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REGULAR ARTICLE

Dimension Analysis of Microstrip Patch Antenna for Different Substrates

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This research presents a comparative analysis of rectangular Microstrip Patch Antenna (MPA) designs using python program for various substrates. Focusing on resonant frequencies from 1 GHz to 5 GHz, it evaluates antennas with 1.6 mm and 0.8 mm thick substrates. A Python program computes antenna dimensions (length and width) for given resonant frequencies, substrate permittivity, and thickness. The program gives a list of tables with design parameter for a rage of resonant frequencies, different substrate and thickness of substrate. Simulations in HFSS validate these results by comparing resonant frequency graphs. This research paper examines how substrate properties – length, width, thickness, and permittivity affect resonance. Six substrates (FR-4, Benzo, RT-Duroid, Nylon, Duroid, and Form) are analyzed to highlight their impact on performance. This readily available list of table helps to design a microstrp patch antenna for any resonance frequency, substate permittivity and thickness, very easily. Features of Python program can be utilized to achieve this design of microstrip patch antenna in a convenient and easily method for this dimension analysis. By changing the range of resonance frequency, it is easy to implement microstrip antenna for any wireless communication applications.

Keywords: MPA, Dimension analysis, PTFE, FR4, RT/duroid.

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1. INTRODUCTION

A Microstrip Patch Antenna (MPA) is a type of antenna commonly used in wireless communication systems because of its compact size, light weight design, and easy integration with printed circuit boards (PCBs) [1-8]. The micro strip patch antenna operates on the principle of electric field excitation between the radiating patch and the ground plane [2]. When the antenna receives an input signal (usually through a feed mechanism), the patch radiates energy into free space.

Neural networks have recently gained attention as a fast and flexible tool for electromagnetic (EM) and microwave modeling, simulations, and optimization [4]. A CAD approach based on neural networks has also been introduced in the microwave community for modeling [5]. A simple Python program can be used to simplify and accurately obtain the design of a microstrip patch antenna [10]. The advantages of Python can be fully utilized to efficiently execute the design steps [9]. However, despite being generated by a program, the resonant frequency of the antenna may exhibit slight variations. These variations can be corrected using artificial intelligence techniques [5]. By training the system with more data, the design process can be refined to achieve a highly accurate antenna design for a specific resonant frequency [4].

2. ANTENNA DESIGN

This research work aimed in analysis of antenna design using different substrate materials. The proposed antenna is designed over different substrate of dimension 60 × 60 × 1.6 mm^3 or 60 × 60 × 0.8 mm^3 each having a specific dielectric constant.The resonant frequency of the antenna is determined by the length and width of the patch, the thickness of the substrate, and the dielectric constant of the material. [2-4]. The size of the patch and thickness of the substrate has an inverse effect on the resonant frequency. The dielectric constant of the substrate is directly proportional to the resonant frequency [7]. Designing a rectangular microstrip patch antenna for a specific resonant frequency involves determining the length and width of the patch for a given substrate with a standard thickness.[4]

The key parameters required for designing microstrip patch antenna are the width and length of the patch. Accurate values for both the width and length have a significant impact on the results [3, 4].

$$\text{Width } W = \frac{c}{2fc}\sqrt{\frac{2}{\varepsilon r+1}} \qquad (1)$$

c – speed of light, f_c – the resonant frequency.

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The effective relative permittivity (ε_{reff}) is calculated from equation (2).

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\frac{1}{\sqrt{1+12(\frac{h}{w})}} \quad (2)$$

εr = relative permittivity, h = height (mm)

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon reff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{w}{h}+0.8)} \quad (3)$$

$$\Delta L = 0.412\frac{(\varepsilon reff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{w}{h}+0.8)}h \quad (4)$$

$$L = \frac{1}{2fc\sqrt{\mu o \varepsilon o}\sqrt{\varepsilon reff}} - 2\Delta L \quad (5)$$

$$L = \frac{c}{2fc\sqrt{\varepsilon reff}} - 2\Delta L \quad (6)$$

Where
L – Actual length of the patch (in mm)
W – Width of the patch (in mm)
μ_0 – Permeability of free space
ΔL – the extended patch length due to fringing effect.

