Optimization of an inset-fed calculations for rectangular microstrip antenna

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Article Info

ABSTRACT

This paper offers an alternative solution to produce a formula to calculate the inset-fed (y_0) feed distance from the edge of the patch in order to obtain the impedance of a rectangular patch microstrip antenna as close to 50 Ohm as possible. The basic calculation refers to Ramesh's calculation formula to calculate the inset-fed (y_0) on a rectangular patch microstrip antenna. From this research it is hoped that a number of correction factors will be obtained which will be multiplied by the Ramesh formula in order to obtain an inset-fed calculation which results in a lower return loss (S_{11}) and voltage standing wave ratio (VSWR). From several calculation attempts, the approximate value for the correction factor is s=0.83477. This s correction factor is then multiplied by Ramesh's calculation formula. In this experiment, a microstrip antenna was simulated using an FR4 epoxy printed circuit board (PCB) with a relative permittivity, $\varepsilon_r = 4.4$, with a thickness of h=1.6 mm. The specified antenna nominal input impedance is 50 Ohms. The transmission line used is a microstrip line with a characteristic impedance of 50 Ohm. The test method used is to compare the results of simulation calculations using the Ramesh formula with the results of simulation calculations using the Ramesh formula multiplied by the correction factor. Tests are carried out using varying working frequencies. From the experimental results it can be seen that the average Return Loss (S_{11}) and VSWR of the antenna are lower when using the Ramesh formula with a correction factor compared to the original Ramesh formula.

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1. INTRODUCTION

Since Desachamps introduced microstrip antennas in 1953 [1], research and development of microstrip antennas for various applications has increased, with the number of scientific articles published in IEEE journals totaling 1360 papers [2]. The first attempt to manufacture microstrip antennas was carried out by Howel [3] and reported in 1972. The scientific article on microstrip antennas was first published by Munson [4] in the IEEE Journal Transactions on Antennas and Propagation in January 1974.

Analysis with transmission line method (TLM) modeling assumes that "the radiating part of the antenna occurs at both ends of the antenna which resembles a slot. Electromagnetic fields are emitted from each slot on either end of the patch antenna. The two fields emitted from the two slots add up to each other in a superposition and form a complete antenna radiation pattern" [5].

Several methods of feeding techniques have been proposed. Rectangular microstrip patch antennas are known to feed rectangular microstrip patch antennas, both contact and non-contact [6]–[11]. Contact feeding includes: (a) patch antenna edge feeding (final feeders), (b) coaxial bait feeding, (c) inset feeding.]

Research by Samaras [12], Basilio [13] and Hu [14] reported that the value of the input resistance of a rectangular microstrip antenna will decrease slowly when the feed point is away from the edge of the antenna patch, and will be zero if the feed point is in the middle of the patch antenna. Thus, at some distance from the edge of the patch, the input resistance of the antenna will be 50 Ohms. If the distance from the edge of the antenna patch to the 50 Ohm input resistance point is expressed by y_0, a formula is needed to determine the distance of y_0.

Matin and Sayeed [15], Carver [8], [16], [17] proposed a method of calculating the input resistance of a microstrip rectangular patch antenna as a function,

$$R_{in}(y = y_o) = \frac{1}{2(G_1 \pm G_{12})} cos^2\left(\frac{\pi}{L}y_o\right)$$

$$R_{in}(y = 0)\, cos^2\left(\frac{\pi}{L}y_o\right) \tag{1}$$

Ramesh proposed [18] a formula to calculate the distance (y_o) from the edge of the patch,

$$y_o = \frac{L}{2} \times 10^{-4}(0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697) \tag{2}$$

where L is the length of the microstrip patch antenna and ε_r is the dielectric constant of the substrate.

Figure 1, shows a typical rectangular patch antenna TLM topology, consisting of a long L ideal, lossless transmission line with a characteristic impedance Zo, terminated at both ends by a network of identical passive ports. In Figure 2, shows the inset-fed terminal with the feed point y_0 from the edge of the patch.
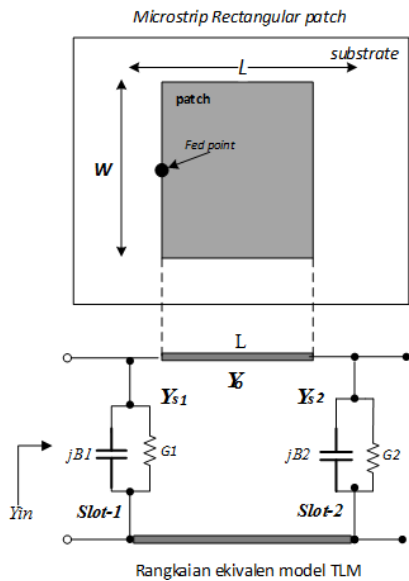

