e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:

https://dergipark.org.tr/en/pub/ijaet

Original Research Article

A new design micropatch antenna for GPS applications on vehicle navigation systems

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ARTICLE INFO

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Received: May 30, 2019
Accepted: Nov 08, 2019

Published by Editorial Board Members of IJAET

ABSTRACT

A new design of the micropatch antenna for GPS applications is studied. 70 antenna iterations working around the L1 band (1575 MHz) with different sized quarter-circular slots on the patch are designed and simulated. In parallel, "design dimensional parameters ("r" slot radius and "h" substrate thickness) and antenna resonant frequencies according to parameters" are applied to curve fitting algorithm and an equation for resonance frequency is obtained based on r and h. The resonance frequency values obtained by proposed equation are compared with simulations.

Keywords: Microstrip antennas, antenna design, GPS navigation systems, vehicle navigation.

1. Introduction

The GPS (Global Positioning System) has revolutionized modern day navigation and position location. It is now the means of tracking and location mapping in most of the aircraft carriers, ships and even in automobiles [1]. The GPS satellite transmits low power radio signals on multiple frequencies. L1 and L2 are the two basic carrier frequencies that contain the navigational signal. The L1 frequency is 1575,42MHz in the UHF band while the L2 frequency is 1227.6 MHz [2].

To make a GPS receiver work efficiently, a GPS antenna should fulfill two main requirements; good radiation pattern in the upper half-plane and RHCP (Right Hand Circular Polarization) [3]. Patch antennas are the most preferred antennas due to their miniature structures. It should also be added that patch antennas also have some drawbacks like low gain, narrow bandwidth, and low power handling capacity. To overcome these limitations, lots of designed antennas are proposed such as a U-shaped slotted patch [4], a triangular patch [5], a circular patch [6], rectangular patch [7], irregular diamond, edge slotted patch [8], etc. Antenna designs with circular slots on microstrip patches to obtain wideband are also proposed [9-11]. Furthermore, different substrate materials and different feeding techniques are also applied [12, 13].

The physical length, L, is the most effective parameter to define resonance frequency of micropatch antenna (MPA). This value should be calculated according to the required resonance frequency. However, to change the value of L means to modify external dimensions of the antenna, which might have conflicts with mounting constraints. In the automotive industry, GPS antennas are mounted inside the shark antennas which are on the roof of the car (Fig. 1) or on the dashboard (Fig. 2). Dashboard in a car is a very tight area and it is very complicated due to having many other components inside. Different antenna components also exist in shark antennas, so minimization of the physical dimensions of a GPS antenna would allow obtaining more space inside.

In this paper, a modified rectangular MPA is studied. A rectangular patch with two quarter-circular slots at the edges is proposed. The radii of the quarter-circular slots are changed proportionally with L of the main rectangle between 0.05L and 0.5L.

The main goals of this study are:

1. to change h to increase bandwidth
2. to change the radii of circular cavities to compensate for the side effects of increasing *h* on the resonance frequency
3. to obtain the resonance frequency function of r and h variables for the proposed design.

For different substrate thickness values, the effects of the slot radius on the resonance frequency are observed. The results are used to obtain a smooth equation for resonance frequency.

Fig. 1. GPS patch antenna inside shark antenna.

Fig. 2. GPS patch antenna inside dashboard

70 models (10 different radii for 7 different substrate thickness values) are simulated. Then, the curve fitting is applied to the results to obtain the equation model which shows the dependence of the frequency on h and r. Consequently, for antenna designers, a simple model has been created that can be useful when used in conjunction with analytical methods. MPA design principles, antenna design with different parameters and its simulation results are mentioned in Section II. Curve fitting, obtained model and the compatibility between simulation and equation results are mentioned in Section III. Finally, in Section IV, the conclusions and the benefits of the model are mentioned.

2. MPA Design and Simulation

MPA antenna, consists of a metallic plate as ground, a radiating patch and a dielectric substrate between them [14].