2.1 Antenna Design using Python Program

The design of the patch antenna for a specific resonant frequency is simplified using a Python program [9, 10]. The program accepts a range of resonant frequencies for which the length and width of the antenna are to be designed. It also accepts the thickness and dielectric constant of the substrate. The program then outputs the length and width for the range of resonant frequencies.

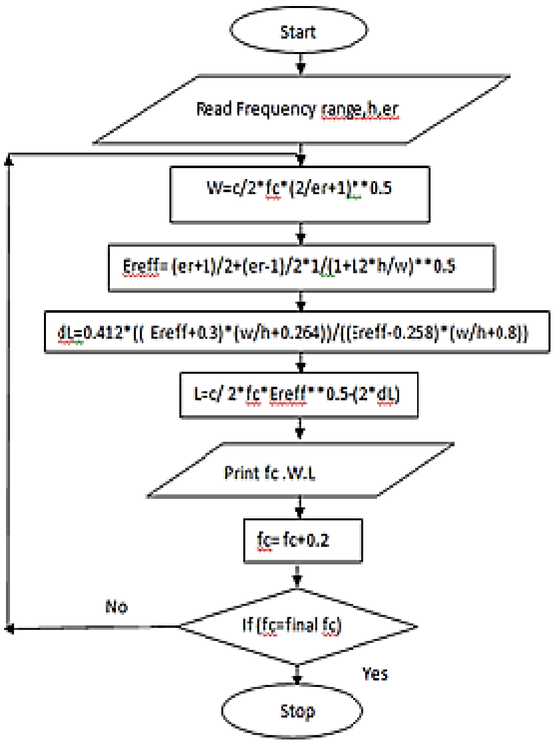

Fig 1 – Flowchart for microstrip antenna design

The methodology shown in Fig. 1 will display the width and length of a patch antenna across a range of frequencies, with an increment of 0.2 GHz. It helps to compare how the resonant frequency of the patch antenna changes with variations in its size. Additionally, it will allow to study the behavior of the patch antenna as the substrate material and its thickness change. After calculating the length and width of the patch, the simulation is carried out using HFSS [8-12]. With the combination of this Python program and the HFSS simulation software, analyzing the performance of a patch antenna with different patch sizes, substrates, and substrate thickness is not a daunting task.

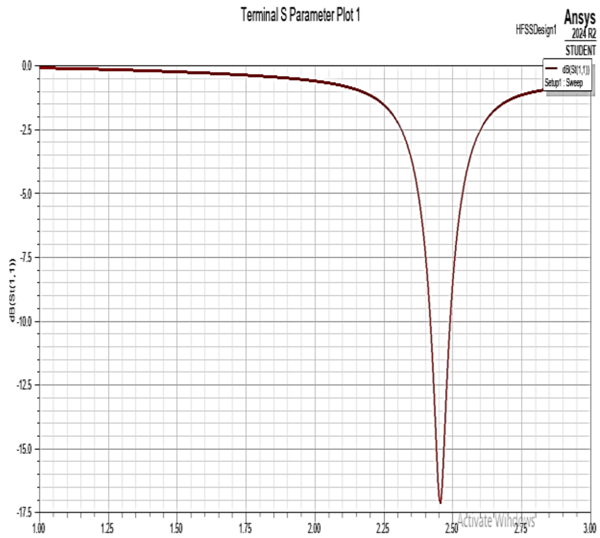

Fig. 2 – Resonant frequency obtained from HFSS

Table 1 – Size Vs Frequency (1.6 mm thickness)

