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Harmonic-suppression Using Adaptive Surface Meshing and Genetic Algorithms

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Abstract— A novel design strategy for microstrip harmonic-suppression antennas is presented. The computational method is based on an integral equation solver using adaptive surface meshing driven by a genetic algorithm. Two examples are illustrated, all involving design of coaxially-fed air-dielectric patch antennas implanted with shorting and folded walls. The characteristics of the antennas in terms of the impedance responses and far field radiation patterns are discussed theoretically and experimentally. The performances of all of the GA-optimised antennas were shown to be excellent and the presented examples show the capability of the proposed method in antenna design using GA.

1. REVIEW AND SUMMARY OF THE METHOD

Harmonic suppression antennas (HSAs) are used to suppress power radiation at harmonic frequencies from active integrated antennas. An antenna that presents a good impedance match at the fundamental design frequency (f_o) and maximised reflection at harmonic frequencies is said to be a harmonic suppression antenna. In addition, the input impedance of any HSA design has to have minimised resistance at the harmonic frequencies and hence will be largely reactive [1, 2]. Several techniques have been proposed to control such harmonics, such as shorting pins, slots or photonic bandgap structures [3, 4]. In [5], the modified rectangular patch antenna with a series of shorting pins added to the patch centre line was applied to shape the radiated second harmonic from the active amplifying-type antenna, in order to increase the transmitter efficiency. Unfortunately, the proposed design does not provide the termination for the third harmonic. A circular sector patch antenna with 120° cut out was investigated and proved to provide additional harmonic termination for the third harmonic, also claiming a further enhancement in the transmitter efficiency [2]. Further, an H-shaped patch antenna was designed and applied in oscillator-type active integrated antennas for the purpose of eliminating the unwanted harmonic radiation [6, 7]. The present work presents a clear motivation to develop a coherent design strategy for microstrip HSA in active integrated applications. The technical work, adopts a computational technique using adaptive surface meshing driven by a genetic algorithm.

The benefit of applying GA methods is that they provide fast, accurate and reliable solutions for antenna structures. A genetic algorithm driver [8–10], written in Fortran, was adopted in this work in conjunction with the authors' Fortran source code [11], which was used to evaluate the randomly-generated antenna samples. Several antenna designs, derived using GA in previous work by the authors [12–14], have shown that the GA method to be an efficient optimiser tool that can be used to search and find rapid solutions for complex antenna design geometries.

An adaptive meshing program was also written in Fortran by the present authors and added as a subroutine to the GA driver, with the primary objective of simulating air-dielectric planar microstrip patch antenna designs: this used a surface patch model in cooperation with a GA. In addition to microstrip patch designs, the program can support the design of any 3D antenna geometry structure, including moderate amounts of dielectric materials. The present work is an extended version of preliminary work reported in [15]. The design of coaxially-fed air-dielectric microstrip harmonic-rejecting patch antennas for 2.4 GHz was investigated, enforcing suppression of the first two harmonic frequencies, using a genetic algorithm. The designs included patch antennas with shorted and folded walls.

2. SIMULATION AND RESULTS

Simple coaxially-fed air-dielectric patch antennas with shorted and folded walls, mounted on an infinite ground plane and operating at 2.4 GHz, were selected for this study as a simple exemplar to demonstrate acceptable harmonic rejection [5].

The proposed outline antenna designs are shown in Fig. 1. The full width shorted patch is subdivided into four trilaterals and two quadrilaterals, including the conducting shorted wall, as illustrated in Figs. 3(a) and 3(b). This design required six parameters to be defined. The second design example is similar to the first, but uses a modified folded wall, as shown in Figs. 3(c) and 3(d), in which the total surface area was subdivided into four trilaterals and three quadrilaterals. The fold in the wall means that it is no longer electrically connected to the ground plane, although the folded portion will provide strong capacitive coupling. In this model eight GA parameters were considered.

Table 1 presents the GA input parameters in which the possible range of values is shown for two examples considered. For this optimisation process, real-valued GA chromosomes were used. It should also be noted that the fundamental, first and second harmonic frequencies were considered within the GA cost function.

For validation, prototypes of the GA-optimised harmonic-suppression antennas (HSAs) of the two models were designed and tested. Copper sheet with thickness of 0.5 mm was used for the patch antenna, shorted/folded wall and the ground plane. The ground plane size was set to 140 mm × 140 mm, this relatively large size being chosen in order to attenuate the effect of the edges of the finite ground plane. The return losses were validated and measured results compared with calculations are shown in Fig. 2. As can be seen, the results for rejection levels of 2nd and 3rd harmonics were quite encouraging and no other resonances or ripples were found over the harmonic frequency bands.