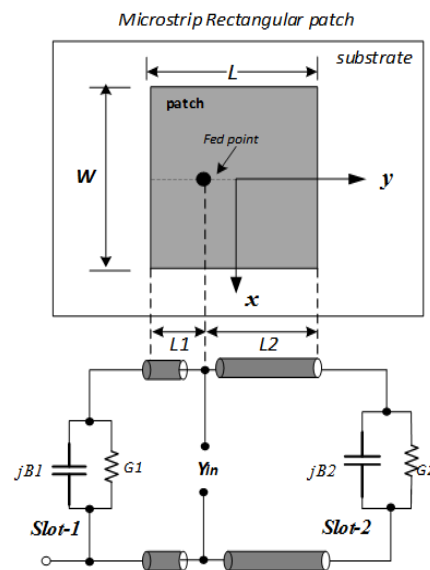Figure 1. Rectangular patch microstrip antenna equivalent circuit

Figure 2. Feeding the rectangular patch antenna at a distance y from the edge of the patch towards the center

2. METHOD

In this paper, we use the experimental method to find the approximation formula in order to obtain more accurate calculation results by referring to the Ramesh formula to determine the Inset-fed distance from the patch antenna edge as written in (2). Working frequency was set at 1 GHz, 1.5 GHz, 1.8 GHz, 2.0 GHz, 2.1 GHz and 2.3. GHz, 2.5 GHz, 3.0 GHz, and 3.5 GHz.

The first step is to calculate y_o using the Ramesh formula. The second step, do the simulation. The third step is changing the y_o distance gradually so that the input resistance is 50 Ohm and the SWR of the antenna is close to 1.0, as well as the lowest return loss (S_{11}). Then a comparison is made between the distance (y_o') according to the experiment to the distance y_o according to the Ramesh formula. The comparison between the distance according to the experimental results and the distance according to the Ramesh formula produces a number of correction factors "s" for the Ramesh equation. In this experiment, the transmission line spacing (x) to the antenna is set at 1 mm and 1.5 mm at each working frequency. Figure 3 shows geometry construction of a rectangular patch antenna using the inset-fed method.
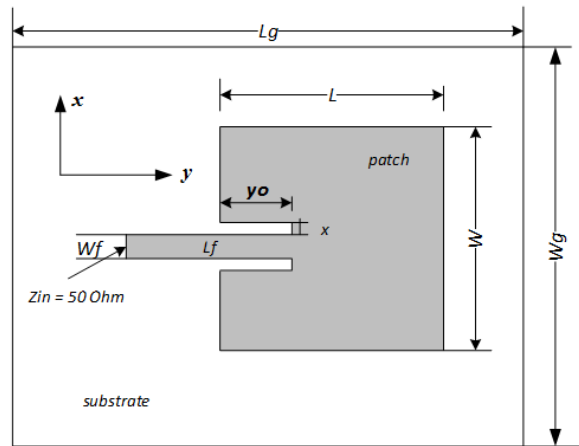

Figure 3. Geometry of microstrip antenna using inset-fed method

The calculation of the patch antenna dimensions follows as [19] and [20] equations with the following steps,
− Calculating the patch width (W) using the equation

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\varepsilon_r+1}} \tag{3}$$

− Calculate the effective permitivity of the substrate ε_e,

$$\varepsilon_e = \frac{1}{2}\left\{\varepsilon_r + 1 + (\varepsilon_r - 1)\left(1 + 12\frac{h}{W}\right)^{\frac{-1}{2}}\right\} \tag{4}$$

− Calculate the patch length using the equation,

$$L_{eff} = \frac{c}{2f_r} \frac{1}{\sqrt{\varepsilon_e}} \tag{5}$$

− Calculates the ΔL patch length, due to the fringing field effect,

$$\Delta L = 0.412h \frac{(\varepsilon_e + 0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h}+0.813\right)} \tag{6}$$

− Calculate the actual length of the patch antenna using the equation,

$$L = L_{eff} - 2\Delta L \tag{7}$$

The material of the antenna used FR4 epoxy printed circuit board (PCB) board with a substrate thickness of $h = 1.6$ mm and $\varepsilon_r = 4.4$. The results of calculating the dimensions of the antenna are shown in Table 1.