Die_Ele	Er=4.4 (FR4)		Er =2.6(Benzo)		r=10.7(Duroid)		Er=3.6(Nylon)		==2.2(RT-Duro		Er==1.05(Foam)	
F in GHz	W	L	W	L	W	L	W	L	W	L	W	L
1	91.29	71.31	111.8	92.51	62.02	45.85	98.91	78.76	118.6	100.5	148.2	144.25
1.2	76.07	59.37	93.17	76.98	51.68	38.17	82.42	65.56	98.82	83.58	123.5	119.86
1.4	65.21	50.83	79.86	65.89	44.3	32.68	70.65	56.13	84.7	71.52	105.8	102.43
1.6	57.05	44.42	69.88	57.57	38.76	28.56	61.82	49.05	74.12	62.47	92.6	89.36
1.8	50.72	39.43	62.11	51.09	34.45	25.34	54.95	43.54	65.88	55.44	82.31	79.19
2	45.64	35.44	55.9	45.9	31.01	22.77	49.45	39.13	59.29	49.8	74.08	71.06
2.2	41.49	32.17	50.82	41.66	28.19	20.66	44.96	35.52	53.9	45.19	67.35	64.41
2.4	38.04	29.44	46.58	38.12	25.84	18.9	41.21	32.5	49.41	41.35	61.73	58.87
2.6	35.11	27.13	43	35.13	23.85	17.41	38.04	29.95	45.61	38.09	56.98	54.17
2.8	32.6	25.15	39.93	32.56	22.15	16.13	35.32	27.77	42.35	35.3	52.91	50.15
3	30.43	23.43	37.27	30.33	20.67	15.01	32.97	25.87	39.53	32.88	49.39	46.67
3.2	28.53	21.92	34.94	28.38	19.38	14.04	30.91	24.21	37.06	30.77	46.3	43.62
3.4	26.85	20.6	32.88	26.65	18.24	13.18	29.09	22.74	34.88	28.9	43.58	40.93
3.6	25.36	19.41	31.06	25.12	17.23	12.41	27.47	21.43	32.94	27.23	41.16	38.54
3.8	24.02	18.35	29.42	23.75	16.32	11.73	26.03	20.26	31.21	25.74	38.99	36.4
4	22.82	17.4	27.95	22.52	15.5	11.11	24.73	19.21	29.65	24.4	37.04	34.48
4.2	21.74	16.53	26.62	21.4	14.77	10.55	23.55	18.26	28.23	23.19	35.28	32.73
4.4	20.75	15.75	25.41	20.38	14.09	10.04	22.48	17.39	26.95	22.09	33.67	31.15
4.6	19.85	15.03	24.31	19.45	13.48	9.57	21.5	16.6	25.78	21.08	32.21	29.71
4.8	19.02	14.37	23.29	18.6	12.92	9.14	20.61	15.87	24.71	20.15	30.87	28.38
5	18.26	13.76	22.36	17.81	12.4	8.75	19.78	15.2	23.72	19.3	29.63	27.16

Table 1 presents the length and width of the patch antenna for resonant frequencies ranging from 1 GHz to 5 GHz, with an increment of 0.2 GHz. It also explains the patch size for different substrates, each with a thickness of

1.6 mm. The substrate materials used for comparison are FR4 (with a relative permittivity, ε_r = 4.4 Benzo (ε_r = 2.6), Duroid (ε_r = 10.7), Nylon (ε_r = 3.6), RT-Duroid (ε_r = 2.2), and Form (ε_r = 1.05). These six common substrate materials are used to compare the behavior of the microstrip antenna. It is easier to analyze the relationship between antenna size and resonant frequency across different substrates using a table rather than a graph. This provides a clearer understanding of how the antenna behaves with different substrates, sizes, and thicknesses.

Table 2 – Size Vs Frequency (0.8 mm thickness)

