ANALYTICAL REVIEW ON GAIN AND BANDWIDTH ENHANCEMENT TECHNIQUES OF MICROSTRIP PATCH ANTENNA

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Abstract— Now a day, the study of microstrip patch antennas has made great progress. If we compare conventional antennas with microstrip patch antennas, then these antennas have more advantages and better prospects, such as they are low volume, smaller in dimension, light in weight, ease of fabrication. Microstrip patch antennas can provide, feed line flexibility, beam steering & Omni-directional patterning, dual polarization, circular polarizations, dual-frequency operation, frequency agility, broad band-width as well. Because of this microstrip patch antennas of all shapes are widely used in different communication systems. However, microstrip antennas have some limitations like low bandwidth due to surface wave losses and low gain when used in conventional form. Being easy to fabricate, low volume and inexpensive microstrip patch antenna is widely used for wireless communication applications. But disadvantages like low gain, narrow bandwidth, etc. limits the performance of microstrip patch antenna. This paper depicts various techniques to overcome limitations of microstrip patch antenna. So this paper focuses on the enhancement of such gain and bandwidth which are reported in literatures.

Keywords— *Microstrip antenna, Gain, Array, Partial gnd and Dielectric, bandwidth etc.*

I. INTRODUCTION

As per IEEE Standards antennas define (IEEE Std 145 1983) "as a means for radiating or receiving radio waves". Initially, microstrip antennas were developed only for space communication, but today due to their advantageous nature they are used in government applications as well as in commercial applications [30-31]. Dielectric material is sandwiched between metallic patch and larger metallic sheets of ground plane and these antennas are developed. Different types of Patches are available in various configurations such as circular, square, rectangular, dipole etc. but out of all these only circular and rectangular patches are mostly preferred for wireless applications, because these provide very low cross polarization radiation. These antennas are developed by using metallic patch and grounded substrate. Following Fig 1.1 shows structure of microstrip antenna

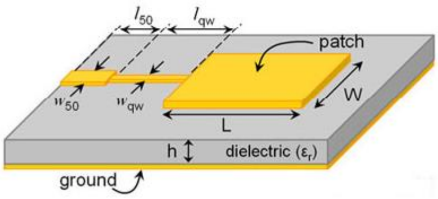

Fig 1: structure of Microstrip antenna

These antennas are easily integrated with microwave integrated circuits and when a particular metallic patch is selected then it is very desirable in terms of higher impedance, resonant frequency and polarization since it is preferred for wireless applications [30-32]. So aim of this paper is to review on different techniques of bandwidth enhancement as well as gain enhancement of microstrip antenna.

Need of higher Bandwidth & Gain for microstrip antenna: Basically the analysis of antenna is based on two important parameters i.e. Gain & Bandwidth. The directivity of the antenna depends on antenna efficiency and directional capabilities of antenna. This antenna directivity is correlated with the Gain of antenna.

As we know the microstrip antenna has a low profile, narrow bandwidth due to surface wave losses, lower gain, but today the development of wireless communications need higher bandwidth and gain. These communication systems require higher gain and higher bandwidth to operate in broad frequency band in order to provide high speed communication. By using various techniques bandwidth & gain of microstrip antenna is improved, which are as follows.

II.GAIN ENHANCEMENT TECHNIQUES OF MICROSTRIP PATCH ANTENNA

1) Change in shape

i*) C shape slotted microstrip patch antenna for wireless system*

This type of antenna [1], design offers low profile, high gain and compact antenna element. The maximum gain is 7.31541 dBi at 2.31610 GHz, antenna and radiation efficiency are more than 95.5319% and bandwidth is 50% from 1GHz to 3GHz. This antenna is suitable particularly for wireless communication application such as Wi-Fi. Return loss 17.2610 can be achieved by using C shape slot on the patch. The antenna bandwidth is 50% from 1GHz to 3GHz and gain is 7.31541dBi. In comparison to simple microstrip rectangular patch antenna, slotted antenna is better because it gives maximum bandwidth. The gain of single patch antenna is 4.22dBi. By adding side parasitic patch, the bandwidth of antenna can be improved upto 375%. The air surveillance radar antenna works from 2.8 to 3.1 GHz band. The S-parameter has a fractional bandwidth of 10%. For the single element absolute gain is 5.57 dBi with very high gain and Dual band return loss at very low frequency. So this antenna is better than the simple microstrip rectangular patch antenna [2].

ii) Gain enhancement of v-slotted triangular shaped microstrip patch antenna for WiMax applications

