2007-9

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Matthias John
Technological University Dublin, matthias.john@tudublin.ie

Max Ammann
Technological University Dublin, max.ammann@tudublin.ie

Recommended Citation

John, M. & Ammann, M. (2007) Wideband Printed Monopole Design Using a Genetic Algorithm. *IEEE Antennas and Wireless Propagation Letters*, Vol. 6, 2007, pp.447-449. doi:10.1109/LAWP.2007.891962

Wideband Printed Monopole Design Using a Genetic Algorithm

Matthias John* Max Ammann†

*Dublin Institute of Technology, matthias.john@dit.ie

†Dublin Institute of Technology

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M. John and M. J. Ammann

***Abstract*—A method for the design and optimization of wideband printed planar monopoles using a genetic algorithm (GA) is presented. This novel technique employs overlapping subpatches which ensures electrical contact in such constellations where two subpatches are touching only at the corner, hence, reducing losses. The method was used to design a wideband monopole antenna with application in higher cellular, WLAN, and UWB. Furthermore, the technique is modified for multigoal optimization to achieve multiple bands and reduce the lower edge frequency. The best solutions were prototyped and a full experimental evaluation was made.**

***Index Terms*—genetic algorithm (GA), printed monopole, wideband antenna.**

I. Introduction

PRINTED planar monopoles are promising wideband antennas and can be easily integrated in communication systems by fabrication onto printed circuit boards. These elements have recently become popular for wireless communications due to their broad bandwidth and appropriate radiation pattern [1]–[4]. Optimization with genetic algorithms (GAs) yield great potential in finding no-conventional solutions to electromagnetic problems. They have been successfully applied to patch antennas [5], [6] and printed monopoles [7]. The antenna presented here is proposed for multimode use in the higher cellular, WLAN, and UWB systems.

II. Introduction to the Genetic Algorithm (GA)

The GA operates on a 16 by 8 binary array which is encoded into a 128 bit (16×8) binary string. This string represents the chromosome. Therefore, the size of the search space is 2^{128}. This 16×8 array is the trial solution. It is mirrored along the *y* axis to create a symmetrical 16×16 element. This principle is illustrated in Fig. 1 where the original 16×8 array is shown on the left.

The GA starts with a population of randomly generated solutions and then evolves it through selection, crossover, and mutation. The probability for selection is computed according to the performance of the antennas generated with these trial solutions. The GA is implemented in MatLab. The trial solutions are passed to CST Microwave Studio (MWS) where the antenna geometry is generated. For every bit which is set in the 16×16 array, a 2×2-mm square subpatch is placed on the substrate. The groundplane, feedline, waveguide port and boundary conditions remain the same for all trial solutions. After the geometry is generated, the performance is evaluated by the FITD solver. Furthermore, MWS computes the fitness function from the return loss of the simulated antenna.

Manuscript received December 8, 2006; revised January 9, 2007. This work was supported by Science Foundation Ireland.

The authors are with the Centre for Telecommunications Value-chain Research, School of Electronic and Communications Engineering, Dublin Institute of Technology, Dublin 8, Ireland (e-mail: matthias.john@student.dit.ie).

Digital Object Identifier 10.1109/LAWP.2007.891962

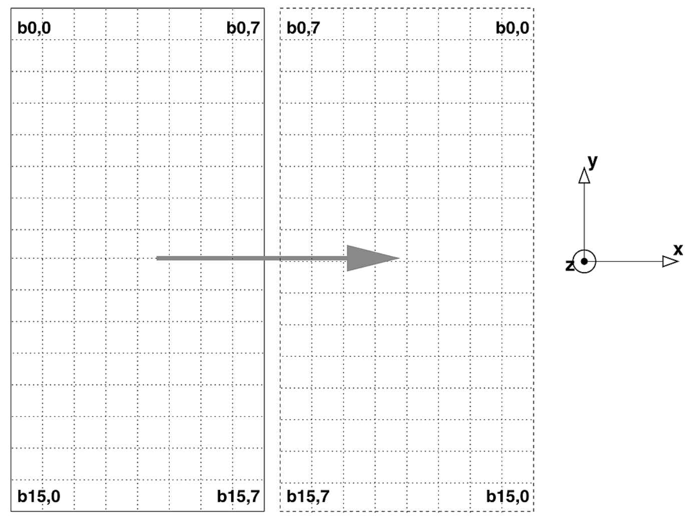

Fig. 1. A 16×8 array mirrored along the *y* axis to create symmetrical 16×16 array.

