International Journal of Computational and Experimental Science and Engineering (IJCESEN)
Vol. 2-No.1 (2016) pp. 52-55
http://dergipark.ulakbim.gov.tr/ijcesen

***ISSN:* 2149-9144**

Research Article

Bandwidth Enhancement of Equilateral Triangle Microstrip Patch Antenna with Slot Loading and Dielectric Superstrate#

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Presented in "2nd International Conference on Computational and Experimental Science and Engineering (ICCESEN-2015)"

Keywords
Triangular microstrip antenna 1
Bandwidth enhancement 2
HFSS 3
Slot loading 4
Dielectric superstrate 5

Abstract: In this study, effects of slot loading and dielectric superstrate techniques, which are the common bandwidth enhancement techniques in literature, are investigated on an equilateral triangle microstrip patch antenna. From these techniques, slot loading is realized by etching parts with various shapes and dimensions from the patch surface without disturbing the integrity. Dielectric superstrates can be chosen with the same or different from the substrate material of the antenna that have the same dimensions with the substrate and cover the whole patch surface. First, these bandwidth enhancement techniques are applied one by one, then with together on the microstrip patch antenna. The antenna is designed on FR-4 and simulated by HFSS. As slot shapes, Parallel (P), U and O slots are preferred. As superstrate, it is chosen with the same substrate specifications and dimensions. After, parameters of the slots are changed systematically, one parameter in each step and the others are fixed, and the parametric analysis is completed. As a result of this analysis, the optimum dimension, shape and superstrate combinations are found that given the best values for both frequencies and bandwidths. This combination is using with P-slot and superstrate together and this design gives the frequencies and the bandwidths, 1730MHz and 2460MHz, % 2.89 and % 2.03, from simulations, 1840MHz and 2530MHz, %3.804 and % 1.581, from measurements, respectively. In addition, it is seen that simulation and experiment results are compatible with each other.

1. Introduction

Microstrip patch antennas have lots of advantages but, they have very narrow bandwidths which is an undesired feature for present wireless and mobile antenna applications. [1,3]. For this reason, there are most studies on searching new, effective and easy applicable bandwidth enhancement methods [1-14]. The common of these methods are; slot loading on patches [1-7], superstrate adding, using thicker substrates that have lower dielectric constant and using matching networks, etc. [1-17]. From these methods, the simplest and easy applicable ones that after the patch is produced are slot loading and superstrate adding [6,7,10,12]. In slot loading, the aim is extending the current path on the patch surface and resonating the antenna at a lower frequency with the same dimensions.

Similarly, if a superstrate is added on a patch antenna, due to the superstrate specifications, the resonant frequency and bandwidth of the antenna can be changed easily. 1,2,6,7,13].

In here, on triangular microstrip Patch antennas, P, U and O slot adding were realized and superstrate addition was realized on the slotted patches. The slot parameters were tried to determine for bandwidth optimization. Simulation and measurements of the designs were completed in laboratory. In the next sections, the study steps will be explained.

2. Antenna Design

The antennas were designed on FR-4 materials that has a dielectric constant of 4.4 and a thickness of 1.6mm, two faces covered with a 35μm- thickness copper plates. The design frequencies are about 1800MHz and 2400MHz, they could be changed due to the slot dimensions and types. As previous, a simple, no slot antenna was designed. HFSS was used for the simulations [18]. By simulation, the feed point of the antenna was determined, then the antenna was produced with a PCB prototyping machine and measured using a network analyzer. The results of the simple antenna were a pioneer for the later studies. The design of the antenna without slots and with superstrate is given in Figure 1.

2.1 Slot loading

In this step of the study, an equilateral triangular microstrip patch antenna was designed by using parameters from [14]. After simulations and experiments were completed, the return loss results were used for determining the resonant frequency and bandwidth of the antennas. Afterwards, with new P-slot parameters were determined with HFSS simulations and the new antennas were produced. The P-slots were transformed to U-slots and the last slot type, O-slot was applied the antennas. Measurements were repeated for all these new antennas. The new antenna parameters can be seen from Table 1.

