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Review Article

Recent Era and Development of Multi-Band Microstrip Patch Antenna

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Abstract – Microstrip patch antenna is being studied by the researchers since last three to four decades as one of the standard planar antenna. Still, it has much room for further improvements. This paper represents methods to achieve the multi-band microstrip patch antenna using single or multi-element via stack or array & comparison of them. Methods will describes to obtain desired requirements such as wideband, high gain and miniaturization. This are the areas in which further research work can be done to enhance the experience of the wireless communication. For better understanding some recently developed antenna designs are described & compared here.

Index Terms – Dual-Band, Gain, Microstrip Antenna, Multi-Band, Multi-Element, Review Article, Review Paper.

1 INTRODUCTION

The concept of microstrip antenna was first introduced in the 1950s [1]. However, this idea had to wait nearly 20 years to be realized after the development of the printed circuit board (PCB) technology in the 1970s [2, 3]. Its structure is so simple that dielectric material is sandwiched between two conducting material, one side radiating patch and other side ground. Microstrip patch antenna are very popular due to its extraordinary advantages like light weight, low profile, planar configuration, ease of fabrication, suitable for arrays and stacked like structure and most promising easily mounted on any rigid surface [4]. They have been widely employed for the civilian and military applications such as television, broadcast radio, mobile systems, global positioning system (GPS), radio-frequency identification (RFID), multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, biological imaging, missile guidance, and so on [5].

This review article gives information about multiband microstrip antenna techniques and structure. Paper focuses on three of the most used techniques to obtain multiband antenna with higher gain.

2 LIMITATION AND ITS REMEDY

Having many advantages of microstrip antennas, they also have some disadvantages too. Like narrow impedance bandwidth, low gain and relatively large size.
To overcome this disadvantages many aspects and developments were discussed in some books [4-8]. Here author describing those problems and its possible solutions in brief.

- The problem of achieving a wide impedance bandwidth we can Use 1) Shorted patch with a thick air substrate. 2) Stacked shorted patches. 3) Embedding suitable slots in the antenna's radiating patch or in the ground plane are also described [6]. To improve the problem of an antenna gain, several designs like compact microstrip antennas with the loading of a high-permittivity dielectric superstrate or the inclusion of an amplifier-type active circuitry have been demonstrated [6].
- Even gain can be improved by stacked or array structure. In array, more than one element connected by the impedance matching network. And in stack method more than one element placed one on another separated by the dielectric material.
- Many techniques have been reported to reduce the size of microstrip antennas at a fixed operating frequency. 1) Shorting wall, 2) Shorting plate or partial shorting wall, and 3) Shorting pin. Even by taking narrow slits and slots at the non-radiating side of the patch or ground as well, reduction in patch size can be possible [6]. With a size reduction at a fixed operating frequency, the impedance bandwidth of a microstrip antenna is usually decreased. To obtain an enhanced impedance bandwidth, one can simply increase the antenna's substrate thickness or let say height to compensate for the decreased electrical thickness of the substrate due to the lowered operating frequency, or one can use a meandering ground plane or a slotted ground plane [6].

From this above discussion, we can conclude that the many methods are there to enhance the performance of the microstrip patch antenna. And all the parameters are dependent on each other. If we try to improve one parameter than another will get reduced. So as per our requirement in the application we will have to deal with this all parameters [7]. For an example on the expense of the bandwidth and gain we can design a compact microstrip patch antenna. Which is small in size but the gain and the bandwidth of this antenna is not so good.

3 MULTI-BAND TECHNIQUES

In today's fast forward world, there is a need of the antenna that can work on more than one operating frequency. That is, only one antenna is sufficient to serve the users, who need to be served for different applications. Now there is requirement of the multi-band microstrip antenna to overcome the problem of the multi-frequency radiation with high gain.