For the optimization a multigoal fitness function was used. The fitness function for the antenna presented consists of two parts. The first is defined as the sum of all S_{11} values that exceed -10 dB, to achieve the maximum bandwidth between 0–10 GHz. The second part is the lower edge frequency f_{LE}. The two parts are weighted at 70% and 30%, respectively. The fitness function is

$$\text{fitness} = 0.7\left[\sum_{n=1}^{N} f_n(S^{11} < -10\ \text{dB})\right] + 0.3[1000 - f_{\text{LE}}]$$

where N is number of frequency points, $N = 1000$.

The population size was set to 50 and evolved over 30 generations. A single run of CST MWS on one trial solution antenna takes approximately 20 min on an Intel P4 1.8-GHz PC. For the given population size and generations, 1500 such runs are necessary. This adds up to 21 days runtime on a single machine.

III. Antenna Geometry

The microstrip-fed GA plate monopole is printed on one side of FR4 substrate of 1.52 mm thickness and metalization

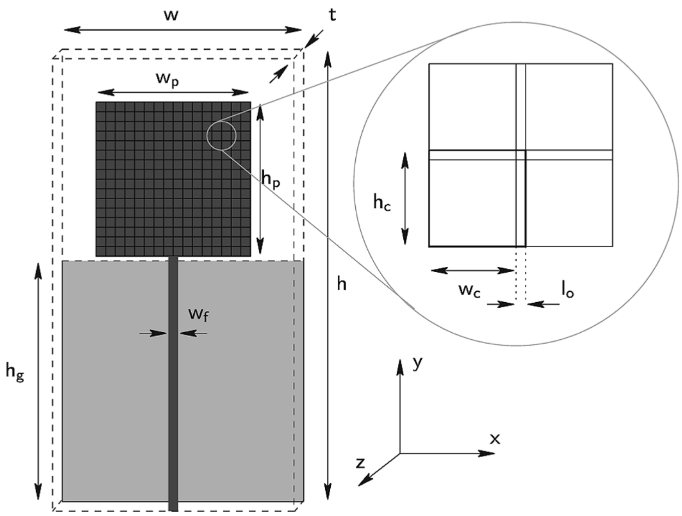

Fig. 2. Antenna geometry and principle of overlapping subpatches.

of 35 μm. The groundplane is located on the rear side. The dimensions of the substrate are $h = 80$ mm and $w = 45$ mm. The groundplane size, which is already optimized for maximum bandwidth [3] is 45 mm^2. The microstrip feedline ($w_f = 2$ mm) is excited by an SMA end-launch connector. The overall dimension of the radiating 16×16 element array of subpatches is $h_p = 29$ mm and $w_p = 29$ mm. Each metallic element of the radiating patch can be switched "on" or "off" by the genetic algorithm. Fig. 2 shows all elements switched "on." The size of each of these subpatches is $h_c = 2$ mm by $w_c = 2$ mm. They are overlapping by $l_o = 0.2$ mm to ensure electrical contact in such constellations where two subpatches are touching only at the corner. This is used to reduce losses in the fabricated antenna [8]. The principle of the overlapping element design is shown in the inset diagram in Fig. 2.

IV. Results

The first set of results presented were optimized with the goal designed to achieve the widest possible bandwidth within the 0 to 10 GHz range while maintaining a low lower edge frequency. The return loss was measured using a Rohde & Schwarz vector network analyzer ZVA24 and it was found to be greater than 10 dB from 1.9 up to 10 GHz. The geometry of the antenna and both the simulated and measured return loss are shown in Fig. 3. Good agreement was achieved. The parasitic elements optimize the effective feedgap between the radiator on one side and the groundplane on the other side. This reduces the monopole height by the otherwise necessary feedgap, which is typically 2 mm for the rectangular or circular geometry. The measured radiation patterns are shown in Fig. 4. It can be seen that the pattern omnidirectionality is reasonably stable with change of frequency for the cellular, WLAN and first generation UWB bands. The maximum gain was found to be 2.6 dBi at 1.6 GHz, 4.1 dBi at 2.4 GHz, 4.0 dBi at 4.6 GHz, and 5.5 dBi at 7.6 GHz.