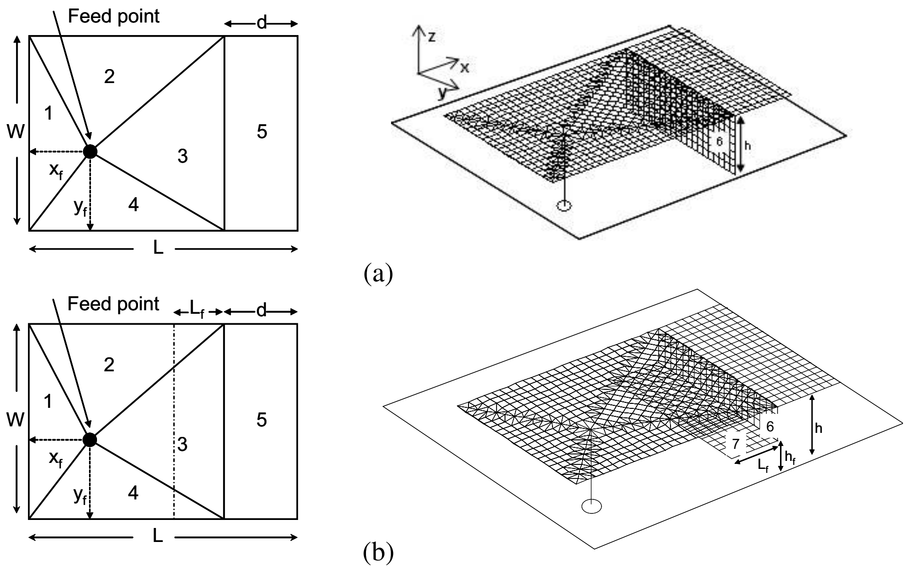

Figure 1: (a), (b) The proposed antenna models for full-width shorted wall; and (c), (d) folded wall. (a), (c): Top view; (b), (d): 3D view of surface patch meshing.

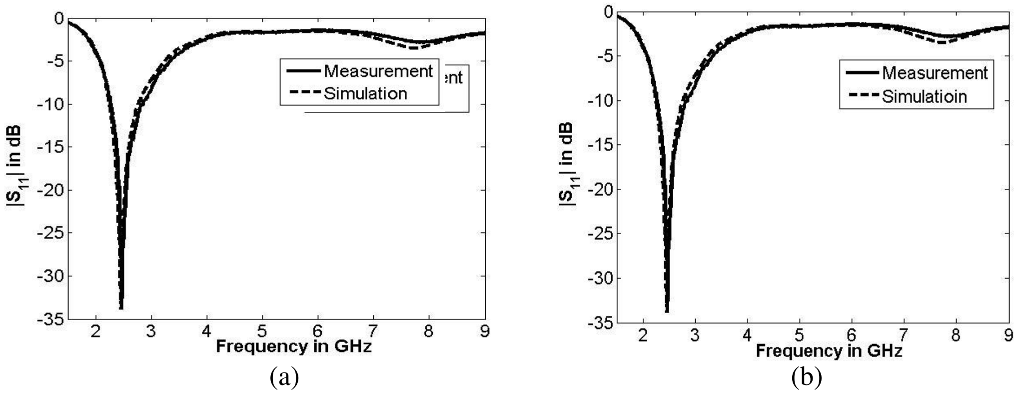

Figure 2: Performance of the measured and calculated return losses of the GA-optimised HSAs; (a) full-width shorted wall; and (b) folded wall.

Table 1: Summary of GA input parameters, antenna variables and best solutions for the proposed designs, including shorted and folded walls.

GA parameters	**Harmonic suppression antenna parameters**	**Fully shorted**	**Folded wall**
	Parameters (m)	Optimal (m)	Optimal (m)
	Antenna length (L) (0.03–0.06)	0.03950	0.04540
No. of population size = 4	Antenna width (W) (0.02–0.06)	0.03305	0.03006
No. of parameters: 6 (Figure 1(a1)), 7 (Figure 1(a2)), 8 (Figure 1 (a3))	Shorting or folded wall position (d) (0.002–0.03)	0.00972	0.00748
Probability of mutation = 0.02	Antenna height (h) (0.003–0.01)	0.0079	0.00989
Maximum generation = 500	Feeding point at x-axis (X_f) (0.004–0.02)	0.00723	0.00571
No. of possibilities = 32768	Feeding point at y-axis (Y_f) (0.004–0.02)	0.01752	0.01392
	Variable shorting wall width (W_s) (0.001–0.03)	-	-
	Extend folded wall length (L_f) (0.005–0.015)	-	0.01327
	Extend folded wall height (h_f) (0.001–0.0035)	-	0.00159

Table 2: Simulated and measured gain values at the fundamental frequency for the two antennas shown in Fig. 1.