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There are many such methods by which we can design a multi-band or a multi-frequency antenna which are, 1) Slot, 2) Stub matching, 3) Multi-element (Array) 4) Stacked structure, 5) Shorting pins, 6) Single feed dual-band, 7) Dual feed dual-band, 8) Notch loaded, 9) Lumped element loading [8].
From this all methods we will discuss about three most used methods that are Slots, Array and Stacked. A brief idea about these all methods,

- In Slots/Slits loaded design we will make slots of the narrow dimensions at the edge of the patch. Now this will induced a second frequency from the edges of that slots/slits. The main patch will radiate at the lower frequency, and the open circuited slots edges will radiate with the higher frequency. But as we have discussed before that the improvement in one parameter is done to the expense of the other one. Same here, by taking slots/slits we reduce the total surface area of the patch. And by reduced patch area we will not obtain high gain.
- In Array type structure we will eliminate that problem of having low gain. By increasing the surface area of the patch. We will take a combination of the more than one element and connect it to the one single network. For achieving multi-bands as an output we will have to take slits and slots on a single element of the patch. And by combining that elements we will create an array to operate in multi-band with the high gain. To excite this type of the network we have to study the feed network or impedance matching network of the array structure. Here on the expense of the size we will improve the gain of the antenna.
- In Stacked type structure also we will eliminate the problem of the low gain. Similar to the array design, on the expense of the size we will get higher gain. But here instead of the length and width of the antenna, here the height of the antenna will get increase. Practical geometry of this design is, on a grounded substrate well put patches one by one on each other. They will be excited by the mutual coupling.

We will discuss some previously designed multi-band structure by methods explained above.

4 COMPARATIVE STUDY

In microstrip antenna research, researcher try to enhance antenna characteristics by applying different methods on the antenna geometry. Some recent work done using those different methods are presented.

4.1 Slot Method

The slotted method is most popular and simple design methodology of getting multi-band antenna design. In this method we itch slots inside the patch to operate in multi frequency with the advantage of reduced size.

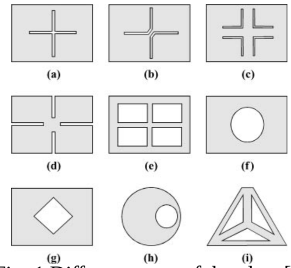

Fig. 1 Different types of the slots [6]

Slot loaded method can be done by using slots and slits. Slits are taken at the edge of the patch and the slot is taken inside the patch. Slits taken at the edge and Slots taken inside the patch resonates at the higher frequency, patch itself resonates at lower frequency [6]. The dimensions of the slots and slits are being taken by the antenna designer of his/her choice. But it has to follow the concept that is slots and slits has to be taken such that the length of the current flowing on the surface of the patch must be increase [6]. If the slots are taken by considering this concept the antenna design will resonates at the multi frequency.

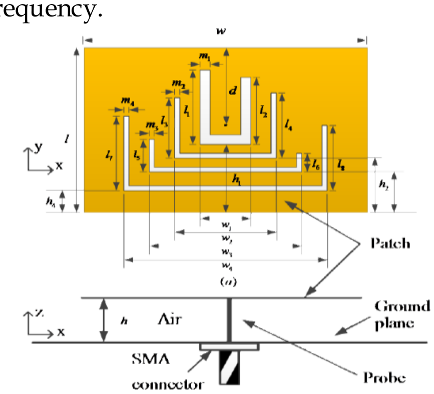

Fig. 2 Four band patch antenna [9]

By this method recently some researchers named Shuo Liu, Shi-Shan Qi, Wen Wu and Da-Gang Fand have introduced a design by taking Alphabetical U type of slots to operate in four band, high gain with linear polarization.

Here, they have taken four asymmetrical U-shaped slots in the single layer rectangular patch. A square shaped length of 50 mm has been taken. Coaxial probe is directly connected to the patch. Air was used as a dielectric medium whose dielectric constant is 1. And the design is simulated on HFSS software.
Design specification of the antenna is given in the table below.

