NUMERICAL INVESTIGATION OF IMPEDANCE VARIATION OF A MICROSTRIP PATCH ANTENNA WITH FEED POSITION

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Abstract

The dependence of the impedance of a rectangular patch antenna on the feed position was studied in the present work. The antenna was fed either by a microstrip line or by a coaxial probe. Both configurations were analysed with a finite-difference time-domain (FDTD) code implemented in a commercially available simulation platform. Numerical results were then compared with measurements that had been published in other studies and with the theoretical impedance variation assumed in the literature. It was shown that the numerical results are in good agreement with measurements, if (a) the real dielectric properties, including losses, are accounted for in the calculations, and (b) sufficiently fine resolution is used. It was also shown that the dependence of the impedance does not follow a cosine-squared variation, when the patch is fed by a microstrip line, but a cosine raised to the forth power.

1. INTRODUCTION

Microstrip patch antennas have been widely used in configurations, where low profile antennas are needed. Their low manufacturing cost and the variety of feed methods, i.e. probe, microstrip line and aperture coupled, make them a very attractive solution in many applications operating at microwave frequencies. In addition, microstrip antennas come in complex shapes, e.g. conformal microstrip antennas, depending on the application. As expected, the input resistance of such an antenna is not affected only by its geometrical shape and dimensions or by the physical properties of the materials involved; it also depends on the way chosen to feed the antenna. The transmission-line model [1] predicts that, when a rectangular microstrip antenna is fed by a probe, its input resistance is proportional to the cosine-squared ($\cos^2$) of the normalised feed point distance from the patch edge. This dependence can also be seen in [2], where measured values of resistance are compared with calculations based on modal analysis for different positions of the probe feed. Using the method of moments (MoM) similar results have been obtained in [3] for three width/aspect ratios of the rectangular patch.

On the other hand, measurements and theoretical calculations on the variation of input impedance for a microstrip-line-fed patch antenna as the inset position changes along the resonant direction of the patch are very rare in the literature. A recent study [4] has shown that for this case the dependence becomes proportional to the fourth power of cosine ($\cos^4$), although there is no theoretical justification for this result.

In the present work, numerical calculations have been performed, in an attempt to show how the input resistance of a rectangular microstrip antenna changes with the feed position, by employing a numerical technique suitable for both microstrip line and probe feeds.

2. MATERIALS AND METHODS

2.1. Method

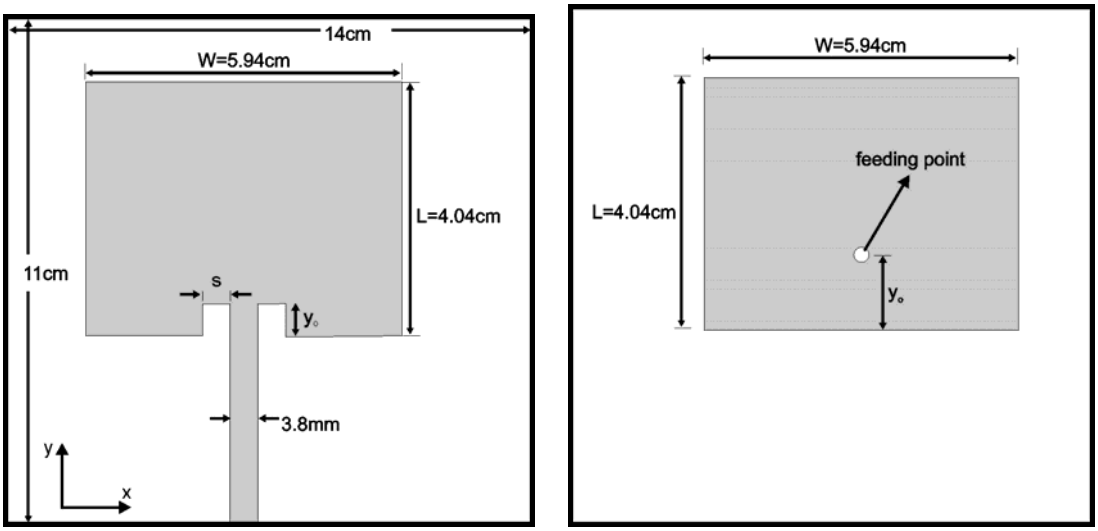
The results were obtained with SEMCAD (Schmid and Partner Engineering AG, Zeughausstrasse 43, 8004 Zurich, Switzerland), a simulation platform for electromagnetic compatibility, antenna design and non-ionising radiation dosimetry. This software implements the finite-difference time-domain (FDTD) numerical technique [5]. The results produced by SEMCAD were then compared with numerical results of other techniques and with measurements [4]. The different behaviour of the input impedance for both methods of feed was confirmed and some important issues of FDTD modelling were investigated.

