A SLIT-LOADED NOTCH-CUT PATCH ANTENNA FOR BROADBAND APPLICATIONS

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Abstract

In this paper we have investigated various meandering techniques for obtaining compact and broadband patch antenna. We have designed a slit-loaded notch-cut patch antenna based on investigations. The antenna patch is fed by coaxial feed. Meandering techniques and the new design are simulated in HFSS environment. Results show good return loss for new design.

Index Terms: Patch antenna, Broadband, Compact, Meandering, Resonant Frequency.

1. INTRODUCTION

Because of developing needs for portable communication devices, microstrip patch antenna has been noted in last decades. Specially it has characteristics such as low profile and low-cost fabrication [1]. It can be easily portable. Conventional microstrip antennas suffer from narrow bandwidth. Increasing frequency results in larger size. This is a challenge for this type of antenna. Make one better results in degrading the other. From other side, compact antenna is a need for portable mobile devices. These make researchers to improve the antenna’s frequency band and size. Many methods have been suggested for upgrading size and bandwidth of antenna. Increasing substrate thickness, using low dielectric substrate, using impedance matching and feeding techniques, and using slot geometry in antennas are some methods for improvement of bandwidth and size [2-5].

2. FREQUENCY CHANGING METHODS

2.1 Size & Frequency Compromise

In microstrip patch antenna, Resonant frequency can be approximately obtained from following relation [6]:

\[ f \approx \frac{c}{2L\sqrt{\varepsilon_r}} \]

This means that with fixed relative permittivity (fixed substrate), directly lower frequency, larger size is obtained, and vice versa. This is a challenge for conventional patch antennas to employing them in broadband applications. In broadband applications, the frequency changeable (decreasing) interval around fundamental resonant frequency has great importance. In mobile or wireless communications, size and frequency interval have great importance. So, Size and frequency, both are important variables in patch antenna design. And lengthening the size is no good solution.

2.2 Available Methods

Compact and broadband antenna is a favorite case. Some techniques are used to compact antenna, and some techniques are used to enhance antenna bandwidth.

Based on recent designs, broadband microstrip antennas have been proposed. Shorted patch, meandered patch, meandered ground plane, inverted U-shaped patch and planar inverted-L patch antennas are main designs.

For example increasing relative permittivity results in size reduction. Because resonant frequency can be obtained from previous relation, in fixed length with increasing \( \varepsilon_r \), frequency is lowered. With increasing \( \varepsilon_r \), frequency is lowered (broad band appl.). With increasing \( \varepsilon_r \), we can have a compact antenna, when resonant frequency fixed. This is shown in figure 1. Left patch belongs to an antenna with \( \varepsilon_r = 3.0 \), \( h = 1.524 \) mm, and right patch is for antenna with \( \varepsilon_r = 28.2 \), \( h = 4.75 \) mm. When frequency fixed, \( L \) is lowered. So increasing \( \varepsilon_r \) makes length decrease (compact appl.) [6].
Meandering technique is one of the effective methods to lower resonant frequency and contains turning surface currents in the patch [7-11]. Meandering can be made by slitting in patch’s edges, or slotting the patch, or truncating patch’s angles, and so on. A meandering design is shown in figure 2. Excited surface currents are meandered and their paths are lengthened, while patch dimensions are fixed, and fundamental resonant frequency is decreased (broadband appl.). Equally, with fixed operating frequency, a large amount size reduction can be obtained (compact appl.) [6].

Lengthening current paths is also done with more techniques. There are some techniques that are not based on a coplanar or single-layer microstrip structure. Using inverted U-shaped patch causes longer patch’s current path and lower resonant frequency. Folded patch, and double-folded patch also result in lengthening patch current paths at the same patch projection area [12,13]. These three techniques are not in coplanar structure. It must be noted that because surface current paths are bent along antenna resonant or excitation direction, resonant frequency is decreased greatly, and so no side current components are produced, where as in coplanar meandering techniques side components exist.

