INPUT IMPEDANCE AND RESONANT FREQUENCY CHARACTERIZATION FOR FOLDED SLOT ANTENNAS THROUGH DOE TECHNIQUES[1]

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I. Introduction

This report is a continuation of [1], where an impedance matching technique for asymmetrical folded-slot antennas (FSAs) was introduced. Design of Experiment (DOE) techniques had been extensively used for improving the robustness of designs. In this work the effect of the design parameters on the FSA frequency response are characterized through DOE techniques. FSAs have recently been studied in [1-3]; folded-slot antennas on semi-infinite substrates are analyzed in [2], where FSA and Double Folded Slot Antennas (DFS) are characterized in terms of their radiation pattern and input impedance. FSAs on thin substrates have been analyzed using FDTD in [3], where the multiple-slot impedance engineering technique was developed.

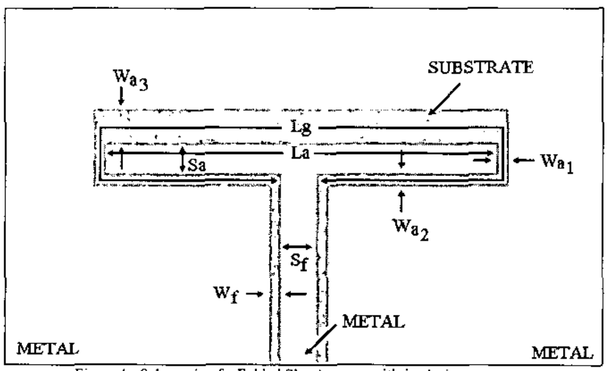

Figure 1. Schematic of a Folded Slot Antenna with its design parameters.

The FSAs considered in this research are fed through coplanar waveguide (CPW) and as shown in Figure 1, they have seven design parameters. These design parameters are L_a, S_a, W_{a1}, W_{a2}, W_{a3}, and the CPW feed (S_f, and W_f). For the proper characterization, we also have to consider the substrates width (h) and its relative permittivity (ε_r). In [1] it was shown that the variation of W_{a3} was able to reduce the folded-slot's high input impedance to a desired value.

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II. Methodology for the Characterization of the Folded Slot Antenna

To make the problem manageable, certain constraints where made. The substrate relative permittivity and its width were maintained constant with values of 3.48 and 0.762 mm respectively. Also, the antenna was fed through a 50 Ω CPW line obtained with a center conductor width of 3.657 mm and a slot width of 0.25 mm. The characterization was accomplished through DOE techniques. At specific values of L_a, a full 2^4 factorial design was used. The four factors observed for the design were S_a, W_{a1}, W_{a2} and W_{a3}, each with values of 0.25 mm or 1 mm. The parameter L_a has values of 23.497 mm, 13.357 mm and 10.157 mm. Each factorial design produced 16 different antennas for a total of 48 different simulations. Each factorial design was analyzed for the effects in our two responses; resonant frequency and input impedance at resonance for two different antenna resonances. The effects of the parameters are useful since they give us an insight on which variables or their interactions are the ones that mainly affect our response variables [4].

III. Characterization of the Folded Slot Antenna

Figure 2 shows a usual impedance response for a FSA. The figure shows 4 resonant points. The trace begins at an open circuit for when direct current (DC) is applied and as the frequency begins to increase we move clockwise until the first resonance is reached, which occurs when the perimeter is approximately $\lambda_g/2$. This first resonance is characterized for having small impedance, almost a short circuit. As the frequency continues to increase, the impedance keeps moving clockwise until the second resonance is found, which occurs when the perimeter is approximately one guided wavelength (λ_g). FSAs are mainly used at this resonance, with the impedance usually higher than 150 Ω. As the frequency increases, the third resonance appears when the FSAs' perimeter is around $3\lambda_g/2$. This resonance is characterized for having a low input impedance value. When the perimeter is approximately $2\lambda_g$, the impedance is approximately an open circuit. This work deals with the second and third resonances.