2.2. Physical model

The antenna modelled was the one, which had been measured for the two types of feed in [4]; the dimensions are shown in Figure 1. In the case of the inset microstrip line feed, the distance s was chosen equal to the width of the microstrip line, i.e. s=3.8mm. In both configurations, the impedance was calculated as a function of y_o, where y_o varied from zero (at the edge of the patch) to L/2=2.02cm (at the centre of the patch). The substrate was a dielectric material of thickness h=1.27mm, $\tan\delta$=0.0019 and dielectric constant ε_r=2.42. This patch is designed to resonate around 2300MHz.

The dimensions of the coaxial feed probe were calculated [6] to achieve a 50Ω impedance. The outer (D) and inner (d) conductor diameters (Figure 2a) were

assumed to be 0.38mm and 0.11mm, respectively. The dielectric constant of the coaxial cable was chosen at ε_r=2.2.



(a) (b)

Figure 1. Dimensions of the examined (a) microstrip-line-fed and (b) probe fed antenna.

2.3. Numerical model

Two numerical models, i.e. a coarse and a fine grid, were used for each feed configuration. The grid was always rectangular and non-uniform. It was generated automatically by the software, which, however, can take into consideration the constraints that the user might wish to apply. As a general rule, meshing was finer at the edges of structures, to allow for a better resolution there. The reason for investigating two grid resolutions was that the dimensions of a micropatch simulated with FDTD are actually extended by approximately half a cell [7]. A smaller cell size, therefore, reduces the dimensions of the patch model and, consequently, the numerical resonance frequency becomes larger. (The resonance frequency is used for determining the numerical input impedance.)

In the case of the antenna fed by an inset microstrip line, the minimum cell size of the coarse grid was 0.3mm (λ_g/280, where λ_g is the guided wavelength at 2.3GHz) and it was applied in the z direction. In the x and y directions, the minimum cell size of 0.5mm (λ_g/160) was applied at material interfaces and the maximum cell size of 2mm was used near the boundaries of the computational domain. The coarse grid consisted of about 56,000 cells. In the fine grid, the cell size at the edges of the patch (in the x

and y directions) was reduced from 0.5mm to 0.1mm. This change resulted in a grid, which comprised about 120,000 cells.

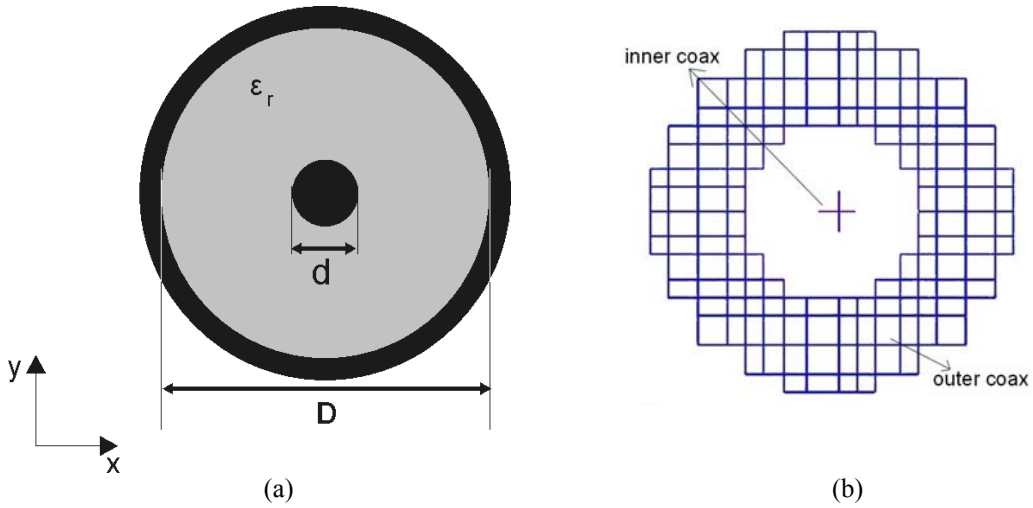


Figure 2. (a) Dimensions of the modelled coaxial feed. (b) Numerical model of the coaxial feed.