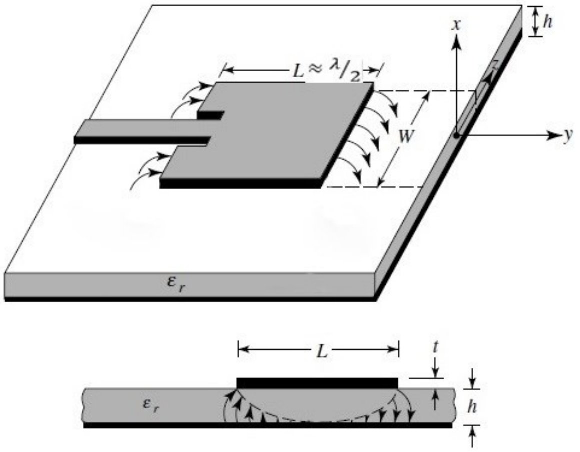

Fig. 3. Microstrip patch antenna structure [14]

h is the dimension of the substrate between ground and patch ($0.003\ \lambda_0 < h < 0.05\ \lambda_0$), where λ_0 is the wavelength in free space. The dielectric constant of substrates that can be used for MPA is in the range of $2.2 \leq \varepsilon_r \leq 12$, [14].

The length of MPA, L, is the most effective parameter to define resonance frequency and it is usually varied between $\lambda_0/3 < L < \lambda_0/2$. For the dominant mode TM_{010} with no fringing its value is defined as $\lambda/2$. [14]. The electrical length of MPA (L_{eff}) is larger than physical length L because of the fringing effects. The difference between the two lengths is linked with dielectric constant and thickness of the substrate. L_{eff} is the sum of physical L and $2\Delta L$ (Eq.1), where ΔL is the function of effective dielectric constant (ε_{reff}) (Eq.3) and the width-to-height ratio (W/h) as in Eq. 2 [17].

$$L_{eff} = L + 2\Delta L \quad (1)$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (2)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (3)$$

Therefore, the actual physical length is

$$L = L_{eff} - 2\Delta L \quad (4)$$

Resonance frequency equation of the MPA is [15].

$$f_r = \frac{c_0}{2L_{eff}\sqrt{\varepsilon_{reff}}} \quad (5)$$

MPA width *W* is important to define the input impedance of the antenna and higher *W* values mean more bandwidth [17].

$$W = \frac{1}{2f_c\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (6)$$

Regarding ground dimensions, similar results for the finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery [2].

In this study, as a first step, a rectangular MPA for f_r=1.575 GHz, λ=0.19m with substrate material duroid (ε_r=2.2) is designed. For maximum bandwidth substrate thickness (h) is chosen as 95 mm which is approximately 5% of wavelength (h_{max}=0.05 λ=9.52mm). Patch width (*W*) and physical length (*L*) are calculated as 75.23 mm (Eq. 6) and 54.41 mm (Eq. 4), respectively, while extension length (*ΔL*) is 4.86 mm (Eq. 2), which are given in Table 1.

Table 1. Parameters of the proposed antenna

Parameter Name	Value
Initial resonance frequency	1.575 [GHz]
Dielectric constant of substrate	2.2
Width of patch (W) (Eq.6)	75.23 [mm]
Length of patch (L) (Eq.5)	54.41 [mm]
Substrate height (h) (for max. BW 5%of L)	9.5 [mm]
Cavity Radius (r) (simulated)	0.05L≤r≤0.5L [mm]
Substrate height (h) (simulated)	6.5≤h≤ 9.5 [mm]

From the simulation results of the rectangular patch antenna (Fig. 4), it is observed that return loss S11=-24.06, the resonant frequency f_r=1.498 GHz and the 10dB bandwidth is BW=135 MHz (Fig. 5) and VSWR=1.337 (Fig. 6).