A V-slotted triangular shaped microstrip patch antenna is presented with enhanced gain for Wi-max applications. The microstrip patch antenna is very popular because of its ease of analysis, low cost, light weight, easy to feed and attractive characteristics. With impedance bandwidth 210MHz, the return loss is below −10dB from 3.54 GHz to 3.75 GHz. The antenna is compact and thin which makes it easily portable. A maximum gain of 7.29dB is achieved at 3.66GHz frequency. The VSWR found to be less than 2 within the operating frequency range. This antenna achieves good impedance matching, stable radiation patterns and high gain. [3]

2) Change in dielectric material

i) Gain enhancement in microstrip patch antennas by replacing conventional (fr-4 and Rogers) substrate with air substrate

Here for gain enhancement we have simply modified the shape of patch such as rectangular, circular and triangular. With respect to each patch they use different substrate materials and observe gain values and compared with each other as tabulated. The patches geometries of these three were investigated theoretically and reasonable values of resonant frequency return loss and gain are examined and compared.

Table 2: Comparisons of patch distribution

Patch Design	Substrate and Gain			
	FR-4	AIR	ROGERS	AIR
Rectangular patch	5.62	9.5	6.07	9.60
Triangular patch	5.5	9.0	5.89	8.89
Circular patch	5.59	9.18	5.97	9.73

ii) Superstate structure

A new single-sided meta surface superstrate-loaded dual band patch antenna on a high permittivity ceramic-filled bio plastic sandwich-material substrate was designed and analyzed for bandwidth and gain enhancements. Based on the measurement results, improvements in the bandwidth and gain were realized. The measured gain improved from 2.12 dBi to 3.02 dBi and from 4.10 dBi to 5.28 dBi in the lower band and upper band. The MSS-integrated antenna exhibits a more directional radiation pattern compared to the patch antenna along with the addition to bandwidth and gain enhancements. A parametric analysis of MSS element sets and ground plane length of the patch antenna was conducted. [5].

Table1.Performance parameters of antenna with MSS and without MSS

Sr no	Parameters	Antenna with MSS		Antenna without MSS	
		Lower Band	Upper Band	Lower Band	Upper Band
1.	Bandwidth	18.8%	23.2%	13.3%	14.8%
2.	Gain	3.14 dBi	6.12 dBi	2.15 dBi	4.69 dBi
3.	Directivity	0.58 dB	6.20 dB	−0.48 dB	2.89 dB

iii) Partial removal substrate

The effects of partial removal substrate on the performance of microstrip patch antenna are investigated to explore an effective yet simple way to enhance the gain of antenna. The aim is to improve gain of a microstrip patch antenna by suppressing surface waves and reducing dielectric loss through partial substrate removal surrounding the antenna. We use this method as open air cavity since the removed substrate can be a large portion. The design with different substrate removals are studied numerically and verified experimentally. As per experimental observation it has been seen that by suppressing surface waves and reducing dielectric loss, the gain of the microstrip patch antenna, especially with high permittivity has been improved up to 2.3–2.5 dB when the substrate surrounding and radiating edges of patch antenna have been fully or partially removed. Meanwhile, the E-plane mutual coupling between the two identical patch antennas at a distance of half operating wavelength has been reduced by 6.9 dB. Therefore, this method is capable of improving gain and maintaining mechanical robustness of patch antennas.[6]

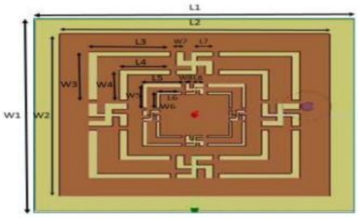

Fig 4: fractal antenna model

3) Hybridization technique

1. *Gain enhancement in microstrip-feed patch antenna using metallic ring*

We know that EM waves are scattered and incident on interface that have small dimensions as compared to the incident EM wave [7]-[8]. Due to this concept there is improvement in the performance of microstrip patch antenna in terms of gain. This interface is created By placing metallic ring around the radiation patch. By using defective ground plane the surface waves are scattered from metallic ring and converted into space waves so in this proposed antenna design radiation in the lateral direction is reduced and surface wave losses are reduced [9] instead of solid ground plane. Therefore by metallic ring and defective ground structure surface wave losses are minimized and surface wave energy is converted into space wave energy. Thus surface wave losses are minimized and gain is enhanced in microstrip patch antenna. This microstrip-feed square patch antenna was designed using a FR-4 substrate (relative permittivity of εr=4.3) with thickness of h=1.6 mm and operating frequency of 5.8 GHz, with dimensions of square patch $L=W$=12.14 mm.[1] For antenna-1 we had achieved 4.7 dB gain and for antenna-2 we had achieved 9 dB gain at resonant frequency in the E-plane. So two-dimensional E-plane pattern shows there is enhancement in gain about 4.3 dB by using metallic ring as compared to square patch without metallic ring and solid ground plane. According to observation whenever metallic ring have higher intensity, antenna exhibits higher gain. The antenna-2 (patch with metallic ring) achieve average gain of 7.99 dB in the frequency range of 5.5–6 Hz and in the same frequency range square patch without metallic ring have average of 4.5 dB gain. Hence patch antenna with metallic ring have higher gain as compared to patch without metallic ring. [10]