Modelling the coaxial cable and the probe in the second feed configuration of the antenna was achieved with the staircasing approximation with a grid step inside the cable of 0.08mm in the x and y directions (Figure 2b). This resolution was used for both the coarse and fine grids of the probe-fed antenna. However, the smallest cell size of 0.03mm was applied in the z direction. In the coarse grid the cell size at the antenna edges in the x and y direction was 1mm and it was reduced to 0.1mm for the fine grid. The number of voxels in the two grids was 70,000 and 110,000, respectively.

The choice of the cell size is dictated both by the minimum wavelength present in the model and by the smallest physical dimension that must be modelled. The pulse that excited the antenna had harmonics up to 4GHz. Since this frequency corresponds to the minimum wavelength, a cell size of 2mm ($\approx\lambda_{min}/25$) could be used. However, in order to model the width of the microstrip line (w=3.8mm) a finer cell size should be used in the x and y directions, which results in a discretized model of more than three cells for the microstrip line. On the other hand, modeling the thin substrate (1.27mm) requires again a cell size less than 2mm in the z direction. Finally, the smallest physical dimension that existed in the coaxial cable was the inner metal conductor representing the probe, with a diameter of 0.22mm; the cell size had to be set at 0.08mm, so that three cells compiled the probe in the coarse grid. The limiting factors in the choice of the cell size are the available computational resources and time.

The computational domain was truncated with a Perfectly Matching Layer (PML) of 6 cells in thickness. All calculations were performed for a Gaussian pulse excitation. The pulse was centred at 2300MHz with T_s=0.3nsec and T_p=0.9nsec, where T_s is the width of the pulse and T_p is the time interval between zero and the peak value of the pulse. These values produced a Gaussian pulse with a frequency spectrum extending from 0.5GHz to 4GHz.

3. RESULTS

The objective of this work is to study numerically how the input impedance of a rectangular microstrip patch antenna varies with feed position. The input impedance is evaluated at the resonance frequency, which is assumed as the frequency of highest resistance. Therefore, it is interesting to see first how the numerically derived resonant frequency changes with the position of the feed point. Figure 3 presents this variation for the two studied feed methods.

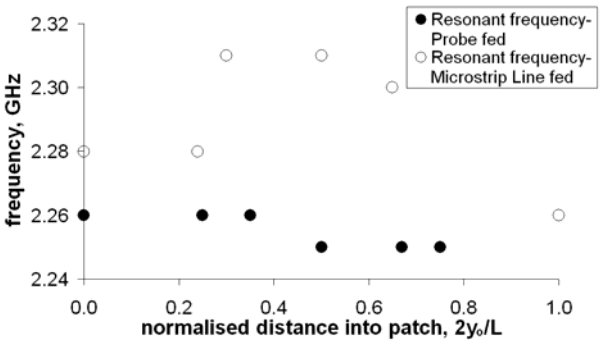


Figure 3. Resonant frequency of the patch antenna for the two feed types and for various positions of the feed.

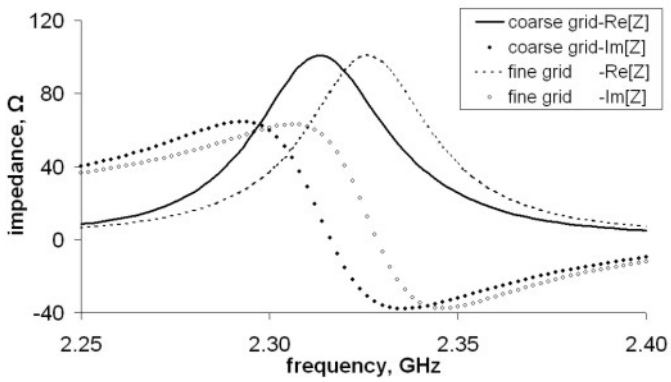


Figure 4. Shift of the calculated resonant frequency of the patch for a finer grid. Microstrip-line feed at y_o=0.3(L/2).