Slotted patch and slit patch have more discussed in papers for compact circularly polarized or dual-frequency microstrip antennas. Figure 3 shows some suitable slots in patch, applied to get circularly polarized or dual-frequency microstrip antennas.

2.3 Meandering Method

Some antennas are meandered by slots. Slot is a slice that is cut from patch. Slots Usually are centrally symmetric (figure 3 except for (h)) [14-27], for circularly polarized case. Orthogonal slots give meandering of current path in two orthogonal directions and are suitable for circularly polarized [14,15], or dual-frequency with orthogonal polarization [16,17] cases. Slot positions can be in radiating or non-radiating sides of patch. For use of slot, some geometry are used. Some slot designs are: cross slot (figure 3(a)), a pair of bent slots (figure 3(b)), a group of four bent slots (figure 3(c)), a perforated square patch or a square-ring patch with a cross strip (figure 3(e)), a circular slot (figure 3(f)), a square slot (figure 3(g)). Figure 3(h) shows an offset circular slot patch [28] (asymmetric). Slotting the patch can also be result in compact microstrip antennas.

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2.3.2 Meandering with Truncation

Sometimes truncation is also used. Truncation is a part that is often cut from angles (corners). Truncation is also usually (axially) symmetric and results in dual-frequency or circularly polarized applications. A perforated tip-truncated triangular patch [29] is shown in figure 3(i). It is really a slot-loaded truncated patch.
Size reduction in compact circularly polarized antenna designs causes in more relaxed manufacturing tolerance than conventional circularly polarized microstrip antenna, at fixed operating frequency. This has great importance in practical applications. One case is corner-truncated square microstrip antenna with four inserted slits and probe feed [30](figure 4). This is really a truncated slit patch antenna.

When the length of slits raises, antenna’s fundamental resonant frequency is lowered and antenna size is reduced at the same operating frequency, and the required size of the truncated angles raises. So more relaxed manufacturing tolerance is made for reducing size of this kind of circularly polarized antenna.

**Fig-4: Geometry of a probe-fed corner-truncated square microstrip antenna with four inserted slits for compact CP radiation[6]**

### 2.3.3 Meandering with Slits

Slit is often a narrow slice that is cut from patch. Slits are not always centrally symmetric. When cut symmetrically, cause circular polarization. Slit makes current paths meandering, similar to slot. In more cases, perhaps for patch’s stability, slit or slot, no both, is used. Nevertheless, if selected well, this combination can effectively meander surface currents and lengthen their paths. It must be noted that slits be in nonradiating edges.

Designing slots and slits must be done with considerations on their positions with respect to our aims, i.e. lengthening current paths. A new design has been reported using a slot in center and inserted slits around it with probe feed in a square patch [31].

**Fig-5: Geometries of a shorted rectangular patch antenna with an L-shaped or a folded slit for dual-frequency operation [6]**

A shorted rectangular patch with an L-shaped or a folded slit [32,33] is suitable for dual-frequency applications (figure 5). We can insert a pair of narrow slots parallel and near the radiating edges of a rectangular patch [10,34] and combine it with slits in the patch. Due to two slots position (figure 6), the patch is suitable for dual-frequency applications. This structure greatly causes meandered current paths.

**Fig-6: Geometry of slot-loaded meandered rectangular microstrip patch for compact dual-frequency operation [6]**

### 2.3.4 Meandering with Notches

Figure 7 shows a design, in which a pair of triangular notches is cut at the patch’s nonradiating edges to make patch current paths longer [11]. Therefore making notches in patch also results in meandering patch currents.
If we cut slits in a rectangular patch, will have figure 2. It meanders current paths greatly. Meandering can be done with notches cut. Different figures can be made. A design with two triangular notches cut is proposed. It is shown in figure 8. These notches meander current paths more than a conventional rectangular patch. Due to be symmetric, this patch antenna is suitable for circular polarization applications.

