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Microstrip Patch Antenna: A Survey

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Abstract: *The sizes and weight of various wireless electronic system have rapidly reduced due to the development of modern integrated circuit technology. A Microstrip antenna (MSA) is well suited for wireless communication due to its low profile, conformal nature, light weight, low cost of production, robust nature and compatibility with microwave monolithic integrated circuits (MMICs) and optoelectronic integrated circuits (OEICs) technologies. In this paper the complete discussion is focused on the working principles, limitations and the applications of microstrip patch antenna.*
Keywords: *Patch Antenna, feed types, parameters, broadband techniques.*

I. Introduction

The field of antenna engineering has a history of 80 years. An antenna is the primary component in a wireless communication system. With the development of MIC and HF semiconductor devices, microstrip and printed circuit have drawn the maximum attention of the antenna community in recent years.

Microstrip Antenna was first introduced in 1950s. However this concept to wait for about 20 years to be realized after the development of printed circuit board (PCB) technology in 1970s. Microstrip antenna found application in different fields due to its compact size, they have widely engaged for the civilian and military application such as radio- frequency identification (RFID), broadcast radio, mobile system, vehicle collision avoidance system, satellite communications, surveillance system, direction finding, radar systems, remote sensing, missile guidance and so on. In spite of various attractive features the microstrip element suffers from an inherent disadvantage of narrow bandwidth and low gain. In microstrip antenna researcher a new trend or solutions are found where the researcher try to improve bandwidth by introducing different structures within the antenna geometry.

II. Microstrip Patch Antenna

Microstrip patch antenna are one of the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well [1], [2], [3]. Patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h, with relative permittivity and permeability ε_r and μ_r.The metallic patch may be of various shapes rectangular, square, triangular etc. The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as a cavity with perfect electric conductor on the top and the bottom surfaces, and a perfect "magnetic conductor" on the sides. When the antenna is get excited at a certain resonance frequency, a strong electric field generates on the surface of the patch that is essentially z directed and independent of the z coordinate. The patch cavity modes are described by a double index (m, n). By considering rectangular patch as shown in a fig.1. (b), having cavity mode (m, n), the electric field become:

$$E_Z(x,y) = A_{mn}\cos\left(\frac{m\pi x}{L}\right)\cos\left(\frac{n\pi y}{W}\right)$$

Where L is the patch length and W is the patch width.

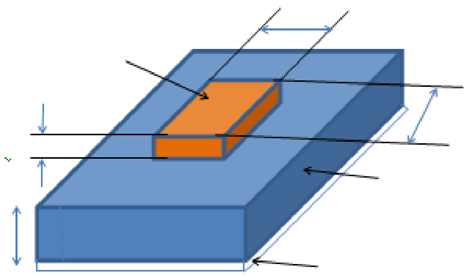

Fig.1. (a)

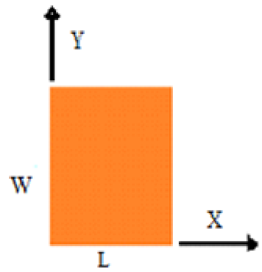

Fig.1. (b)

A strong surface current produce due to strong electric field on the bottom of the metal patch that is x directed, operated in the (1, 0) mode is given by:

$$J_{\delta x}(x) = A_{10}\left(\frac{\frac{\pi}{L}}{j\omega\mu_{0\mu_r}}\right)\sin\left(\frac{\pi x}{L}\right)$$

For this mode the patch may be regarded as a wide microstrip line of width W, having a resonant length L that is approximately one-half wavelength in the dielectric. The current is maximum at the centre of the patch, x=L/2, while the electric field is maximum at the two "radiating" edges, x=0 and y=l .in patch antennas the width W is usually chosen to be larger than the length (W=1.5L is typical) to maximise the bandwidth, since the bandwidth is proportional to the width.

III. Type of Feed

Brief descriptions of each of the common feed techniques are presented in the following section.

3.1 Coaxial Feed

In this configuration the inner conductor of a coaxial connector extends through the substrate and is connected to the radiating patch while the outer conductor is connected to the ground plane. The location of the feed pin is selected to provide the best impedance match. This method is easy to fabricate but it suffers from small bandwidth and the spurious radiation. Thicker substrates can increase surface wave and generate a high cross polarized field [4].