Type of antenna		**Full shorted wall**		**Folded wall**	
Antenna gain (dBi)		Measured	Simulated	Measured	Simulated
Frequency (GHz)		$f_o = 2.47$		$f_o = 2.45$	
x-z plane	H.P.[1]	−8.35	−24.74	−13.45	−23.71
	V.P.[1]	4.14	4.06	5.01	5.03
y-z plane	H.P.	1.71	2.29	3.11	3.98
	V.P.	0.54	0.16	2.04	2.50

The input impedances of the prototype antennas were also measured over a wide frequency band as shown in Fig. 3. The measured input impedance of these antennas at the fundamental operating frequency and its first two harmonics shows that almost perfect matching to 50 Ω was attained at the fundamental frequency, while fairly small resistive impedances at harmonic frequencies were observed.

The simulated and measured radiation patterns in the z-x plane for the prototype antenna shown in Fig. 1 is presented in Fig. 4 the fundamental, second and third harmonic frequencies. The results are in good agreement and confirm viable levels of suppression of 2nd and 3rd harmonic levels. The fields for the second antenna design is quite similar thus are not shown here. These levels may be summarised as follows: for the fully-shorted wall design the maximum 2nd and 3rd harmonic radiation amplitudes were lower than 13 dB and 18 dB (respectively) below the fundamental for the z-x plane and 10 dB and 9 dB below for the z-y plane.

The simulated and measured gain values at the fundamental frequency for the two antennas shown in Fig. 1 are presented in Table 2. The simulated and measured co-polar gain values show reasonable agreement, although the differences in the cross-polar gain values are more significant. The cross-polar results are inherently weaker and hence more susceptible to minor deviations in the practical test implementation.

It was found that the full-width shorted-wall prototype antenna was resonant at 2.47 GHz and presents quite a wide bandwidth of around 500 MHz. The reflection coefficient level at the first and second harmonic frequencies was found to be 1.71 dB and 2.45 dB, respectively. These results are quite acceptable, as compared with HSAs published in the open literature [15]. It is notable that the measured resonant frequency of the prototype antenna shows good agreement with the prediction. The third prototype exhibited approximately 380 MHz bandwidth, centred at a 2.45 GHz resonance frequency. The rejection levels of the 2nd and 3rd harmonics were about 1.5 dB and 1.9 dB respectively.