TABLE 1
OPTIMIZED DIMENSIONS OF ANTENNA (MM) [9]

Parameter	Value	Parameter	Value
l_1	16	w_2	18
l_2	15	w_3	22.5
l_3	9.5	w_4	26
l_4	10	h_1	7
l_5	4.5	h_2	5
l_6	2	h_3	3

l_7	10.8	h_4	1
l_8	10	W	38
m_1	1.6	L	27.5
m_2	1	D	15.5
m_3	1	H	5
m_4	1	W_g	50
w_1	14.2	L_g	50

The strategy was to first design a U-slot patch antenna with broadband and then introduce the second U-slot to produce a notch at the central frequency, so that the total band can be divided into two sub-bands. Thereafter, the third and the fourth U-slots were introduced to produce two notches at the central frequencies of the two sub-bands so that the sub-bands can be divided into four bands as required. Like this way they have designed a four band microstip patch antenna with high gain. We have discussed that taking slots will give us the multi frequency operation on the expense of the gain, here higher gain is achieved because they have used air as a substrate. So the dielectric loss is low and we get higher gain compare to other substrate material.

Results

Simulation and measured results of this antenna design almost similar.

TABLE 2
SIMULATED AND MEASURED IMPEDANCE BANDWIDTH [9]

Frequency (GHz)	**Simulated** (%)	**Measured** (%)
3.35	2.0	2.1
3.70	3.3	3.3
5.20	4.5	7.1
5.80	5.0	5.0

All the center frequencies are corresponding to WiMAX and WLAN. Location of the U-slots doesn't affect the frequencies and they were chosen for having the best impedance matching. There are discrepancy between simulated and the measured S_{11} due to the fabrication and assembly errors.

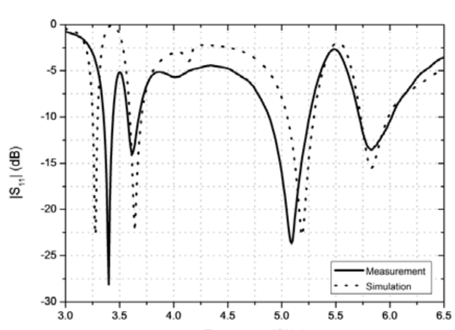

Fig. 3 Measured and simulated reflection coefficient [9]

The measured and the simulated results of the peak gain of the proposed antenna are shown in the figure below.

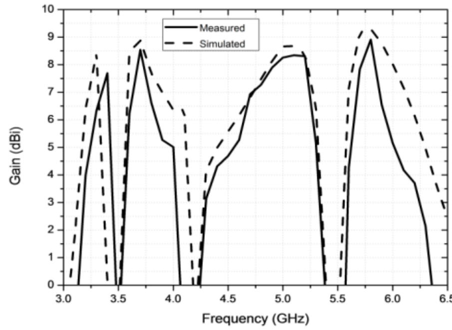

Fig. 4 Measured and simulated gain of the antenna [9]

It can be seen that the measured peak gains of the antenna is 7.6dBi, 8.6dBi, 8.5dBi, and 9.0dBi. To check the effect of the ground size on the antenna gain, they have taken same size of the ground and the patch as well.

4.2 Array Method

We can improve the performance of the antenna system by using array instead of the single element. We can enhance gain and directivity and some other parameters which are difficult to implement with the single element. Feeding of microstrip array antenna is by series-feed network or corporate feed network.

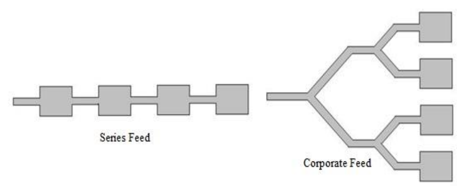

Fig. 5 Feed to array [10]

For enlarging the size of the antenna without changing the dimensions of the single element will create a bunch of the radiating elements. This new form of the multi-element structure is called array [6].