2. Gain enhancement of a microstrip patch antenna using reflecting layer

This antenna is suitable for specific applications, such as security and military systems, which require a narrow bandwidth and a small size. This work is focused on increasing the gain as well as reducing the size of unidirectional patch antenna. This unidirectional antenna has higher gain and higher front to back ratio (F/B) than the bidirectional one. This is achieved by using a second flame retardant layer (FR-4), coated with an annealed copper of 0.035mm at both sides, with an air gap of 0.04 $\lambda 0$ as a reflector. By use of a dual substrate layer of FR-4 we will get gain of 5.2 dB with directivity of 7.6 dBi, F/B of 9.5 dB, and has impedance bandwidth of 2% and very low complexity −18dB return losses are achieved. Dual layer patch antenna.

Design	fr (GHz)	S11(dB)	G(dB)	D(dBi)	Sie(L×W×H)
First Stage	2.423	-7.85	2.22	6.340	55×60×1.6
Second Stage	2.411	-25.028	3.30	5.938	55×60×1.6
Proposed design	2.45	-28.028	5.4	7.747	55×60×8.37
Conventional	2.344	-12.617	3.11	5.02	40×40×1.6

Table 3: Design distribution

during fabrication. A unidirectional and low profile microstrip patch antenna of 0.069 $\lambda 0$ has been introduced. Second layer of FR-4, which is coated with copper, reduced the back lobe and enhanced the gain upto 5.4 dB as well as increased the directivity, upto 7.74 dBi with F/B ratio of 9.5 dB. This antenna shows flexibility during the optimization technique and simulation results are evaluated by measurements [11].

4) Microstrip antenna array

This section includes enhancement of gain using array configuration and rectangular shape micro strip patch antenna. Array configuration allows patches to be arranged in two different manners i.e. linear array configuration and phase order array configuration. In linear order, patches are arranged in a series manner while in phase order each radiating element (patch) is provided with a phase shifts of theta. Beams are formed after phase shift of theta through each radiating element. Many other works addresses the integrated problem of maintaining gap between patches, dimensions of antenna and location of feed line. To the best of our knowledge, the problem of maximizing gain and reduction in losses has not been addressed within the same global optimization process. In this paper, we address the optimal planning of arrangement of metallic radiating element on dielectric substrate. In our design, antenna parameter has improved using linear array configuration. By using array structure there is 97.89% increase in gain of RMPA.[13] In an array, there are five controls that can be used to shape the overall pattern of antenna. These are-

1. Structure of overall array (linear, circular, rectangular, spherical, etc.)
2. Relative displacement between the elements.
3. Excitation amplitude of individual elements.
4. Excitation phase of individual elements
5. Relative pattern of individual elements

The example of 4 element microstrip array is shown in figure:-

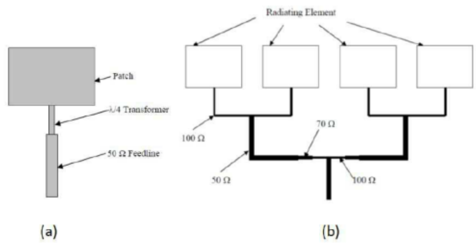

Fig 2 :(a) single array (b) array element structure

Table 4:Compare with array and without array

Sr.No.	PARAMETER	SINGLE PATCH	ARRAY
1.	Reflection coefficient(S11)	-29.5575	-38.7036
2.	VSWR	1.0688	1.0234
3.	Gain(IEEE)	2.8647	5.6692
4.	Gain (Abs)	7.970	8.709

III. BANDWIDTH ENHANCEMENT TECHNIQUES

Various techniques have been proposed to increase the bandwidth of microstrip patch antennas which may be classified based on:

1. Describing the Q-factor of patch by increasing the substrate height or lowering the dielectric constant.
2. Use of impedance matching networks.
3. Use of multiple resonators located in one plane.
4. Use of multi-layer configurations with vertically stacked resonator geometries.
5. with hybrid techniques.