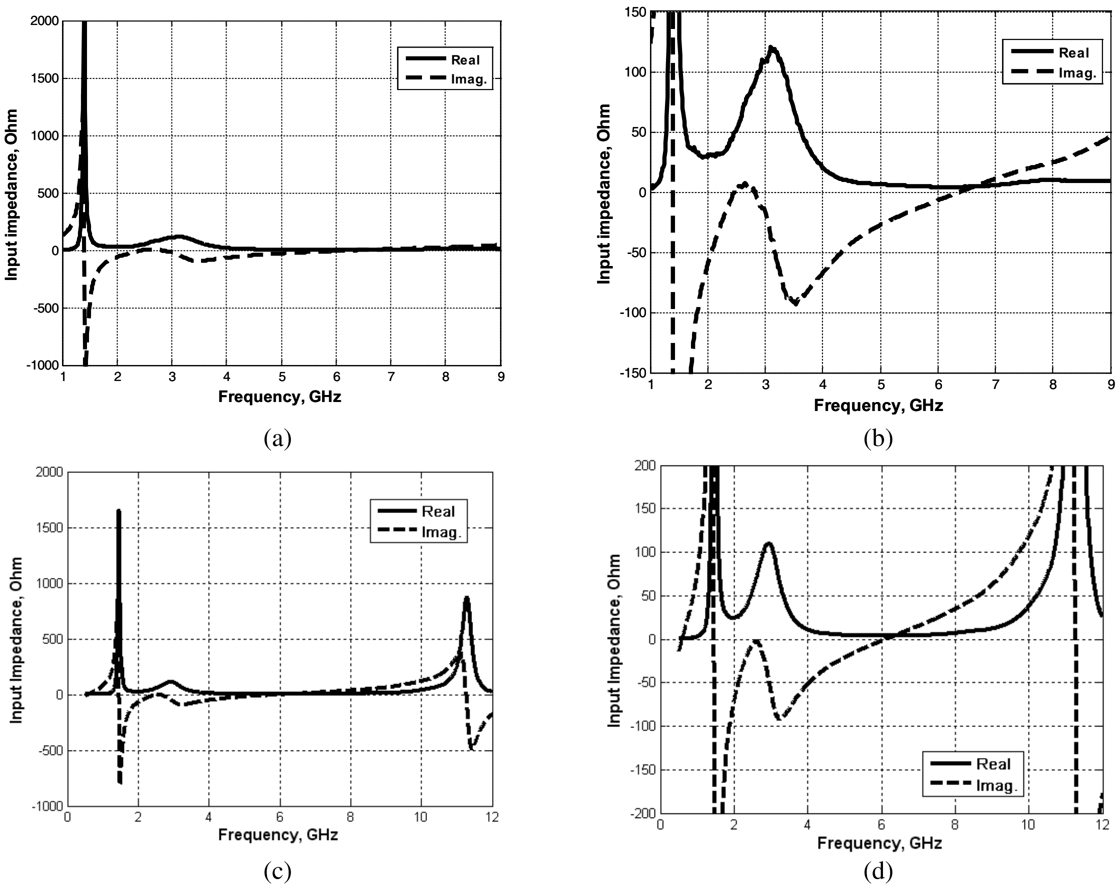

Figure 3: The overall measured input impedance of the patch antennas; (a), (b) full-width shorted wall; and (c), (d) folded wall. (b), (d) show detail expanded from (a), (c).

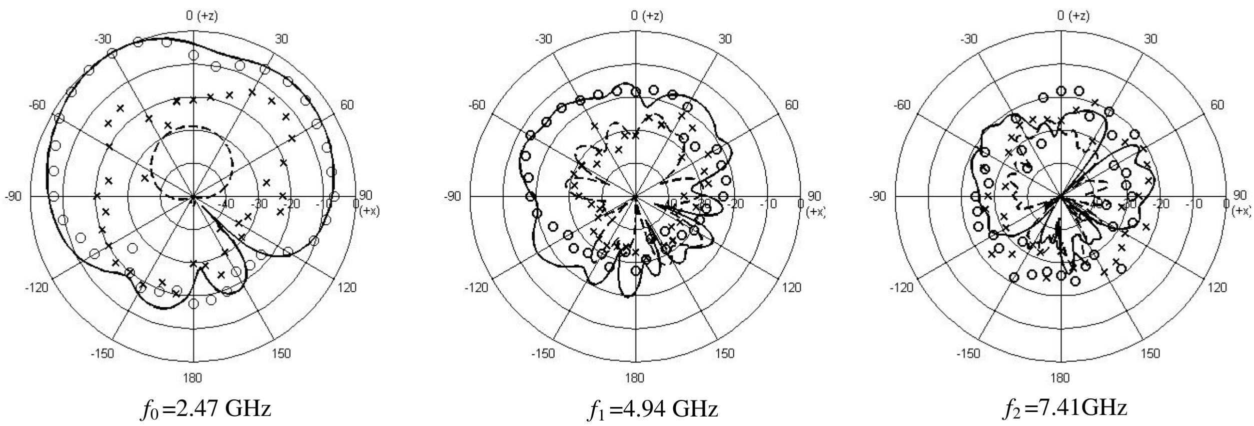

Figure 4: Measured and simulated radiation patterns of the proposed GA-optimised HSA with full-width shorted wall for 2.47 GHz, 4.94 GHz and 7.41 GHz over: z-x plane; ('—' measured E_θ, 'ooo' simulated E_θ, '- - -' measured E_ϕ, 'xxx' simulated E_ϕ).

3. CONCLUSIONS

A novel technique for the design and optimisation of harmonic-suppression patch antennas, applying adaptive surface patch models and genetic algorithms, has been presented. Hardware realisations of three coaxially-fed air-dielectric microstrip patch antennas were used to evaluate and validate the design theory. Comparison of return loss and far field radiation pattern measurements showed good agreement with the predictions. The examples presented confirmed the capability of the proposed method for antenna design using GA and adaptive surface meshing, showing reasonable stability and accuracy in the results.

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