Table 1. Dimension of antenna

Freq (GHz)	L (mm)	W (mm)
1.0	71.312763252152	91.287092917528
1.5	47.414170319053	60.858061945018
1.8	39.435120371176	50.7150516208492
2.0	35.441361286606	45.643546458764
2.1	33.728628022213	43.470044246442
2.3	30.748033312001	39.690040398925
2.5	28.242105653345	36.514837167011
3.0	23.431760501435	30.429030972509
3.5	19.987974567339	26.082026547865

The next step is to calculate the inset-fed length and transmission line gap (x) to the antenna patch. In this experiment, the gap (x) between the microstrip line and the patch antenna was set from 1 mm, 1.5 mm. As a comparison, we will calculate the inset-fed distance from the edge of the patch (y_o) with the Ramesh equation [17], and Vinayak [21],

$$y_o = \frac{L}{2} \times 10^{-4}(0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697) \qquad (8)$$

The next step is to do an experimental test to obtain a correction factor "s" in order to obtain the optimal y_o distance in order to obtain an antenna impedance of 50 ohms. The number of correction factor "s" is tested is: (1) three rectangular microstrip patch antennas are designed that work at frequencies of 1 GHz, 1.5 GHz, 1.8 GHz, 2.0 GHz, 2.1 GHz and 2.3. GHz, 2.5 GHz, 3.0 GHz, and 3.5 GHz, with a distance of y_o following Ramesh's equation, then (2) also designed three antennas with a frequency the same, but the distance y_o using the developed Ramesh equation. Furthermore, the simulation is carried out and the results are compared.

In this experiment, the gap (x) between the microstrip line and the patch antenna was set from 1 mm and 1.5 mm. The antenna material is PCB Epoxy FR4 with a thickness of h = 1.6 mm and $\varepsilon_r = 4.4$. Through several experiments, it was concluded that the calculation of y_o in the Ramesh formula becomes more accurate when the Ramesh equation is multiplied by a correction factor of $s = 0.83477$, such that the Ramesh equation becomes,

$$y_o' = (s)\left(\frac{L}{2} \times 10^{-4}(0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697) \qquad (9)$$

$$y_o' = (0,83477)\left(\frac{L}{2} \times 10^{-4}(0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697) \qquad (10)$$

3. RESULTS AND DISCUSSION

At the initial stage, several experiments were carried out to determine the ideal y_o distance to produce the smallest return loss (RL). The best experimental results for the ideal y_o distance are then compared to the results of Ramesh's calculations. Comparisons were made based on the same working frequency, and a number was obtained which became the correction factor for Ramesh's formula of $s = 0.83477$. The next stage is to design a rectangular patch micrsostrip antenna by applying the calculation of the distance y_o according to Ramesh and according to the results of the development of the Ramesh formula.

From (8), the inset-fed distance y_o calculated to be applied to the rectangular patch microstrip antenna design with operating frequencies: 1 GHz, 1.5 GHz, 1.8 GHz, 2.0 GHz, 2.1 GHz and 2.3. GHz, 2.5 GHz, 3.0 GHz, and 3.5 GHz. The results of the simulation calculations are shown in Table 2. Then by using the Ramesh formula development equation in (10), the inset-fed distance is calculated which is given the notation (y_o') to be applied to the rectangular patch microstrip antenna design with working frequency: 1 GHz, 1.5 GHz, 1.8 GHz, 2.0 GHz, 2.1 GHz and 2.3. GHz, 2.5 GHz, 3.0 GHz, and 3.5 GHz. The results of calculations and simulations are as in Table 2.

In general, it can be seen that applying the correction factor to the Ramesh equation to calculate the inset-fed distance y_o on a rectangular patch microstrip antenna, can significantly improve the performance of

the antenna. Comparison of the VSWR value according to the Ramesh formula and according to the Ramesh formula with the correction factor as a function of frequency is shown in Figure 4 and Figure 5.