V. Optimization for Phase Linearity

The optimization goal was now modified to achieve a linear phase response. A linear phase response is required for distortionless pulse communication [9]. Therefore, part of the goal was computed by numerically deriving the phase of the return loss at each frequency point. If a change in the sign of the derivation is found, the phase is nonlinear at this point and the fitness of this trial solution is set to zero

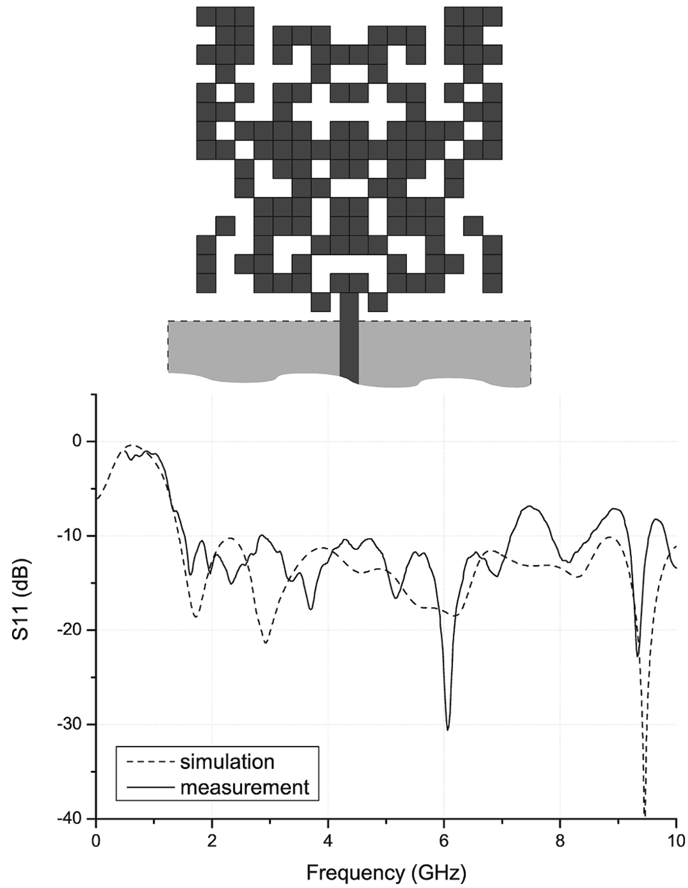

Fig. 3. Antenna geometry optimized for wide bandwidth with simulated and measured return loss.

$$\text{fitness} = \begin{cases} 0 \quad \text{if} \quad \operatorname{sgn}\left(\partial \arg\left(S^{11}(n)\right)\right) \\ \qquad \neq \quad \operatorname{sgn}\left(\partial \arg\left(S^{11}(n+1)\right)\right) \\ \sum_{n=1}^{N} f_n(S^{11} < -10\,\mathrm{dB}). \end{cases}$$

This fitness functions gives solutions with smooth phase changes and no sign change in the derivation a better fitness value.

The measured phase response of the best solution with this goal is shown in Fig. 5. This figure also shows the phase of the wide-band optimized design for comparison. It can be seen that the phase of the optimized design changes rather smoothly while the slope of the plot for the other patch changes sign multiple times.

VI. Conclusion

A GA-based optimization technique employing an array of overlapping subpatches is shown to provide promising new geometries for wideband applications. The results using a mir-