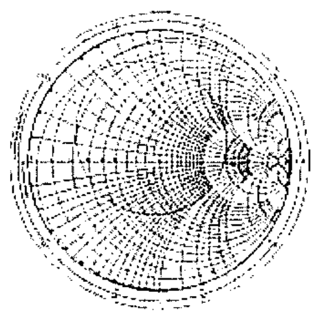

Figure 2. Usual Input Impedance response for a FSA.

As mentioned in the introduction, the values for L_a where set to 23.497 mm, 13.357 mm and 10.157 mm. By setting the parameters S_a, W_{a1}, W_{a2}, and W_{a3} to a value of 0.25 mm and for each of the respective L_a values the approximately resonant frequencies are 5 GHz, 9 GHz and 12 GHz. The factorial designs were analyzed for resonant frequency and input impedance at resonance for the λ_g and the $3\lambda_g/2$ resonances. Table 1 shows the designs and the obtained responses for the λ_g resonance, the results for the $3\lambda_g/2$ resonance where omitted due to space limitations.

Table 1. 2^4 factorial designs and the two responses (F_{res} and Z_{in}) for the λ_g resonance.

					L_a = 23.497 mm		L_a = 13.357 mm		L_a = 10.157 mm	
Design	S_a (mm)	W_{a1} (mm)	W_{a2} (mm)	W_{a3} (mm)	f_{res} (GHz)	Zin (Ω)	f_{res} (GHz)	Zin (Ω)	f_{res} (GHz)	Zin (Ω)
0	0.25	0.25	0.25	0.25	5.02	145.90	8.98	154.00	12.07	169.80
A	0.25	0.25	0.25	1	4.94	54.40	8.44	65.15	11.02	77.25
B	0.25	0.25	1	0.25	5.24	274.90	9.43	285.95	12.81	292.55
BA	0.25	0.25	1	1	5.17	134.65	9.04	149.45	11.98	157.15
C	0.25	1	0.25	0.25	4.70	159.95	8.05	184.70	10.55	214.10
CA	0.25	1	0.25	1	4.62	60.65	7.58	77.80	9.67	97.90
CB	0.25	1	1	0.25	4.91	254.30	8.44	322.75	10.99	350.30
CBA	0.25	1	1	1	4.84	147.95	8.05	177.90	10.90	204.45
D	1	0.25	0.25	0.25	4.94	153.35	8.65	162.25	11.45	173.50
DA	1	0.25	0.25	1	4.92	71.65	8.39	78.85	10.91	85.90
DB	1	0.25	1	0.25	5.15	252.40	9.10	261.55	12.03	275.20
DBA	1	0.25	1	1	5.10	142.00	8.89	144.30	11.72	142.40
DC	1	1	0.25	0.25	4.59	164.90	7.66	189.55	9.87	213.55
DCA	1	1	0.25	1	4.58	79.10	7.50	93.60	9.45	109.30
DCB	1	1	1	0.25	4.80	267.95	8.13	294.30	10.31	326.85
DCBA	1	1	1	1	4.77	153.70	7.92	175.00	10.12	190.75

a. Calculated effects at the λ_g resonance

When the parameter L_a was fixed to 23.497 mm, as can be seen from Table 1, the resonating frequencies for the antennas vary between 4.583 GHz and 5.242 GHz. This change in the resonant frequency was due to the variation of parameters S_a, W_{a1}, W_{a2}, and W_{a3}. Nevertheless all the parameters and their interactions did not affect the response with the same intensity. Through DOE techniques we can conclude that the individual effects as well as the interaction between $W_{a3}*S_a$ are the only ones which have a significant effect in our response (f_{res}). The values for the calculated effects for the 3 different L_a values are presented in Table 2. On this range the effect that mainly cause the variations on f_{res} was the effect of parameter W_{a2} which negatively affect (reduce the resonant frequency as it increases) the resonant frequency. It is interesting to observe the positive effect of W_{a2} in the resonant frequency. It would be expected that increasing the antenna dimension will decrease the resonant frequency. The overall outcome of the effects increases as the value of the parameter L_a decreases, this because the expected resonant frequency increase and the antenna becomes more sensitive to its design parameters.