Die_Ele Er=4.4 (FR4)			Er =2.6(Benzo)		Er=10.7(Duroid)		Er=3.6(Nylon)		Er=2.2(RT-Duro		Er==1.05(Foam)	
F in GHz	W	L	W	L	W	L	W	L	W	L	W	L
1	91.29	71.45	111.8	92.86	62.02	45.9	98.91	78.98	118.6	100.8	148.2	145.32
1.2	76.07	59.52	93.17	77.35	51.68	38.25	82.42	65.8	98.82	83.95	123.5	120.92
1.4	65.21	51	79.86	66.27	44.3	32.78	70.65	56.38	84.7	71.91	105.8	103.49
1.6	57.05	44.61	69.88	57.96	38.76	28.68	61.82	49.32	74.12	62.87	92.6	90.42
1.8	50.72	39.64	62.11	51.5	34.45	25.48	54.95	43.83	65.88	55.85	82.31	80.26
2	45.64	35.66	55.9	46.33	31.01	22.93	49.45	39.43	59.29	50.22	74.08	72.13
2.2	41.49	32.4	50.82	42.1	28.19	20.83	44.96	35.83	53.9	45.62	67.35	65.47
2.4	38.04	29.68	46.58	38.57	25.84	19.09	41.21	32.84	49.41	41.79	61.73	59.93
2.6	35.11	27.39	43	35.59	23.85	17.61	38.04	30.3	45.61	38.54	56.98	55.24
2.8	32.6	25.42	39.93	33.03	22.15	16.34	35.32	28.12	42.35	35.76	52.91	51.21
3	30.43	23.71	37.27	30.81	20.67	15.24	32.97	26.24	39.53	33.35	49.39	47.73
3.2	28.53	22.21	34.94	28.87	19.38	14.28	30.91	24.59	37.06	31.24	46.3	44.68
3.4	26.85	20.89	32.88	27.16	18.24	13.43	29.09	23.13	34.88	29.37	43.58	41.99
3.6	25.36	19.72	31.06	25.63	17.23	12.67	27.47	21.84	32.94	27.72	41.16	39.6
3.8	24.02	18.67	29.42	24.27	16.32	11.99	26.03	20.68	31.21	26.24	38.99	37.46
4	22.82	17.72	27.95	23.04	15.5	11.38	24.73	19.63	29.65	24.9	37.04	35.53
4.2	21.74	16.86	26.62	21.93	14.77	10.83	23.55	18.69	28.23	23.69	35.28	33.79
4.4	20.75	16.09	25.41	20.92	14.09	10.33	22.48	17.83	26.95	22.6	33.67	32.2
4.6	19.85	15.37	24.31	20	13.48	9.87	21.5	17.05	25.78	21.59	32.21	30.76
4.8	19.02	14.72	23.29	19.16	12.92	9.45	20.61	16.33	24.71	20.67	30.87	29.43
5	18.26	14.12	22.36	18.38	12.4	9.06	19.78	15.67	23.72	19.83	29.63	28.21

Fig. 3 and 4 show the relationship between microstrip antenna size and resonant frequency for substrates of 1.6 mm and 0.8 mm thickness, respectively. Each graph contains six color-coded lines representing different substrates. In Fig 3, the lines are linear but not parallel, illustrating how antenna length and width vary with frequency. The width is always greater than the length, and lower frequencies correspond to larger antennas [13]. The inverse relationship between size and frequency is nonlinear – size changes more significantly from 5 GHz to 4.8 GHz than from 1.2 GHz to 1 GHz. At lower frequencies, small frequency shifts require substantial size adjustments, while at higher frequencies, the size change is minimal.

The graph shows that at higher frequencies, most lines converge, indicating similar antenna sizes across different substrates, while at lower frequencies, they diverge significantly. This suggests that antenna size variation is more pronounced at lower frequencies. Additionally, the length of each line varies, highlighting non-uniform size changes across substrates. The relative permittivity (ε_r) inversely affects antenna size – lower ε_r (e.g., 1.05) results in larger antennas,

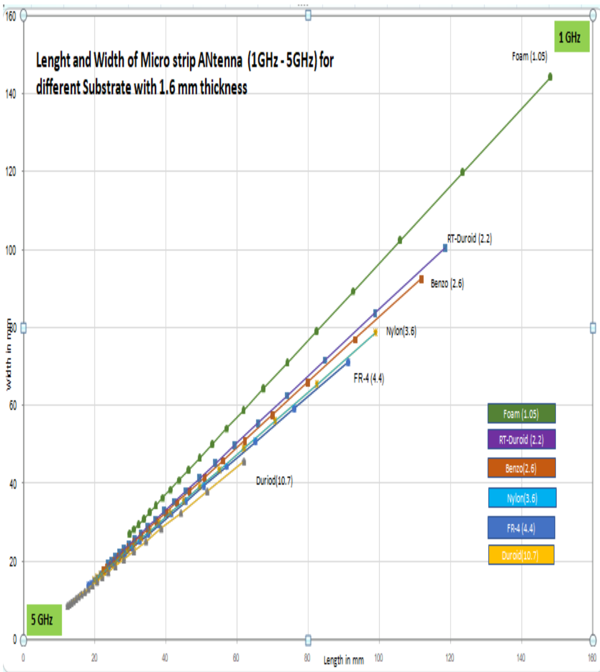

Fig. 3 – Size of antenna vs Resonant frequency of different substrate with 1.6 mm thickness

while higher ε_r (e.g., 10.7 for Duroid) leads to smaller antennas at the same frequency. Thus, using a higher permittivity substrate enables a more compact antenna design [11].