1. Parametric change for reducing q-factor

The expression for bandwidth gives dependence of the Q-factor of microstrip antenna on its bandwidth. It may be observed that Q-factor, dependent mainly on radiation losses, is inversely proportional to height of the substrate (h) and directly proportional to the permittivity of substrate for the bandwidth of microstrip larger thickness substrates with lower dielectric constants. Bandwidths up to 15% may be obtained at the expense of an increase in antenna height. However such thick substrates are not desirable or practical because of the increase in probe inductance leading to input matching problems, increase in spurious feed radiation, excitation of surface waves and non-conformability to curved surfaces. Methods have also been explored to increase the bandwidth by introducing air-gap between the substrates and the ground plane in a microstrip patch antenna and thus changing the effective permittivity. All these methods are based on the concept of decreasing the resonator Q-factor.

2. Impedance matching networks

Microstrip antenna has narrow band impedance characteristics and its radiation pattern presents appreciable wide band characteristics. So, an entirely different approach of broad banding is made use of by employing the wide band impedance matching technique to reduce the return loss at the input of the resonant patch antenna. The impedance matching may be achieved with a reactive matching network designed by combining the transmission line model for the antenna with a suitable model of the microstrip-matching network. All the above technique are based on parametric changes and impedance matching networks have not yet succeeded in providing an optimum configuration for wide bandwidth microstrip patches to be used as line array element.

3. Multiple resonator configurations

Use of multiple resonant patches located in the same plane has been explored by several investigators. The principle used in these configurations is that the stagger tuned coupled resonators can yield wider frequency response similar to the case of multistage stagger tuned amplifier circuits. Although wide band designs extending to parasitically coupled arrays have been reported, the method suffers from two disadvantages that increase in physical area of the element and asymmetry observed in the radiation pattern with frequency.

4. Stacked multiple resonator configurations

In this approach broad banding two or more layers of dielectric substrates are used. Resonant patch radiators are stacked one above the other with intervening dielectric layers, sharing a common aperture area. Two layer configurations are very common, the two patches being of identical or of slightly different sizes offering dual resonant structures. Dual-band structures with dual resonant frequency characteristics have also been developed with stacked structures with and without air-gap. Although till today, convenient practical design and analysis procedures are not available, the vertically stacked multi-resonator configurations have become the most widely used broadband microstrip antenna elements, their general advantages being:
1. Sharing of a common aperture and thus compatibility with the array structure.
2. Stagger tuning resulting in increase in the bandwidth.
3. One of the multiple revenant frequencies and the polarization schemes.
4. Use of different substrates and Inter resonator spacing to meet with optimum needs. The disadvantages relate only to fabrication and mechanical concerns.

5. Hybrid techniques.

i) Defective ground structure

There are new concepts applied to distributed microwave circuits. One such technique is defected ground structure or DGS, where the ground plane metal of a microstrip (or strip line, or coplanar waveguide) circuit is intentionally modified to enhance performance. The name for this technique simply means that a “defect” has been placed in the ground plane, which is typically considered to be an approximation of an infinite, perfectly-conducting current sink. Of course, a ground plane at microwave frequencies is far removed from the idealized behaviour of perfect ground. Although the additional perturbations of DGS alter the uniformity of the ground plane, they do not render it defective. This is the most common application of DGS for antennas, as it can reduce side lobes in phased arrays, improve the performance of couplers and power dividers and reduce the response for both transmit and receive out-of-band signals. An interesting application combines the slot antenna and phase shift behaviours of DGS. An array can be arranged on a flat surface and illuminated by a feed antenna, much like a parabolic reflector antenna. The re-radiating elements introduce additional loss, but the convenience of a flat form factor is attractive for transportable equipment or applications where a low-profile is essential. [10]

2. Slot loaded Patch

As the simple Microstrip antenna has low bandwidth, one technique to improve this is done by cut a slot in the patch of half wavelength long at desired resonant frequency [17]. Slots are embedded in the printed patch. Their dimensions and positions are selected in order to the first two broadside-radiation modes of the patch be perturbed. This is done in a way that their resonance frequencies get close to each other to form a wide impedance bandwidth [18,19]. There are different types slots e.g. commonly used slot are u-slot, E-slot H-Slot etc.In [20] wideband u-shaped parasitic elements are incorporated into radiating edges of a rectangular patch. Antenna is fabricated on FR4 substrate shows an impedance bandwidth of 27.3%. In this type of antenna covers the triple band at LTE TDD No. 34 (2.0175 GHz), WLAN (2.45 GHz), and WiMax (3.5 GHz) bands. Resonance occurs in the parasitic patches due to the perturbation and electromagnetic coupling.