3.2 Edge Feed

In this configuration a conducting strip is connected directly to the edge of the microstrip patch. This type of feed arrangement has the advantage of being photo etch processed along with the patch itself thus reducing manufacturing cost.

3.3 Aperture Coupled

In this configuration a ground plane is sandwiched between two layers of the substrate material, separating the radiating patch. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane which is usually cantered under the patch [5].

Aperture coupled elements have been demonstrated with bandwidths up to 10-15% with a single layer [3], [6], [7] and up to 30-50% with a stacked patch configuration [8]-[10].

3.4 Proximity Coupled

In this configuration the whole antenna consists of a grounded substrate where a microstrip feed line is located. Above this material is another dielectric layer with a microstrip patch etched on its top surface. The power from the feed network is coupled to the patch electromagnetically, thus creating an alternative to the shortcomings of the contacting feeding techniques.

In contrast to the direct contact methods, which are predominantly inductive, the proximity-coupled patch's coupling mechanism is capacitive in nature. The difference in coupling significantly affects the obtained impedance bandwidth, thus, bandwidth of a proximity-coupled patch is inherently greater than the direct contact feed patches [11].

IV. Fundamental Specification of Microstrip Patch Antenna

There are number of parameters require to specify the performance of patch antenna.

4.1. Polarization

The plane wherein the electric field varies is known as the polarization plane. Microstrip antenna basically shows two types of polarization, namely linear and circular.

The linearly polarized patch shows the variation of electric field only in one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch. The one main trouble with linear polarization is the orientation of the antenna is variable or unknown.

The circularly polarized patch antenna presents an attractive solution over linear polarization, provides more flexibility in the angle between transmitting and receiving antennas, reduces the effect of multipath reflections, enhances weather penetration and allows for the mobility of the transmitter and the receiver [12], [13], [14].

Single fed circularly polarized microstrip antennas are considered to be one of the simplest antennas that can produce circular polarization [15]. Several techniques were used to achieve circular polarization in single fed microstrip antenna.

One of the basic perturbation techniques to achieve circular polarization is truncate corner of patch antenna. Thus circular polarization using such technique can be achieved by building a patch with two resonance frequencies in orthogonal directions and using the antenna right in between the two resonances at f0, as shown in a fig (2).

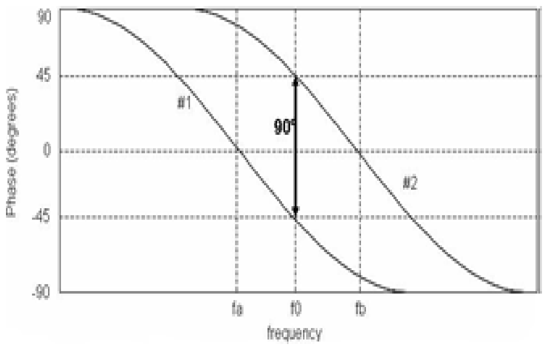

Fig.2.

There are two modes that should be strongly excited with a 90 phase difference. This technique is widely used in GPS antennas [16].

4.2 Matching of Microstrip Lines

A matching network must be implemented on the feed network, in order to minimize reflections, thereby enhancing the performance of the antenna.

Matching of microstrip transmission lines is done by matching each line to the source, its interconnecting transmission lines, and to the edge of the patch antenna. The patch antenna edge connected to the transmission lines is given an inset to match the radiating edge impedance of the patch antenna to the characteristic impedance of a transmission line. The characteristic impedance of a transmission line of a microstrip fed patch is designed with respect to the source impedance.

The characteristic impedance Zo of the transmission line with respect to the source impedance Zs is,

$$Zo = nZs$$

Where the factor n is the number of twigs emanating from a node connected to a source.

In most microstrip patch antennas the feed line impedance is 50 ohm, whereas the radiation resistance at the edge of the patch is on the order of a few hundred ohms depending on the patch dimension and the substrate used.

The characteristic impedance for a single, duplex and quadruple antenna, illustrate in fig (3) is 50, 100 and 200 ohms respectively.

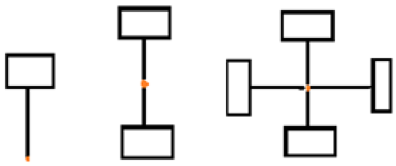

Fig.3. (a) Single antenna, **(b)** duplex antenna and **(c)** quadruple patch antenna.