Table 2. Calculation result of return loss and VSWR

No	Freq (GHz)	y_0 (mm)	x (mm)	Return Loss (dB)	VSWR	y'_0 (mm)	x (mm)	Return Loss (dB)	VSWR
		Ramesh Formula				Ramesh Formula with correction factor			
1	1.0	21.90175702	1.0	-9.1560	2.0698	18.2829297	1.0	-12.0587	1.6649
2	1.0	21.90175702	1.5	-08.6910	2.2669	18.2829297	1.5	-11.1581	1.8234
3	1.5	14.56123591	1.0	-16.4449	1.3545	12.1552829	1.0	-19.5423	1.2357
4	1.5	14.56123591	1.5	-12.8227	1.5923	12.1552829	1.5	-16.9746	1.3301
5	1.8	12.11045172	1.0	-18.7029	1.2627	10.10944179	1.0	-21.6158	1.1811
6	1.8	12.11045172	1.5	-12.8100	1.4179	10.10944179	1.5	-21.8150	1.0840
7	2.0	10.88376055	1.0	-16.6782	1.3435	9.085436794	1.0	-18.9351	1.2549
8	2.0	10.88376055	1.5	-18.3934	1.2735	9.085436794	1.5	-26.3702	1.1009
9	2.1	10.35769148	1.0	-21.1357	1.1924	8.214487105	1.0	-21.5611	1.1823
10	2.1	10.35769148	1.5	-17.4350	1.3104	8.214487105	1.5	-26.3675	1.1009
11	2.3	9.442197256	1.0	-22.6716	1.1587	7.882063003	1.0	-20.6034	1.2058
12	2.3	9.442197256	1.5	-20.1849	1.2170	7.882063003	1.5	-22.0918	1.1706
13	2.5	8.672498668	1.0	-20.0870	1.2198	7.239541713	1.0	-18.6864	1.2633
14	2.5	8.672498668	1.5	-21.9312	1.3679	7.239541713	1.5	-18.4547	1.2714
15	3.0	7.194998943	1.0	-23.9592	1.1354	6.006169268	1.0	-16.4755	1.3531
16	3.0	7.194998943	1.5	-18.8403	1.2581	6.006169268	1.5	-17.7743	1.2968
17	3.5	6.137242629	1.0	-22.8029	1.1561	5.123186029	1.0	-16.2020	1.3664
18	3.5	6.137242629	1.5	-15.9437	1.3796	5.123186029	1.5	-23.4085	1.1449

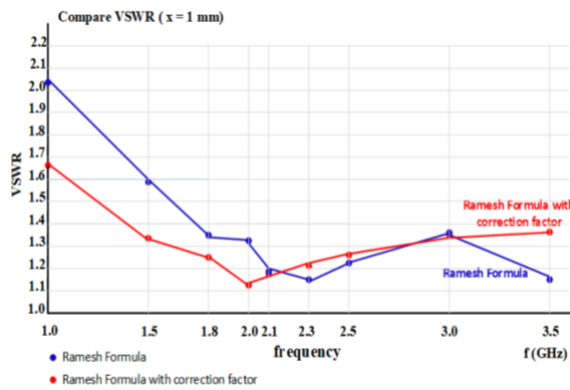Substrate Parammeter: FR4 Epoxy, $\varepsilon_r = 4.4$, h=1.6 mm.

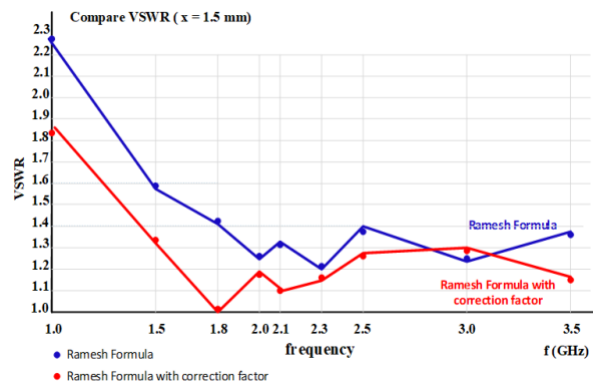Figure 4. VSWR graph of Ramesh's formula compared to Ramesh's formula with correction factors (x=1 mm)

Figure 5. VSWR graph of Ramesh's formula compared to Ramesh's formula with correction factors (x=1.5 mm)

The results of the proposed calculations produce a lower VSWR value at the resonant frequency than the results obtained by Panda [22] and Chemkha [23]. In terms of antenna efficiency, Samarthay *et al*. [21] experiment obtained greater efficiency.

4. CONCLUSION

Based on the experimental results it can be concluded that calculation of y_0 distance using the Ramesh formula with a correction factor *s=0.83477* results in a lower Return Loss (S11) and VSWR compared to using the original Ramesh formula.

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