In the case of a microstrip-line-fed patch, the choice of the cell size affects the resonance frequency. By reducing the cell size in the antenna from 0.5mm to 0.1mm, the resonant frequency occurs at a value higher by about 10MHz (Figure 4). However, the computational cost for predicting resonance better is very high in terms of CPU time. It is important to note that the value of the predicted input impedance does not change for the coarse and the fine grid. The antenna bandwidth can also be estimated with the software from the values of SWR at its input. The bandwidth for which the antenna exhibited an SWR smaller than 2:1 was found BW=30MHz or 1.3%.

The resonant mechanism is depicted in Figure 5, which shows the distribution of the E_z field component. (Field strength is normalised to the maximum value of the cross section.) This field distribution corresponds to a patch fed by a microstrip line at y_o=0.3(L/2) and harmonic excitation at frequency 2314MHz. At this frequency, λ_g in the microstrip can be calculated theoretically [6] as 85.2mm, whereas its numerical value is found at 90mm (about 5.8% higher).

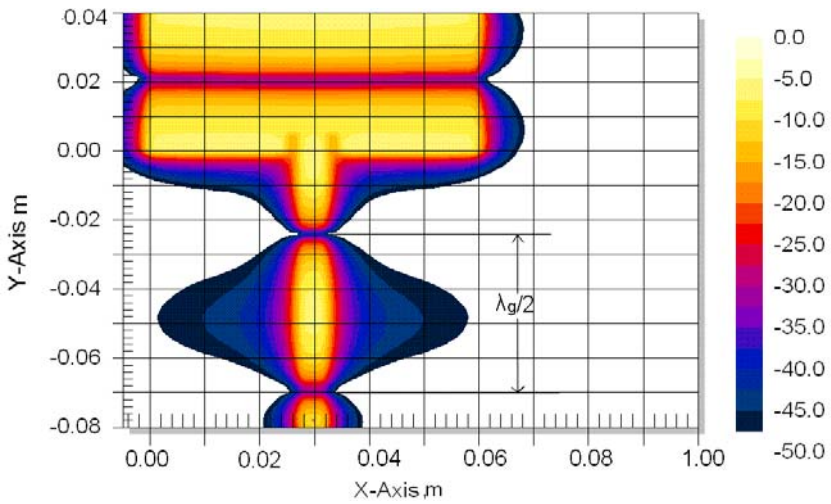


Figure 5. Resonant mechanism shown as the distribution of the dominant electric field strength inside the substrate. Microstrip-line feed at y_o=0.3(L/2).

As mentioned above, the substrate used was a dielectric material of tanδ=0.0019. The value of the impedance diminishes as losses become larger, but these losses do not affect the frequency at which resonance occurs. The values of impedance were examined for two numerical models, one with losses and one without. In accordance to [8] differences up to 18Ω (11%) occurred for the case of the microstrip-line-fed antenna, therefore substrate losses have been taken into account in the calculations.

Table 1 shows the percentage difference of the real part of the impedance, as calculated for the material with and without losses.

Table 1. Difference in the calculated impedance when losses are considered.

Normalised distance	Microstip-line-fed			Probe-fed		
	Value (Ω) tanδ=0	Value (Ω) tanδ=0.0019	Difference (%)	Value (Ω) tanδ=0	Value (Ω) tanδ=0.0019	Difference (%)
0.00	181	163	11.04	187	169	9.63
0.24	124	112	10.71	-	-	-
0.25	-	-	-	150	136	9.33
0.30	101	92	9.78	-	-	-
0.35	-	-	-	117	102	9.40
0.50	46	42	9.52	77	72	8.57
0.65	14	13	7.69	-	-	-
0.67	-	-	-	35	32	8.57
1.00	12	11	9.09	0	0	0.00

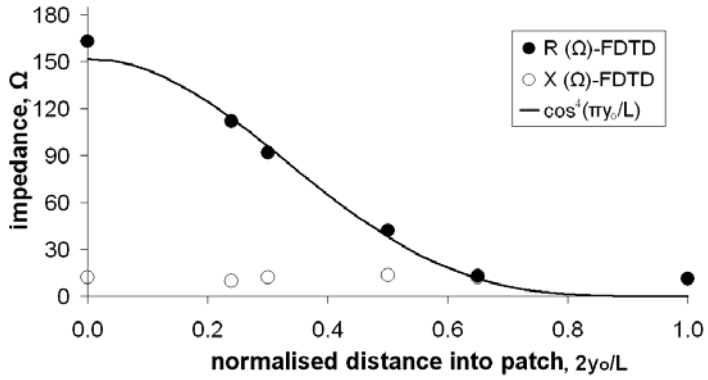


Figure 6. Variation of input impedance of the microstrip-line-fed antenna with feed position.