Fig 4 shows the relationship between substrate dimensions and resonant frequency for a 0.8 mm thick microstrip antenna. As substrate thickness increases, antenna size decreases slightly. Using the given design methods, the width remains constant while the length varies slightly for 1.6 mm and 0.8 mm substrates at the same frequency. The graph indicates that the slope represents size variation with frequency changes, increasing as frequency decreases. A lower relative permittivity or substrate thickness further steepens the slope.

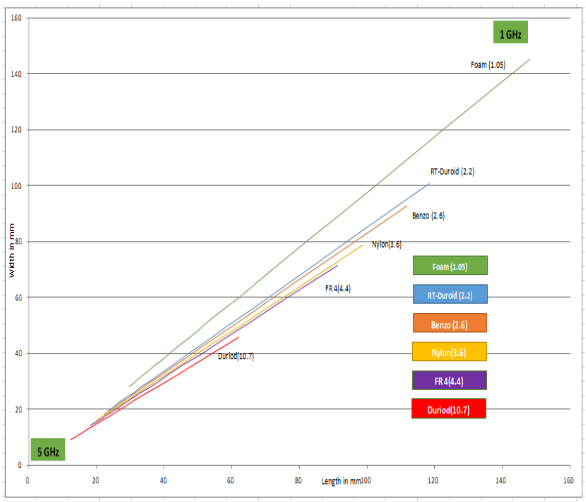

Fig. 4 – Size of antenna Vs Resonant frequency of different substrate with 0.8 mm thickness

Fig. 4 shows the relationship between resonant frequency and antenna size for 0.08 mm thick substrates.

Both Figures 3 and 4 share similar properties, differing only in substrate thickness. As thickness increases, antenna size decreases for a given frequency. The key difference is the slope – Fig. 4 has steeper slopes than Fig. 3, indicating larger antenna sizes. Thus, resonant frequency is primarily influenced by antenna size, substrate thickness, and material.

3. CONCLUSIONS

This research analyzes rectangular microstrip patch antennas using python program and HFSS simulations, highlighting the effects of substrate materials and thickness. The results show that higher relative permittivity enables compact designs, while thickness variations significantly impact performance. These findings aid antenna design for wireless communication, where size, frequency, and materials are crucial. Future work may explore reconfigurability and advanced fabrication for improved versatility.

The program generates a table listing antenna length and width for each resonant frequency, from start to end, with specified increments. By adjusting frequency range, step size, and dielectric constant, users can customize antenna design parameters easily. This readily available table helps to design a microstrp patch antenna for any resonance frequency and substrate very for easily.

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Розмірний аналіз мікросмужкової патч-антени для різних підкладок

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Це дослідження представляє порівняльний аналіз конструкцій прямокутних мікросмужкових патч-антен (MPA) за допомогою програми Python для різних підкладок. Зосереджуючись на резонансних частотах від 1 ГГц до 5 ГГц, вона оцінює антени з підкладками товщиною 1,6 мм та 0,8 мм. Програма Python обчислює розміри антени (довжину та ширину) для заданих резонансних частот, діелектричної проникності та товщини підкладки. Програма надає список таблиць з параметрами проектування для діапазону резонансних частот, різних підкладок та товщини підкладки. Моделювання в HFSS підтверджує ці результати шляхом порівняння графіків резонансних частот. У цій дослідницькій роботі розглядається, як властивості підкладки – довжина, ширина, товщина та діелектрична проникність – впливають на резонанс. Проаналізовано шість підкладок (FR-4, Benzo, RT-Duroid, Nylon, Duroid та Form), щоб висвітлити їхній вплив на продуктивність. Цей легкодоступний список таблиць допомагає дуже легко спроектувати мікросмужкову патч-антену для будь-якої резонансної частоти, діелектричної проникності та товщини підкладки. Можливості програми Python можна використовувати для досягнення цієї конструкції мікросмужкової патч-антени зручним та простим методом аналізу розмірів. Змінюючи діапазон резонансної частоти, легко реалізувати мікросмужкову антену для будь-яких застосувань бездротового зв'язку.

Ключові слова: MPA, Аналіз розмірів, PTFE, FR4, RT/дюроїд.