Each antenna in an array is called an element, it can be anything from simple dipole antenna, monopole antenna, horn antenna or microstrip antennas. Array structure of the microstrip antenna is used to improve the directivity, efficiency and gain. That is because radiation from one element will not give desired results we need to design array to overcome these drawbacks [10].

By applying this some researchers named Sai Ho Yeung, Alejandro García-Lampérez, Tapan Kumar Sarkar and Magdalena Salazar-Palma has designed array antenna which has one driven element which is directly excited by the power source other four elements will get energized by parasitic coupling. Substrate material used has 2.2 dielectric constant with 1.57 mm thickness.

Here, they have proposed two type of the dual-band array design.

Type 1

It has two stubs at the both sides of the rectangular patch to improve the impedance matching. This rectangular center patch is nothing but the driven element. Radiating elements designed in an E-shape are used. E-shape is made up by taking slots, this type of the element can generate more than one frequency.

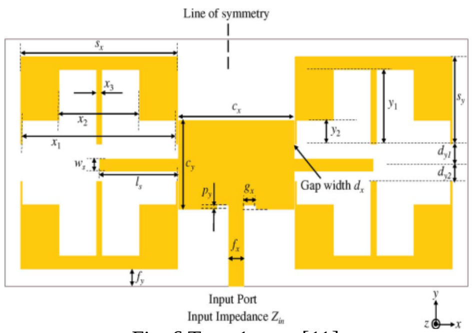

Fig. 6 Type 1 array [11]

Type 2

They have reduced the size of the radiating elements. From have taken half of the E-shape resulting in the smaller antenna design.

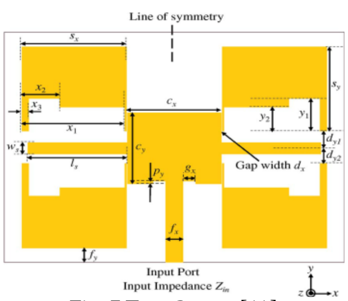

Fig. 7 Type 2 array [11]

TABLE 3
OPTIMAL DIMENSIONS FOR THE DUAL-BAND ARRAY TYPE-1 [11]

Dual-band Array Type-1				
Parameter	value		Parameter	value
c_x	36.99		s_x	50.20
c_y	25.57		s_y	25.18
f_x	4.89		d_x	0.25
f_y	5.00		d_{y1}	6.02
p_y	1.21		d_{y2}	4.71
w_s	3.50		g_x	3.80
l_s	25.22		x_1	49.20
y_1	21.40		x_2	25.71
y_2	6.73		x_3	1.75

TABLE 4
OPTIMAL DIMENSIONS FOR THE DUAL-BAND ARRAY TYPE-2 [11]

Dual-band Array Type-2				
Parameter	value		Parameter	value
c_x	26.87		s_x	29.99
c_y	24.71		s_y	29.33
f_x	4.89		d_x	0.22
f_y	5.00		d_{y1}	5.95
p_y	0.96		d_{y2}	5.32
w_s	3.97		g_x	3.67
l_s	28.43		x_1	29.49
y_1	11.31		x_2	10.90
y_2	8.38		x_3	1.94

Results

Simulated and measured return loss of the dual-band arrays are shown in the figure below.

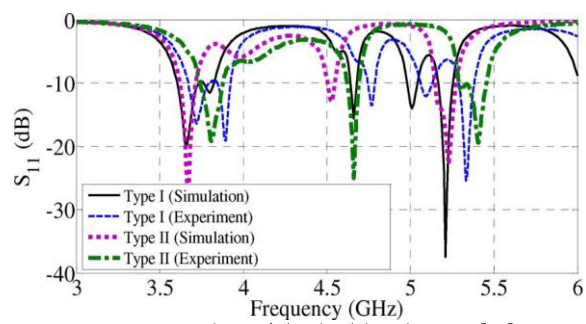

Fig. 8 Return loss of the dual-band arrays [11]

The measured return loss of the type-1 array is better than 10dB between 3.85-3.92 GHz (1.80%) and 5.29-5.38 GHz (1.69%). And for type-2 array it's been between 3.74-3.88 GHz (3.67%) and 5.29-5.45 GHz (2.98%).