3 .Multilayer broadband MSA

Multilayer structure is more than one patch is stacked on substrate of different layer. The height of the antenna is increased but size in planner direction is remaining similar. Two types of coupling techniques are used in layered structure 1. Electromagnetic coupled MSA 2. Aperture coupled MSA [21]. Using multilayer structure yield impedance bandwidth of 114% [22] has been achieved. In [22] MSA has implemented using patch and parasitic radiating element on a stacked FR4 substrate. Parasitic patches are produced two resonances within central location of frequency band 3- 11 GHz. In this structure the additional c-slot is introduced in ground plane and then optimized with E-slot on the parasitic patch which enhances the bandwidth more. There are two types of electromagnetically coupled MSA bottom patch is fed with coaxial cable and upper patch is with the use of layered structure the parasitic patches are optimized to obtain the broad bandwidth [23-29]. The effect of the length of lower patch and upper patch in the stacked configuration is very important to remain the VSWR=2 circle. The value of air gap is chosen according to wide bandwidth and gain requirement. For different value of Δ (air gap) bandwidth is increase and decrease given in [30]. Another techniques to enhance the Microstrip antenna is aperture coupled MSA which yield a bandwidth of 70 %given in [31]. Advantages of such configuration are that patch is fabricated on the top patch that enhances the BW and feed line is at the lower substrate that reduces the radiation losses.

4. GAIN AND BANDWIDTH BOTH ENHANCEMENT METHODS:-

i) Bandwidth and gain enhancement of multiband fractal
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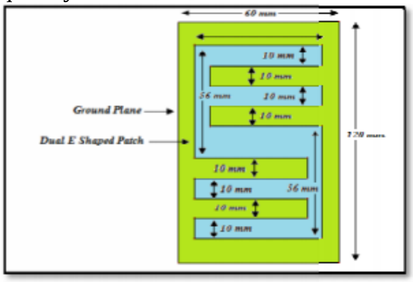
The Sierpinski carpet fractal antenna is capable of creating multiband frequencies. There are four resonant frequencies appearing at 0.85 GHz, 1.83 GHz, 2.13 GHz and 2.68 GHz. The simulated results show that return loss is more than -15 dB, VSWR is less than 1.3, directivity is more than 6 dBi, and gain is more than 6 dB [14]. Multiband property is achieved with multiple iterations. Gain is enhanced with multiple iterations. Bandwidth enhancement for multiple iterations is compared. So size of Antenna is reduced by using fractal shapes with multiple iterations.

2. Design and enhancement of gain & bandwidth of rectangular patch antenna using shifted semi- circular slot technique

Microstrip antennas are used in wireless communication applications. A rectangular patch antenna loaded with a semi-circular slot to operate at 5.25 GHz with moderate gain (about 8.53dBi), bandwidth (96.7 MHz) and a good matching (S11=24.13dB). We can enhance the gain value by changing the feed point position using some mathematical analysis. The proposed antenna design operates at a frequency of 5.25GHz and has the bandwidth of 96.7MHz (5.2011GHz -5.2971GHz). The IEEE 802.11ac is a standard under development which will provide high throughput in 5 GHz band. Both the feed probe positions and slot positions are varied to achieve an optimum bandwidth and gain. The Shifted slot increase the bandwidth by 33.82% and more gain is obtained 8.53dBi. The antenna also provides good matching with return loss (S11= -24.13dB) [15].

3. Design and development of dual e-shaped microstrip patch antenna for bandwidth and gain enhancement

A dual E-shaped antenna is designed by cutting four notches in rectangular shaped microstrip antenna. The simulation result shows good enhancement in bandwidth and gain which also shows that the designed antenna structure can work in three different frequency bands.[14]



Design of dual microstrip patch antenna

Those three frequency bands have bandwidth 6.85%, 6.98% and 38.94%. The antenna structure also provides a gain of 5.82dBi and antenna efficiency of 85%. [16]

5. CONCLUSION

Many researchers have analyzed different methods to improve gain & bandwidth of microstrip antennas. If gain & bandwidth of MSA is improved then it can be used in frequency range of 800-1200 MHz as well as in various wideband applications such as wireless local area network. But still there is scope for improvement of gain and bandwidth using different hybrid techniques. A detailed literature survey has been carried out and various techniques of enhancement bandwidth and gain antenna are presented in this paper. The future work includes selection of a specific antenna design use of software for simulations then a prototype will be built tested and measured to verify the performance and parameter requirement and aim to get bandwidth and gain enhancement with suitable technique.

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