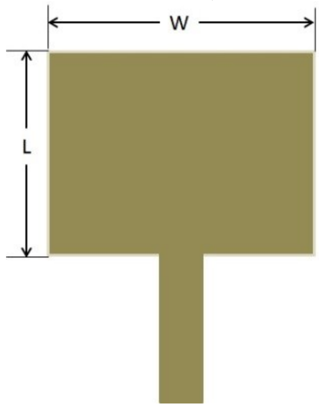

Fig. 4. Top view of the rectangular MPA

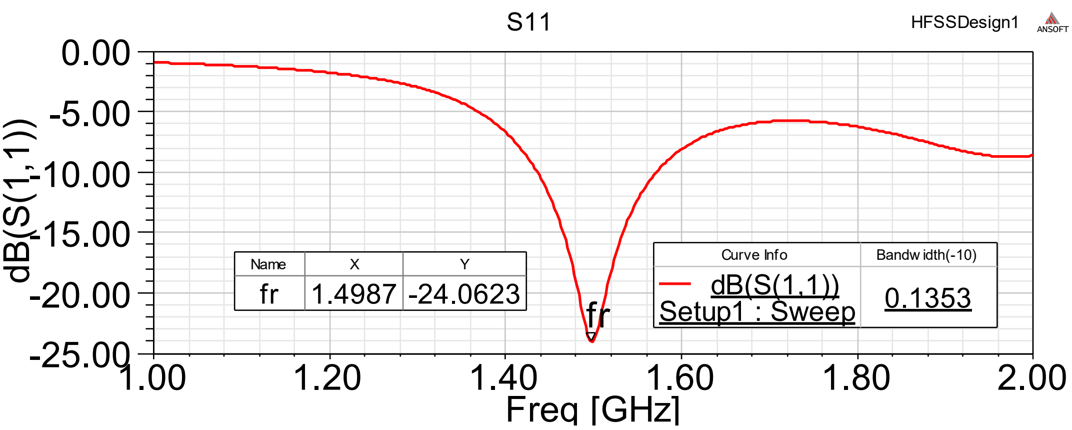

Fig. 5. Return loss S (1,1) of the rectangular MPA

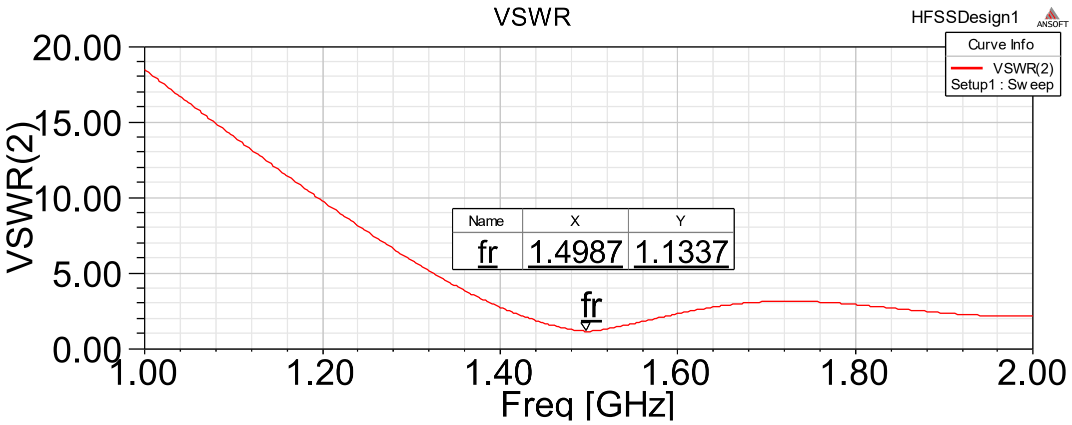

Fig. 6. VSWR of the rectangular MPA

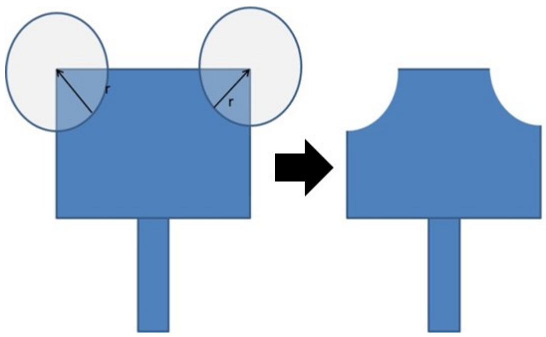

Fig. 7. The design of the proposed antenna with quarter-circular slots on rectangular MPA

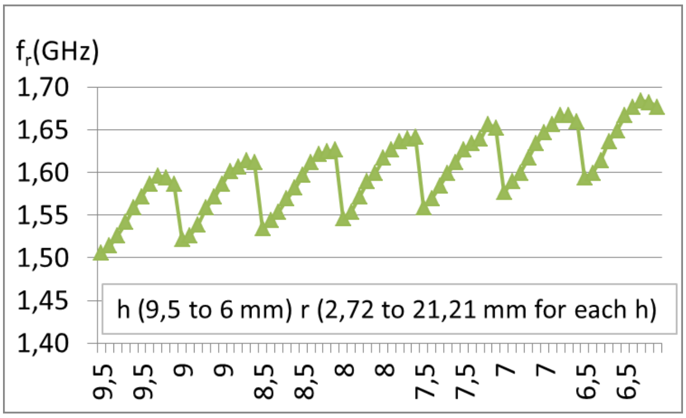

Fig. 8. f_r values obtained by 70 iterations

Then the proposed antenna with two quarter-circular slots (centers on the top right and left corners of the rectangular patch), is designed ($0.05L \leq r \leq 0.5L$) (Fig 7). 10 different radius values are used for quarter-circular slots. And each model is simulated for 7 different h values. That is 70 simulations are performed for the designed antenna and f_r and BW values are obtained to observe the impacts of circular slots (Table 2). The f_r values obtained by simulations are also given in Fig. 8.