Simulated and measured antenna efficiencies are,

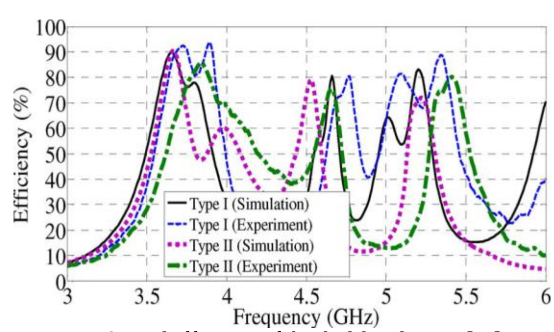

Fig. 9 Total efficiency of the dual-band arrays [11]

TABLE 5
ANTENNA EFFICIENCY FOR DUAL-BAND ARRAYS [11]

Type-1	
Frequency (GHz)	Efficiency (%)
3.89	93.7
5.34	88.9
Type-2	
Frequency (GHz)	Efficiency (%)
3.84	85.9
5.41	80.1

Simulated and experimental gains are shown in the figure below.

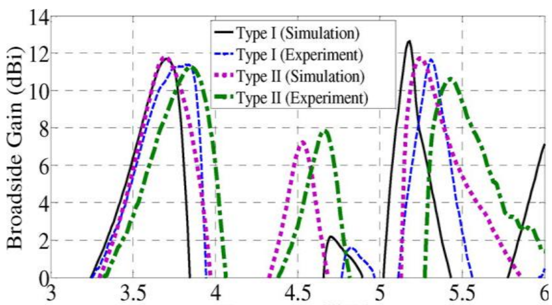

Fig. 10 Gain of the dual-band arrays [11]

TABLE 6
MEASURED GAIN FOR THE ARRAYS [11]

Type-1	
Frequency (GHz)	Gain (dBi)
3.84	11.39
5.31	11.67
Type-2	
Frequency (GHz)	Gain (dBi)
3.85	11.28
5.43	10.62

4.3 Stacked Method

In this type of method elements are excited by mutual coupling and they are placed above the main patch. Figure shows the different stacked structure.

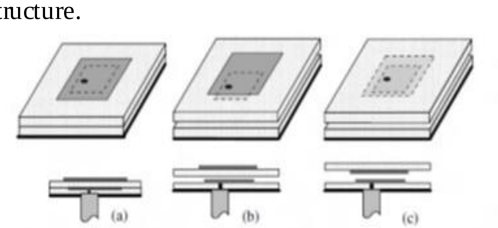

Fig. 11 Stacked coupling schemes [12]

First three arrangements are basic stacked microstrip patch antenna. Bottom patch is directly fed by the coaxial probe or strip line and it is usually smaller than the top parasitic element. By this method we can improve impedance bandwidth and antenna gain. For enhancing the gain two or more elements are stacked right above the main excited element. It has one drawback that it increases lateral height [12].

By applying this method some researchers named Jimmy Gautam and N. Jayanthi has proposed dual-band stacked patch antenna for WiMAX application works on 3.4 GHz and 5.6 GHz. It has asymmetrical U-slot on lower patch and rectangular patch on upper patch. They have used Rogers Duroid 5880 as a dielectric medium and it has slight different dielectric constant for both upper patch (2.2) and the lower patch (2.22). They have succeed in lengthen the path of the surface current by taking U shaped slot in the conducting element. So resonant frequency may get reduced and size reduction is achieved. Antenna geometry is shown in figure.