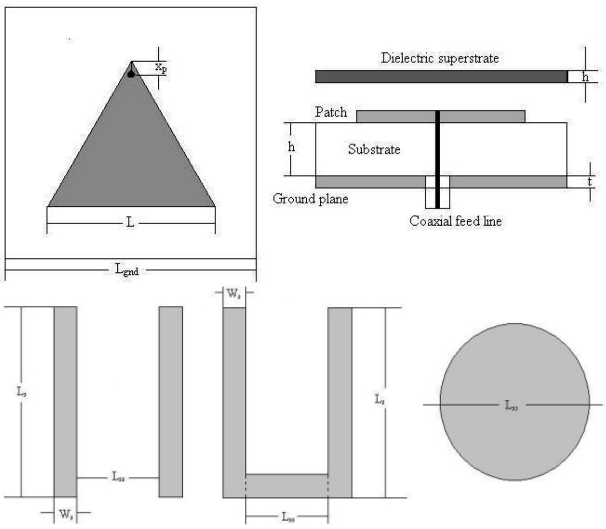

Figure 1. *Microstrip Patch Antenna, with Superstrate Addition and Slot Types*

In the next step, designs with U and O-slots which are common in literature were realized like seen from Figure 1. The U-slots were obtained from the P-slot designs by unifying the two vertical slots with a horizontal slot that has the same width with the other slots and a length named as L_{SS}. For these slot type designs, only two designs that gave the best simulation results were produced and measured.

Table 1. *Antenna Parameters and Results for Antennas with P-Slots from [14]*

No	L_s	W_s	L_{ss}	x_p	L	L_{gnd}	h	ε_r	t
1	17		22	20,4					
2	19		18	19,6					
3	21		18	18,7					
4	23	1	18	18,0	50	75	1,6	4,4	0,035
5	23		16	19,0					
6	23		14	19,8					
7	30		10	21,2					

No	$f_{r1[14]}$	$f_{r1\_sim.}$	$f_{r1\_meas.}$	$f_{r2[14]}$	$f_{r2\_sim.}$	$f_{r2\_meas.}$
1	1838	1750	1920	2743	2480	2750
2	1863	1780	*	2674	2570	*
3	1800	1760	1870	2572	2520	2590
4	1754	1780	1830	2486	2670	2530
5	1802	1790	1860	2552	2550	2550
6	1844	1810	1980	2580	2730	2560
7	1740	1720	2010	2365	2730	2410
No	BW_1 [14]	BW_1 sim	BW_1 meas	BW_2 [14]	BW_2 sim	BW_2 meas
1	1,400	1,714	0,129	1,300	2,016	*
2	1,500	1,685	*	1,300	1,946	*
3	1,600	2,273	0,128	1,400	1,984	1,931
4	1,700	2,247	0,150	1,500	1,498	1,976
5	1,800	2,235	2,151	1,700	1,961	1,176
6	1,800	2,210	11,616	1,700	1,961	1,953
7	1,900	2,210	10,945	1,700	1,961	2,490

Here, all dimensions are in mm, all frequencies are in GHz and all bandwidths are in %.

Where;
U: U-slot design,
O: O-slot design,
P: P-slot design,
L_s: Vertical slot length or the diameter of the O-slot,
W_s: Slot width,
L_{SS}: Horizontal slot length or the distance between Parallel slots,
x_p: The feed point,
L_{gnd}: The ground plane length,
L: The length of triangular patch,
h: The substrate and the superstrate thickness,
ε_r: the dielectric constant of the substrate and the superstrate,
t: the thickness of the copper plates.

2.2 Superstrate addition

In the next step, a superstrate that has the same specifications with the dielectric substrate of the antennas was added on various types slotted microstrip patch antennas. The simulations and experiments were repeated for these superstrated antennas. The antenna design with superstrate can be seen in Fig.1 and 2.

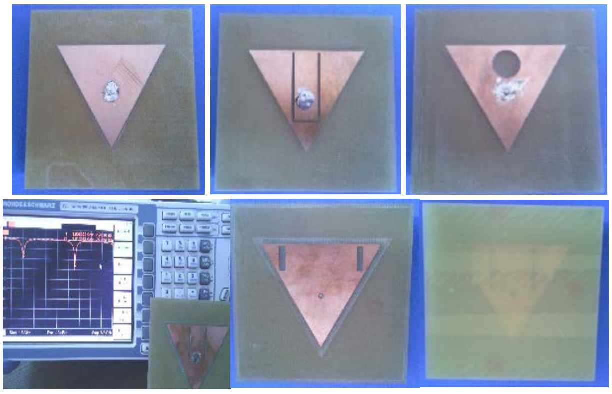

Figure 2. *Application of Designed Microstrip Patch Antennas*

Table 2. *Results for Antennas with P-Slots from [14] added Superstrate*

No	$f_{r1\_sim.}$	$f_{r1\_meas.}$	$f_{r2\_sim.}$	$f_{r2\_meas.}$
1	1710	1870	2410	2680
2	1670	*	2180	*
3	1720	1810	2480	2520
4	1660	1770	2310	2470
5	1670	1800	2320	2450
6	1700	1840	2350	2060
7	1710	2030	2450	2300
No	$BW_{1\_sim.}$	$BW_{1\_meas.}$	$BW_{2\_sim.}$	$BW_{2\_meas.}$
1	2,924	0,128	*	*
2	*	*	2,294	*
3	1,163	0,165	2,016	1,984
4	1,807	0,168	2,165	2,024
5	2,395	1,667	2,155	1,224
6	2,353	1,630	1,702	11,165
7	2,339	11,823	1,224	3,478

3. Results

In this study, a simple equilateral triangular microstrip patch antenna, without any slot, based on antenna parameters from [14], was designed and it was seen that, adding various types of slots on a simple patch can cause more than one or two resonant frequencies different from the design frequency. So the impedance bandwidth of the antenna can be enhanced by this method.