The characteristic impedance of the transmission line therefore depends on the source impedance as well as the number of the patch antenna. Good impedance matching provides maximum power transfer and hence better radiation characteristic.

4.3 Radiation Efficiency

The radiation efficiency is defined as the ratio of power radiated in to space to the total input power, which is the sum of power dissipated by conductor loss, power dissipated by dielectric loss and surface wave radiation. The radiation efficiency of the patch antenna is affected not only by conductor and dielectric losses, but also by surface wave excitation.

As the substrate thickness decreases, the effect of conductor and dielectric losses become more severe, limiting the efficiency, whereas the surface wave excitation limiting the efficiency due to mutual coupling between element in an array that cause undesirable edge diffraction at the edge of the ground plane or substrate, which often contributes to distortions in the pattern and to back radiation. The phase velocity of surface wave strongly dependent on the dielectric constant and thickness of the substrate. The excitation of a surface wave in a dietetic slab is baked by ground plane has been well studied (Collin, Field Theory of Guided Wave).

By using thicker substrate with proper coupling or feeding scheme radiation efficiency of patch antenna can be improved.

4.4 Bandwidth

One of the important parameter of microstrip patch antenna is Bandwidth. The bandwidth of the antenna is defined as the range of frequencies, over which the performance of the antenna with respect to some characteristic conforms to a specific standard.

Several definition of bandwidth exist, are discussed below-

4.4.1. Impedance Bandwidth/Return Loss Bandwidth

The impedance bandwidth of microstrip patch antenna is defined as the impedance variation with frequency of the patch antenna element results in a limitation of the frequency range, over which the element can be matched to its fed line. Impedance bandwidth is usually specified in terms of a return loss or maximum SWR (defined in terms of input reflection coefficient) typically less than 2.0 or 1.5 over a frequency range.

4.4.2. Radiation Bandwidth

The radiation bandwidth of MSA is defined as the frequency range over which the radiating power is within 3 dB of the incident power and the radiation pattern is essentially the same, well studied in [17].

4.4.3 Polarization Bandwidth

This is the frequency range wherein the antenna maintains its polarization.

The major limitation of microstrip patch antenna is narrow bandwidth but, today wireless communication systems require higher operating bandwidth. Such as about 7.6% for global system for mobile communication(GSM; 890-960 MHz), 9.5% for a digital communication system(DCS; 1710-1880MHz), 7.5% for a personal communication system(PCS; 1850-1990 MHz) and 12.2% for a universal mobile communication system(UMTS; 1920-2170 MHz) [18]. To achieve these required bandwidths many technique are used and some of them are explained in this paper.

V. Bandwidth Enhancement Technique for Microstrip Patch Antenna

Narrow bandwidth available from printed microstrip patches has been recognised as one of the most significant factors limiting the wide spread application of this class of antenna.

5.1 Modified Shape Patch Broadband Microstrip Patch Antenna

In this technique bandwidth enhancement is done by changing/modifying the shape of radiating patch. It is found that some shapes of patches lower q factor as compared to other therefore having high bandwidth [18]. These patches shapes include annual ring, rectangular/square ring, shorted patch and other geometries. There are several designs of MPA with modified patches provide improve range of bandwidth as:

1) Diamond shaped slot patch: Bandwidth achieved is 13.58%when compared with conventional circular patch [19].
2) T slot rectangular patch: Impedance bandwidth of 25.23% with average gain of 7.43dBi is obtained [20].
3) U shaped slot with single layer single patch: Air substrate of 12mm is used to yield bandwidth of 27.5% [21].
4) E-h shaped patch: Yielded bandwidth is about 27% [22].

5.2 Planner Multiresonator configuration of Broadband Microstrip Patch Antenna

In such configuration of MSA multiple resonators are placed near to each other , only one is fed and other are parasitically coupled, it is also known as gap coupling. Another way used to feed multiresonator configuration is to directly connect the patches via microstrip line. In some cases hybrid coupling is also used which include gap and direct coupling [23]. Some multiresonator configuration are-

1) Shifted parasitically coupled multiresonator configuration: Improves impedance bandwidth from 65 MHz to 251 MHz (about four times) with minor variation of resonance frequency from 2.989 GHz of reference patch to 3.023 GHz [24].