According to the simulations, the following results are observed:

i. When r is increased until 0.45L, f_r and bandwidth are also increasing,

ii. Lower values of h cause narrower bandwidth (as expected) but the higher resonance frequency in comparison with higher values of h.

3. Model Acquisition and Verification

In this study h and r parameters are used as the variables to adjust f_r and bandwidth. Assuming that W and L are constant, h and r parameters are varied to obtain corresponding f_r values and to generate a dataset, with 70 x 3 parameters (r, h, f_r). As a result, an equation with 2 variables (r, h) is proposed and studied. A dataset, with 70 x 3 parameters (r, h, f_r), is applied to the curve-fitting process Assuming that *W* and *L* are stable, h and r parameters are used as the equation inputs and f_r is the output.

The MATLAB software is used for the curve-fitting method to obtain a relationship between the design parameters (h,r) and the corresponding resonance frequency (f_r) of the proposed antenna. To ensure the robustness of the design, a 3rd-degree polynomial model is studied (Eq. 7).

$$f_r(r,h) = A + B*r + C*h + D*r^2 + E*r*h + F*h^2 + G*r^3 + H*r^2*h + I*r*h^2 + J*h^3 \quad (7)$$

Table 2. Simulation results of 70 iterations

	From design		From Simulation			From design		From Simulation	
	r(mm)	h(mm)	fr(GHz)	BW(MHz)		r(mm)	h(mm)	fr(GHz)	BW(MHz)
1	2,72	9,5	1,51	137	36	16,32	8	1,62	137
2	5,44	9,5	1,51	138	37	19,04	8	1,63	146
3	8,16	9,5	1,53	144	38	21,77	8	1,64	149
4	10,88	9,5	1,54	150	39	24,49	8	1,64	138
5	13,60	9,5	1,56	155	40	27,21	8	1,64	120
6	16,32	9,5	1,57	166	41	2,72	7,5	1,56	98
7	19,04	9,5	1,59	174	42	5,44	7,5	1,57	97
8	21,77	9,5	1,60	180	43	8,16	7,5	1,58	102
9	24,49	9,5	1,59	158	44	10,88	7,5	1,60	107
10	27,21	9,5	1,59	137	45	13,60	7,5	1,61	114
11	2,72	9	1,52	130	46	16,32	7,5	1,63	125
12	5,44	9	1,53	132	47	19,04	7,5	1,63	130
13	8,16	9	1,54	135	48	21,77	7,5	1,64	133
14	10,88	9	1,56	141	49	24,49	7,5	1,66	130
15	13,60	9	1,57	149	50	27,21	7,5	1,65	111
16	16,32	9	1,59	159	51	2,72	7	1,58	82
17	19,04	9	1,60	174	52	5,44	7	1,59	81
18	21,77	9	1,61	165	53	8,16	7	1,60	83
19	24,49	9	1,61	158	54	10,88	7	1,62	93
20	27,21	9	1,61	136	55	13,60	7	1,63	100
21	2,72	8,5	1,53	120	56	16,32	7	1,65	106
22	5,44	8,5	1,54	124	57	19,04	7	1,66	122
23	8,16	8,5	1,55	126	58	21,77	7	1,67	126
24	10,88	8,5	1,57	132	59	24,49	7	1,67	118
25	13,60	8,5	1,58	137	60	27,21	7	1,66	100
26	16,32	8,5	1,60	147	61	2,72	6,5	1,59	55
27	19,04	8,5	1,61	152	62	5,44	6,5	1,60	56
28	21,77	8,5	1,62	160	63	8,16	6,5	1,61	65
29	24,49	8,5	1,62	146	64	10,88	6,5	1,64	68
30	27,21	8,5	1,63	126	65	13,60	6,5	1,65	77
31	2,72	8	1,55	110	66	16,32	6,5	1,67	94
32	5,44	8	1,55	112	67	19,04	6,5	1,68	110
33	8,16	8	1,57	115	68	21,77	6,5	1,68	114
34	10,88	8	1,59	123	69	24,49	6,5	1,68	109
35	13,60	8	1,60	126	70	27,21	6,5	1,68	95

where *A, B, C, D, E, F, G, H, I, J* are the calculated constants and they are given in Table 3.

For 70 pairs of r and h values, f_r values calculated (f_c) with Eq. 7 are compared with f_r values obtained by simulation (f_s) (Fig. 9).