It seems that meandering characteristics of mentioned figure is lower than figure 2. Simulations also show it. For more meandering, we cut four slits from non-radiating edges. This will lengthen current paths. Producted patch is shown in figure 9. Slits can be in the same size, but longer size in two central

3. SIMULATIONS & RESULTS

At first, we simulate conventional rectangular patch antenna. Simulation is done by HFSS software. Main variables are listed in table 1. Patch is fed by coaxial feed. Figure 10 shows antenna simulation. The substrate is Rogers RT/duroid 5880 (tm) with Relative Permittivity 2.2. Return Loss plot for this patch is shown in figure 11. Obviously, lower resonant frequency is 2.36 GHz.

<table>
<thead>
<tr>
<th>Table 1: Antenna Dimensions</th>
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<td>Length of Rectangular Patch</td>
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<td>Width of Rectangular Patch</td>
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<td>Thickness of the Substrate</td>
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<td>Relative Permittivity of the Substrate</td>
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Simulation is continued from the patch in figure 2. Effect of this figure is tested. Three slits are cut. Each slit is 0.2 wide, and 2.2 long. Slits are cut from non-radiating edges. Return loss for slit-loaded patch is shown in figure 12. The smallest resonant frequency is 1.1 GHz, which is lower than conventional patch frequency. Decreasing (changing) resonant frequency is a need for broadband applications.

At second stage, effect of various notches is simulated. Several notch-cut patches are designed. These designs are shown in figure 13. Triangular cuts in (a) are 1.12cm wide and 1.94cm long. Trapezoid cuts in (b) have 2.65,5.3cm parallel sides and 2.3 cm height. Rectangles in (c) are the same and they are 1cm wide and 3cm long. Radius of semicircles in (d) is 1.15cm. Triangular cuts in (e) are 1.73cm wide and 3cm long. Overall rectangle in all designs is also 3cm wide and 4cm long.

Simulation of designs is done similar to rectangular patch. After simulation, return loss plots have been drawn in figure 14(a)-(e) respectively. Resonant frequency of five designs in figure 13(a)-(e) are respectively: 1.83, 1.7, 1.63, 1.6, 1.6 GHz. In these designs, frequency is lowered compared to conventional rectangular patch. It is due to meandering characteristics of them. But, Their frequency is not lower than that of figure 2.
At next stage, four slits are cut in figure 13(a) and 13(d) at non-radiating edges. Two resulted designs are shown in figure 15(a)-(b). Slits in figure 15(a) are 0.2×1cm and 0.2×2.25cm. Slits in figure 15(b) are 0.2×1.1cm. It helps us to compare results with each other, and with plots of figure 14, to find a better design.

New simulations are done with two designs, similar to conventional patch. Return loss plots of mentioned designs is shown in figure 16(a),(b) respectively. It is seen that figure 15(a) results in 1 GHz resonant frequency, and figure 15(b) leads to 1.6 GHz. It is obvious from figure 15 that slits in (b) cause no more meandering effects over circular notches (compared to figure 13(d)). But in (a), slits make current paths longer, therefore decrease resonant frequency compared to figure 13(a). And frequency in 15(a) also becomes lower than figure 2. So the patch in (a) forms more broadband antenna, or in fixed frequency builds more compact antenna. Figure 15(a) causes good circular polarization, and figure 15(b) has better dual-frequency case. Note that any combination must be suitable to get better results. The combination in 15(a) is more suitable than 15(b).

4. CONCLUSION

Various patch designs with notch-cuts is investigated. And based on them, a slit-loaded patch with triangular notches is proposed and simulated. The patch is central symmetric. Simulations show that every combination is not suitable for meandering and making antenna compact and broadband. It is shown that new design makes current paths longer, and greatly meandered, and is suitable for compact or broadband circular polarization applications.

REFERENCES