2) Gap-couple multiresonator and stacked configuration: Yielded bandwidth of 25.7% with more than 10dB gain [25].

3) Directly coupled and parasitic configuration: Impedance bandwidth of 12.7%(365MHz) is obtained, which is 6.35 times when compared with the simple patch i.e. 2% (54 MHz) at same centre frequency of 2879 MHz [26].

5.3 Multilayered Configuration of Broadband Microstrip Patch Antenna

In multilayered configuration, patches are placed over different dielectric substrate and they are stacked on each other. Based on the coupling mechanism, these configurations are of two types electromagnetically-coupled or aperture-coupled. Electromagnetic coupled MSA one or more patches are located on different dielectric layers. Patch dimension and dielectric constant of substrate may be different whereas resonant frequency is closer to each other for obtaining broad bandwidth. In aperture coupling, the field is coupled from the microstrip feed line placed on the other side of the ground plane to the radiating patch through an electrically small aperture /slot in the ground plane. Some multilayered configurations are as-

1) Multilayered configuration of patches: Nearly 70%of bandwidth can be generated by using multilayered configuration of radiating patch [27].

2) Dual frequency stacked patch with reactive loading: Bandwidth enhancement factor is 22.3 and 18.7 for 1.524 GHz resp, which is further 12% and 15% for their respective bands [28].

5.4 Stacked Multiresonator Configuration of Microstrip Patch Antenna

In this configuration multiresonator and stacked configuration are combined to provide broadband MPA, some are as-

1) Gap-coupled planner multiresonator and stacked configuration: Provides bandwidth of 25.7% with more than 10 dB gain [25].

2) Stacked U-slot microstrip antenna incorporating E shape and modified half shape radiating patch configuration: Maximum impedance bandwidth of 60.2% can be obtained by this configuration [29].

VI. Applications of Microstrip Patch Antenna

The microstrip patch antennas are famous for their performance and robust design. Microstrip patch antennas have applications in various fields such as in the medical field, satellites and even in the military system just like in the rockets, aircrafts, missiles and many more. Some of these applications are discussed as below-

6.1 Global Positioning System Application

Microstrip patch antennas having high permittivity sintered substrate material for global positioning system (GPS). These antennas are circularly polarized, very compact.

6.2 Radar Application

Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna system, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas.

6.3 Mobile and Satellite Communication System

Mobile communication requires small, low profile, low cost antenna. Microstrip patch antenna meets all the necessities and a number of microstrip antenna have been designed for use in mobile communication system. In case of satellite communication, circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed point.

6.4 Radio Frequency Identification

RFID used in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8GHz depending on its application.

6.5 Patch Antenna for Medical Application

It is found that in the treatment of malignant tumors the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should posses light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the microstrip radiator for including hyperthermia was based on the printed dipoles and annular rings which were designed on S-band. And later on the design was based on the circular microstrip disk at L-band.

6.6 Reduced Size Microstrip Patch Antenna for Bluetooth Application

In this, the microstrip antenna operates in the 2400 to 2484MHz ISM band. Although an air substrate is introduced, microstrip antenna occupies a small volume of 33.3x6.6x0.8 mm3.

VII. On-Going Project on Microstrip Antenna

7.1 Study and optimization of Microstrip Antenna System to receive satellite link moving trains.
7.2 Development of a super heterodyne microwave interferometer and Langmuir probe system for the purpose of low-pressure continuous plasma condition monitoring (Funded by IRPA).
7.3 Development of 2.3 GHz two beam microstrip phased array antennas using 2 bits phase shifter (Funded by UNITEN).
7.4 The stacked ultra-wide band antenna: Development and application in wireless PAN (Funded by Ministry of Science under eScience).
7.5 Development of a 2.4 GHz microstripline educational trainer set for the purpose of imparting high frequency microwave technology tp student, scientist and engineer (Funded by IRPA).

VIII. Conclusion

The research motivation of this project is to well observation of microstrip patch antenna. The technological advancement of the microstrip antenna is increasing day by day. A lot of research work is going on microstrip antenna for its better utilization in the future. Many techniques are used for compensating the gain and bandwidth of the microstrip antenna, all are discussed in this paper. The survey shows that the microstrip antenna is one of the light weighted, compact size antenna that can be used for number of application.

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