Table 3. Calculated constants of the 3rd degree polynomial

A=2.538	*B=-0.001349*	*C=-0.3041*
D=0.000293	*E=0.000986*	*F=0.03242*
G=-0.00001172	*H=0.00001514*	
I=-0.00008751	*J=-0.001249*	

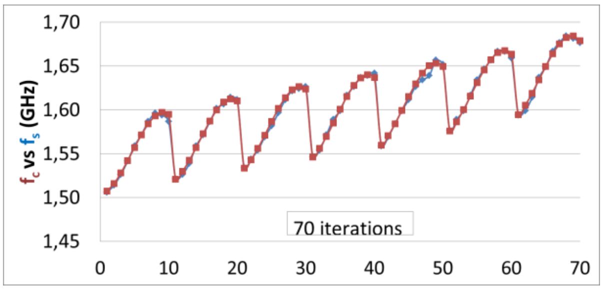

Fig. 9. Comparison between simulation and equation results

The error between them is calculated by Eq. 8.

$$\%error = \left(\frac{|f_C - f_S|}{f_C}\right) 100 \quad (8)$$

It is observed that the error values are varying between 0% and 0.67%, and the average error is 0.14% (Table 4).

Table 4. The resonance frequencies obtained by simulation (f_s) and equation (f_c)

N	fs(simulation)	fc (equation)	% Error	N	fs(simulation)	fc (equation)	% Error
1	1,506	1,507	0,09	36	1,617	1,615	0,08
2	1,514	1,516	0,13	37	1,627	1,628	0,07
3	1,526	1,528	0,12	38	1,637	1,636	0,02
4	1,541	1,542	0,04	39	1,639	1,640	0,04
5	1,559	1,557	0,12	40	1,642	1,637	0,30
6	1,571	1,571	0,00	41	1,559	1,560	0,06
7	1,587	1,584	0,17	42	1,569	1,570	0,08
8	1,596	1,593	0,20	43	1,584	1,584	0,01
9	1,594	1,597	0,18	44	1,599	1,599	0,01
10	1,587	1,595	0,52	45	1,612	1,615	0,22
11	1,521	1,521	0,04	46	1,627	1,630	0,19
12	1,526	1,530	0,23	47	1,634	1,642	0,47
13	1,539	1,542	0,23	48	1,639	1,650	0,67
14	1,559	1,557	0,12	49	1,657	1,653	0,21
15	1,571	1,572	0,07	50	1,652	1,649	0,13
16	1,587	1,587	0,04	51	1,576	1,576	0,05
17	1,602	1,600	0,12	52	1,589	1,586	0,17
18	1,607	1,609	0,13	53	1,599	1,600	0,06
19	1,614	1,613	0,09	54	1,617	1,615	0,07
20	1,612	1,610	0,08	55	1,634	1,631	0,19
21	1,534	1,533	0,03	56	1,647	1,645	0,07
22	1,544	1,543	0,06	57	1,657	1,657	0,04
23	1,554	1,556	0,13	58	1,667	1,665	0,09
24	1,569	1,571	0,13	59	1,667	1,668	0,05
25	1,582	1,587	0,32	60	1,659	1,663	0,25
26	1,597	1,601	0,31	61	1,594	1,594	0,03
27	1,612	1,614	0,15	62	1,599	1,605	0,39
28	1,622	1,623	0,07	63	1,614	1,619	0,30
29	1,624	1,627	0,15	64	1,637	1,634	0,15
30	1,627	1,624	0,17	65	1,649	1,650	0,03
31	1,546	1,546	0,03	66	1,667	1,664	0,18
32	1,554	1,556	0,14	67	1,677	1,675	0,10
33	1,571	1,569	0,12	68	1,684	1,682	0,11
34	1,589	1,585	0,27	69	1,682	1,684	0,14
35	1,599	1,600	0,09	70	1,677	1,679	0,13
Avarage error (%)							0,14

4. Conclusion

In this article, a modified rectangular MPA with circular cavities was studied. After overviewing of these studies, the following results are obtained:

a. Increasing r is ensuring more bandwidth and ascending resonance frequency without changing outer dimensions of MPA till r=0.45L as seen in Table 2

b. Impacts of increasing r has similar behavior at different values of h and behavior similar to linear tendency as seen in Fig. 8

c. Having same fr with different r and h sizes (Table 2 iteration 8 and 44 have both 1.60 GHz) can ensure flexibility to designers

d. Lower values of h cause narrower bandwidth (as expected) but the higher resonance frequencies.

e. Results with linear tendency have let us to search for equation model giving very close results to simulation results obviously seen in Table 4 and Fig. 9.

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