When a superstrate was added on the slotted patch, the first resonant frequency became higher, the second resonant frequency became lower and the first and the second bandwidths became larger than previous designs.
New simulation and measurement results for P-slot designs are given in Table 3. The best results were obtained with the design of using P-slot and superstrate together.

Table 3. *Simulation and Experimental Results of Microstrip Patch Antennas with Slots and Superstrate*

No	Slot Type	L_s	W_s	L_{ss}
1	No Slot	*	*	*
2	U	30	1	10
3	O	*	*	6.5
4	P	22	1	11

No	Slot Type	f_{r1sim}	f_{r1meas}	f_{r2sim}	f_{r2meas}
1	No Slot	1840	1940	*	2080
2	U	1720	1770	3030	3120
3	O	1830	1890	*	*
4	P	1820	1830	2660	2080
No	**Slot Type**	BW_{1sim}	BW_{1meas}	BW_{2sim}	BW_{2meas}
1	No Slot	1,087	4,639	*	2,404
2	U	2,326	2,260	1,650	1,282
3	O	2,186	7,513	*	*
4	P	2,747	3,279	1,880	4,808
No	**Superstrate & Slot Type**	$f_{r1\_sim.}$	$f_{r1\_meas.}$	$f_{r2\_sim.}$	$f_{r2\_meas.}$
1	No Slot	1770	1930	3100	3390
2	U	*	1720	2670	2040
3	O	1740	1870	3130	3360
4	P	1730	1840	2460	2530
No	**Superstrate & Slot Type**	$BW_{1\_sim.}$	$BW_{1\_meas.}$	$BW_{2\_sim.}$	$BW_{2\_meas.}$
1	No Slot	*	1,554	2,258	2,065
2	U	*	2,326	1,873	8,333
3	O	1,724	2,139	1,278	0,893
4	P	2,890	3,804	2,033	1,581

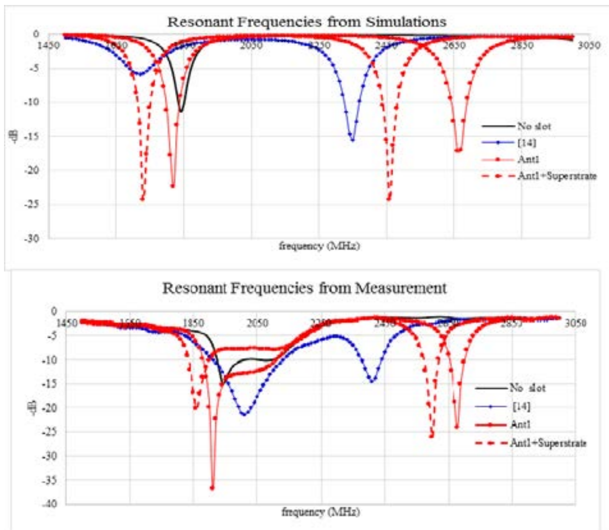

Figure 3. *Comparison of Resonant Frequencies from Simulations and Measurements*

Most of the antennas had a larger value from experimental results than simulation calculations. Experimental and simulation results were compatible with each other in an acceptable degree while the impedance bandwidths showed an increase more than two times of the simulation results.

4. Conclusion

In this study, two common bandwidth enhancement methods in literature are applied to equilateral triangular microstrip patch antennas. One of the methods is slot loading and the other one is adding superstrate. The reason of choosing these methods are that they can applied after the patch antenna produced, easily. These methods are applied to the antennas one by one, then with together. It can be said that using more than one bandwidth enhancement method is more effective. In the study, various types of slots are used for comparison of different slot type effects on resonant frequency and bandwidth of the antennas. The best results are obtained by etching P-slots on the antenna than adding a superstrate with the same dielectric substrate specifications. Simulation and experimental results of the study are compatible. There is small shifting between some of simulations and measurements because of not optimizing the slot and superstrate parameters at the same time, but one after another. More different slot shapes and different superstrates can be applied to microstrip antennas in the next studies. As another topic, the effects of the slot and supertstrate parameters on antenna bandwidth and frequency will be investigated with together in the near future.

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