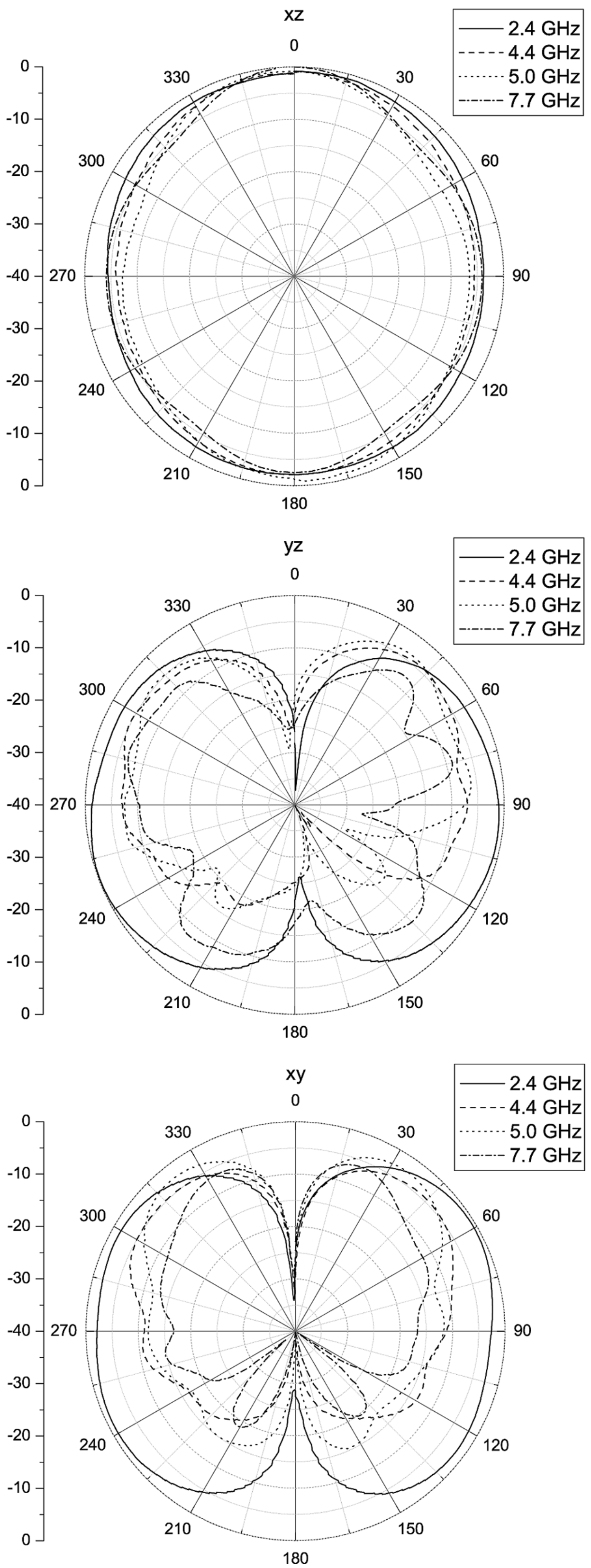

Fig. 4. Measured radiation patterns for the (xz), (yz), and (xy) planes.

rored symmetrical array illustrate a reasonable omnidirectionality over the full impedance bandwidth. The requirement for

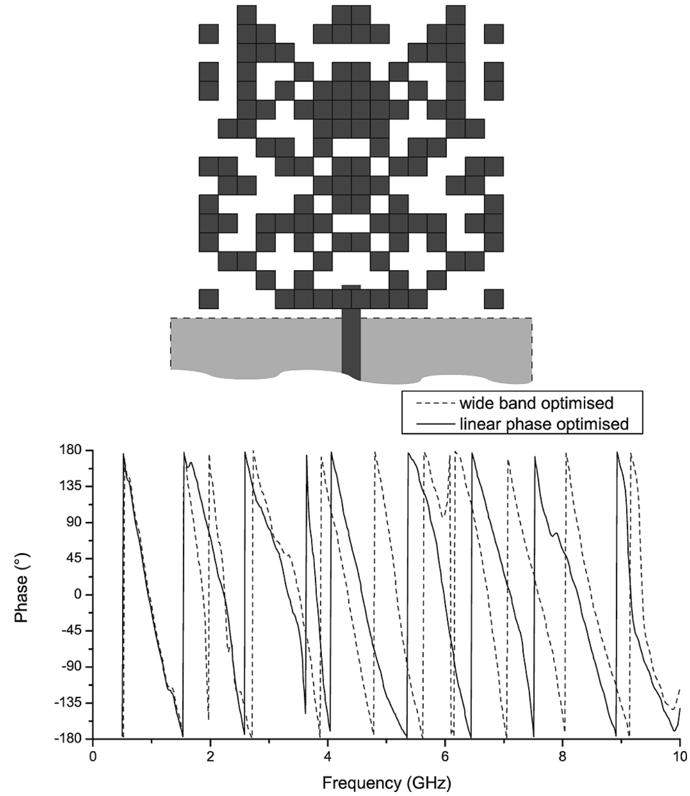

Fig. 5. Antenna geometry optimized for linear phase response with measured phase of the return loss.

the feedgap has been eliminated by this technique, enabling a somewhat smaller antenna.

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