Table 2. Calculated effects for the λg resonant frequency.

La (mm)	W_{a3}	W_{a2}	W_{a1}	S_a	$W_{a3}*S_a$
23.497	-0.025	0.100	-0.170	-0.037	0.013
13.357	-0.160	0.230	-0.470	-0.110	0.060
10.157	-0.270	0.370	-0.760	-0.260	-

Table 3 shows the calculated effects responsible for the variations in the input impedance at the respective resonant frequency. Supporting the work presented in [1] it is observed that the parameter W_{a3} has a large negative effect, which permits us to reduce the usually high input impedance at this resonance. It can also be seen that the parameter W_{a2} has a positive effect, which means that increasing W_{a2} will increase the input impedance at the resonant frequency. The parameter W_{a1} becomes significant as L_a decreases.

Table 3. Calculated effects for Z_{in} at the λg resonant frequency.

La (mm)	W_{a3}	W_{a2}	W_{a1}	$W_{a3}*W_{a2}$
23.497	-51.85	46.12	-	-7.06
13.357	-55.81	50.33	13.38	-8.92
10.157	-59.42	49.90	20.84	-9.35

b. Calculated effects at the $3\lambda_g/2$ resonance

The calculated effects for the $3\lambda_g/2$ resonant frequency and impedance at resonance are shown in Table 4 and in Table 5. As calculated and presented in Table 4, the only significant effects are the single effect of W_{a3}, W_{a2} and S_a. In this case, for the three values of L_a, the dominant effect was that of W_{a3}. If we make L_a equals to 10.157 then the only significant effect is that of W_{a3}.

Table 4. Calculated effects for the resonant frequency

La (mm)	W_{a3}	W_{a2}	S_a
23.497	-0.210	0.160	0.130
13.357	-0.270	0.240	0.180
10.157	-0.530	-	-

Table 5 shows the response for the input impedance at the $3\lambda_g/2$ resonance. The positive effect for the W_{a2} dimension suggests that we can increase the short circuit like impedance on this resonance to a desired value. The negative interaction suggests that if we increase W_{a2} and decrease W_{a1} we can maximize this effect.

Table 5. Calculated effects for Z_{in} at the 3λg/2 resonant frequency.

La (mm)	W_{a2}	W_{a1}	$W_{a1}*W_{a2}$
23.497	9.70	-2.40	-
13.357	12.19	-3.42	-2.17
10.157	13.64	-3.56	-2.55

IV. Conclusions

This work presents a characterization of FSAs due to its design parameters through DOE techniques for the responses resonant frequency and input impedance at the resonant frequency for the λ_g and $3\lambda_g/2$ resonances. The calculated effects are useful since they give us an insight on the effect of the design parameters on the antenna. It was verified that at the λ_g resonance the parameter W_{a3} has a great influence in decreasing the antenna input impedance. It was also found that increasing the dimension W_{a2} will increase the resonant frequency for the λ_g resonance, opposite as it would be expected. For last, in the $3\lambda_g/2$ resonance we are able to increase the usually low input impedance by increasing the parameter W_{a2} making it a useful resonance.

V. References

[1] N. López-Rivera, and R. A. Rodríguez-Solís, "Impedance Matching Technique for Microwave Folded Slot Antennas", IEEE AP-S Symp. Dig., 2002, Vol. 3, pp. 450-453.

[2] H. Tsai, R. York, "FDTD Analysis of CPW-Fed Folded-Slot and Multiple-Slot Antennas on Thin Substrates", IEEE Transactions on Antennas and Propagation, Vol. 44, NO. 2, February 1996, pp. 217-226.

[3] T. Weller, L. Katehi, and G. Rebeiz, "Single and Double Folded-Slot Antennas on Semi-Infinite Substrates", IEEE Transactions on Antennas and Propagation, Vol. 43, NO. 12, December 1995 pp. 1423-1428.

[4] D. C. Montgomery, *Design and Analysis of Experiments.* New York: Wiley, 2000 (fifth edition).