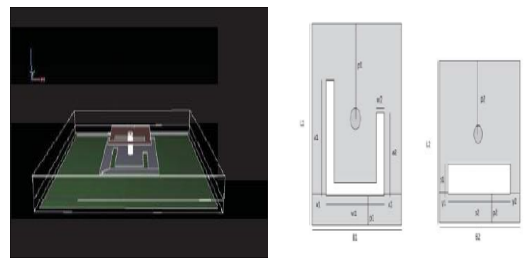

Fig. 12 stacked design with lower and upper patch [13]

TABLE 7
DIMENSIONS FOR THE STACKED DESIGN [13]

Parameters	Value (cm)	Parameters	Value (cm)
B1	19.1	W1	12.7
L1	21.2	W2	1.6
B2	14.5	A1	11.9
L2	12.7	A2	8.93
S1	2.3	S2	10.5

Results

Simulated return loss of the proposed design is given in the table.

TABLE 8
SIMULATED RETURN LOSS [13]

Frequency (GHz)	S_{11} (dB)
3.4	-31
5.6	-41

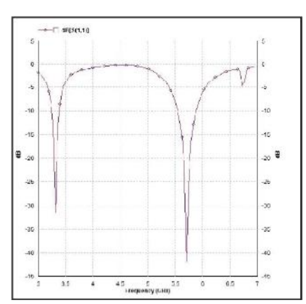

Fig 13 Return loss of stacked design [13]

Bandwidth with respect to the S11 below -10dB is 146 MHz (4.29%) at the 3.4 GHz and 355 MHz (6.32&) at 5.6 GHz.

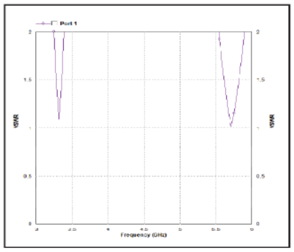

Fig. 14 Bandwidth of the stacked design [13]

Antenna efficiency is 83% at the 3.4 GHz and 98% at the 5.6 GHz.

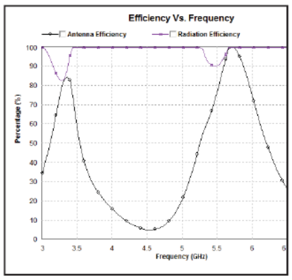

Fig. 15 Efficiency of the stacked design [13]

Gain of the proposed design is 3.43dBi for 3.4 GHz and 7.25dBi for the 5.6 GHz.

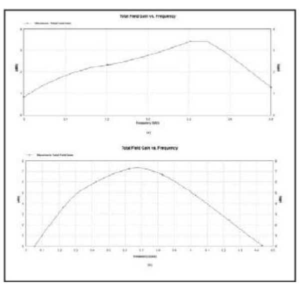

Fig. 16 Gain of the stacked design [13]

We have discussed three methods of the multi-band microstrip antenna so far. In first method we are having antenna design which works on four different frequency. It works for the Wi-MAX and WLAN. We have seen it achieves very high gain with the single element because of the air has been taken as the substrate and its loss free. In second method we have discussed a four parasitic elements are being excited by the driven element. Antenna works in dual-band for WiMAX applications. They have used a material with low dielectric constant so that most of the radiation will pass the material and couple with patch. Obtained high gain. In third method we have discussed stacked design of two patches one on another. It works in dual-band for WiMAX application. They have use single dielectric material with low dielectric constant. It has two different dielectric constant. High gain is being achieved.

TABLE 9
COMPARISON OF THREE METHODS

	Bandwidth	Gain	Size	Fabrication
Slots	Moderate	Low	Small	Easy
Stack	High	High	Big	Difficult
Array	Moderate	High	Big	Easy

5 CONCLUSION

We have discussed a current era of the multi-band design by three methods. Here I have focused on two points that are multi-band and high gain. Single element designs are not appropriate for all the application so that we need a high power antenna for communication (i.e. Base Station Antenna), to fulfil this problem we have to use an array or a stacked like structure. We can improve the gain of the single element design by making a structure with the help of multi elements.

Furthermore, we can even design high gain multi-band antenna with having superstrate on the main patch. Another way of getting increased gain is to have parasitic elements over the patch itself. By using this techniques we can reduce a size of the array so as cost effective.

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