The dependence of the input impedance of the microstrip-fed antenna is shown in Figure 6 as the feed position changes from the edge to the centre of the patch. The values of the resistance seem to follow the $\cos^4$ distribution, normalised at y_o=L/4. Compared with the results of [4], the numerical values are higher but they seem to converge to the measured ones as the feed position moves toward the centre of the patch. On the contrary, the numerical values of reactance appear in agreement with the measured ones. One would expect that symmetrical excitation of the patch (y_o=L/2) should lead to zero resistance, since no mode can be excited. However, experimental [4] and numerical results (this work) show that input resistance takes some value (approximately 10Ω) for this case, as well (Table 2). In order to feed the

patch with a microstrip line, it is obligatory to cut the patch and destroy its symmetry. Thus, a mode that is produced makes the patch radiate. Table 2 shows that calculations based on the transmission line theory [10] fail to predict this phenomenon. This behaviour is not expected in the case of the probe-fed patch, which is always symmetrical.

Table 2. Results for the microstrip-line feed.

		FDTD		Measured[1] [4]		Transmission Line Model [10]	
Normalised distance	$\cos^4(\pi y_o/L)$	Value (Ω)	Difference (%)	Value (Ω)	Difference (%)	Value (Ω)	Difference (%)
0.00	152	163	7	145	5	158	4
0.24	114	112	1	109	4	132	14
0.30	96	92	4	80	20	121	21
0.50	38	42	10	38	0	75	49
0.65	11	13	13	9	26	41	72
1.00	0	11	-	10	-	0	-

[1]The measured values are taken from the graphs of the publication.

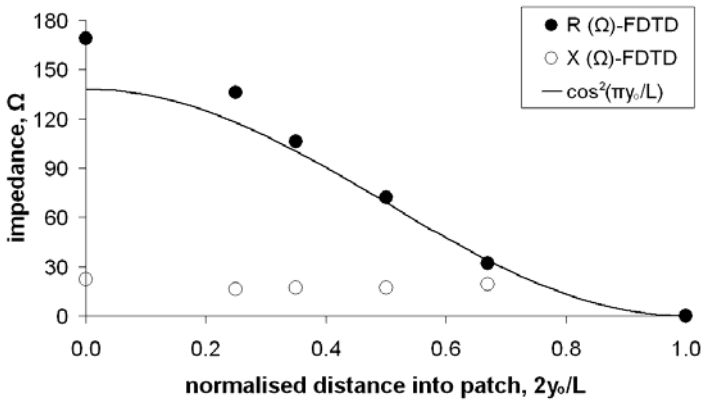


Figure 7. Variation of input impedance of the probe fed antenna with feed position.

In the probe-fed antenna (Figure 7), the numerical values near the edge of the patch were found greater not only than the measured ones but also than the values expected theoretically, following the $\cos^2$ distribution [1]. As the feed point approaches the centre of the patch, this divergence becomes smaller. The numerical values of the reactance were again similar to the measured ones and independent of the feed position. Table 3 includes the impedance values calculated with FDTD and the transmission line theory and those measured for the two feed methods.

Table 3. Results for the probe feed.

		FDTD		Measured[1] [4]		Transmission Line Model [10]	
Normalised distance	$\cos^2(\pi y_o/L)$	Value (Ω)	Difference (%)	Value (Ω)	Difference (%)	Value (Ω)	Difference (%)
0.00	138	169	18	150	8	157	12
0.25	118	136	13	120	2	129	9
0.35	100	106	5	100	0	108	7
0.50	69	72	4	69	0	72	4
0.67	34	32	6	30	13	24	41
1.00	0	0	0	0	0	0	0

[1]The measured values are taken from the graphs of the publication.

4. CONCLUSIONS

Numerical calculations were performed, in order to evaluate how the input impedance of a microstrip patch antenna changes with the position of the feed. Two different types of feed were considered, a microstrip line and a coaxial probe. The results verify that in the case of the microstrip feed, the values follow a $\cos^4$ variation with the distance of the feed point, instead of a $\cos^2$ that is usually considered in the literature. The numerical values were found in good agreement with experimental measurements in the literature. These values were obtained for the realistic case of a substrate material with losses and for a fine discretization of the antenna, especially at its edges.

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