate.

Kin-Lu and Jen-Yea Jan [86] proposed a broad band design for a circular microstrip antenna with reactive loading integrated with a circular patch. Using this method bandwidth of ~3.2 times that of a conventional circular microstrip antenna has been achieved.

Y.X Guo et al. [87] presented a broad band U-slot circular patch antenna with L-probe feeding with a foam layer of thickness ~0.1λ0 supported substrate. An impedance bandwidth of 38% and gain of 6.8dBi have been achieved.

L-probe proximity fed short circuited quarter wave length patch antenna is presented by Y.X.Guo et al. [88]. The antenna provided an impedance bandwidth of 39% and a gain of >7dBi.

R.B Waterhouse [89] developed a stacked shorted patch antenna for broadband operation. This proposed antenna has an impedance bandwidth greater than 30%.

Lakhdar Zaid et al. [90] designed a dual frequency broadband antenna with stacked quarter wave length elements. The structure offers two modes with different radiation characteristics with a bandwidth of 30% for a VSWR<2.

W.K. Lo et al. [91] proposed a circularly polarized circular patch microstrip antenna with a cross slot using an L-shaped probe fed by a microstrip line. With single L-probe, the impedance bandwidth, axial ratio bandwidth and gain bandwidth are 27, 3.47 and 26% respectively.

Kin-Fai Tong et al. [92] developed a broad band U-slot rectangular microstrip patch antenna on microwave substrate. The dielectric constant of the substrate is 2.33. The antenna has achieved a maximum impedance bandwidth of 27%. They presented the theoretical analysis also.

Sean M. Duffy [93] described a bandwidth enhancement design technique for electromagnetically coupled microstrip antennas by utilizing a tuning stub. Using this method the bandwidth of a conventional proximity coupled antenna is increased from 4.8 to 8.4 % and the bandwidth of a stacked aperture coupled antenna is increased from 27.5 to 34.5%.

Jia-Yi Sze and Kin-Lu Wong [94] demonstrated a novel bandwidth enhancement method of microstrip antennas by loading a pair of right angled slots and a modified U-shaped slot in a rectangular microstrip patch. They have achieved a bandwidth as large as about 2.4 times that of a corresponding unslotted rectangular microstrip antenna.
J.S Baligar et al. [95] presented a novel microstrip antenna consisting of a stacked annular ring coupled to a shorted circular patch. This new geometry offers a large bandwidth, higher gain and lower cross polarization levels.

Y.W Jang [96] described a cross shaped microstrip line fed slot antenna of large bandwidth. The antenna offers a bandwidth of 98.95%.

Wen–Hsiu Hsu and Kin-Lu Wong [97] designed a new circular patch antenna with an impedance bandwidth greater than 25% and a peak antenna gain about 8.3 dBi. The circular patch antenna has a thick air substrate and pair of wide slits are cut in the circular patch to facilitate the antenna's impedance matching. The circular patch is supported by a conducting post, which is also connected to a 50Ω microstrip feed line.

M.D Van Wyk and K.D Palmer [98] described a novel single layer rectangular patch antenna using a coupled line feed. This coupled line matching technique increases the bandwidth of the patch antenna by a factor of more than 2.5 times as compared to the normal edge fed patch with the same geometrical dimensions.

Yong-Xin Guo et al. [99] designed and studied a broad band single layer annular ring microstrip antenna fed by an L-shaped probe. It achieved, for the TM_{11} an impedance bandwidth of about 33% and a maximum gain of 7.5 dBi, and for the TM_{12} mode 27% bandwidth. A foam layer substrate of thickness around 10% of the operating wavelength in free space is used as the supporting substrate.

Yong-Woong Jang [100] presented a wide band T-shaped microstrip fed printed slot array antenna. This antenna is fabricated on a substrate having permittivity 4.3 and thickness 1mm. The antenna offers a bandwidth of approximately 53.9% for return loss less than or equal to -10dB. The bandwidth of the twin slot is ~1.06% larger than that of single slot antenna.

Yong-Woong Jang [101] proposed a new structure of an aperture coupled T-shaped patch microstrip fed triangular patch antenna, which has a similar radiation properties, with an advantage of being smaller than the aperture coupled rectangular antenna or microstrip slot antenna. The antenna has a bandwidth of 44.5%.

Y.X Guo et al. [102] developed wide band T-probe proximity fed regular circular and compact semicircular antennas. For the regular circular patch antenna, using a foam thickness ~0.13λ_0 as a supported substrate an impedance bandwidth of 35% and a gain of over 8 dBi have been obtained. For the semicircular patch antenna, an impedance bandwidth of 56% and a gain of over 4.5 dBi are achieved with the same substrate.

A.K. Shackelford et al. [103] presented a small size probe fed notched patch antenna with a shorting post. The area of the patch has been reduced to 94% with a bandwidth of 13.2%.

Fa–Shian Chang and Kin–Lu Wong [104] proposed a novel broad band design of probe fed patch antenna suitable for applications in DCS cellular system base station. The antenna has a thicker air substrate for broad band operation, and is fed by a probe feed with a short probe pin, which is connected through a triangular conducting patch to one of the patch's radiating edges.

Yong-Woong Jang [105] developed a wide band double T-shaped microstrip line fed slot antenna. The antenna offers a bandwidth of 114% (VSWR<2).

B.L. Ooi et al. [106] investigated the characteristics of a novel rectangular patch with an offset F-shaped probe. The patch height is approximately 9% of the designed wave length. An impedance bandwidth of 36% and an average measured gain of approximately 5dBi are achieved for the first dominant mode. For the higher order mode the impedance bandwidth extends to 64% and provides an average gain of 3dBi.

Y.X Guo et al. [107] designed a wide band L-probe fed shorted triangular patch antenna. Using a foam layer of thickness ~0.13λ_0 as a supported substrate, an impedance bandwidth of 61% (SWR<2) and a gain of over 4dBi have been obtained.

Yong-Xin Guo et al. [108] presented the design of L-probe proximity fed patch antenna. An impedance bandwidth of 30% and an average gain of 7.5 dBi have been achieved for the design. They also presented the FDTD analysis of the L-probe fed antenna.