2007-01-01

Spline Based Geometry for Printed Monopole Antennas

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) Spline Based Geometry for Printed Monopole Antennas. *Electronics Letters*, vol. 43. no. 6 March 15, 317-319. doi:10.1049/el:20073802

Funder: Science Foundation Ireland

Spline-based geometry for printed monopole antennas

M. John and M.J. Ammann

A novel Bézier spline-based geometry for printed monopole antennas is presented. Quadratic curves are used to describe the outline of the radiating element. The geometry is optimised by a genetic algorithm. A small number of control points are used to define the geometry, ensuring a small search space for the GA. The resulting antenna has an impedance bandwidth from 1.44 to 14.7 GHz.

Introduction: Geometries of recent UWB antennas are based on simple geometric elements, such as rectangles [1], circles [2] or ellipses [3], or a combination of these [4, 5]. This Letter proposes a geometry based on quadratic Bézier curves (splines). Splines are curves generated by quadratic interpolation between control points. The benefit of this technique is an inherently rounded shape of the radiating element. The design overcomes the geometrical constraints of a circular or elliptical disc and the difficulty of combining simple geometric elements. A genetic algorithm (GA)-based optimiser is used in the design process. GAs have been used for a variety of electromagnetic problems [6, 7], including the design of printed monopole antennas [8, 9].

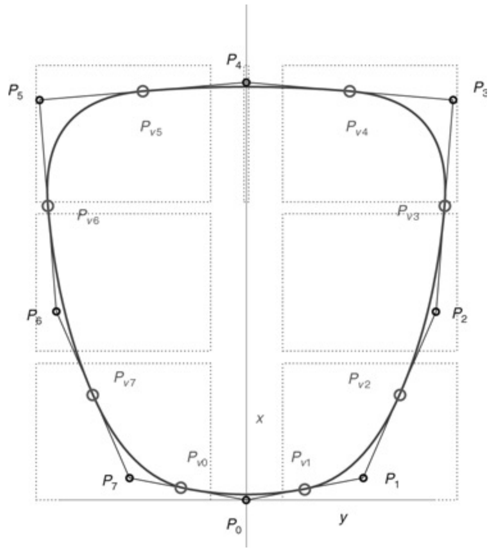

Fig. 1 *Bézier spline outline and its control points (P_n), virtual control points (P_{vn}) and boundaries of the control points*

Spline-based geometry: The outline of the radiating element is described by a quadratic Bézier spline. This spline curve is defined by eight control points P_0–P_7. Fig. 1 shows the outline curve and its control points. Point P_0 is fixed at (0,0), the point where the antenna is fed by a 50 Ω microstrip line. Points P_1–P_3 are defined by their x- and y-co-ordinates. Point P_4 is fixed at $y = 0$ and can only be positioned along the x-axis. Points P_5–P_7 are derived from points P_1–P_3 by mirroring them along the x-axis. This creates a radiator with x-axis symmetry and provides quasi-omnidirectional radiation patterns in the H-plane (y–z plane). The low-frequency resonant modes yield omni-directional properties irrespective of the symmetry, but the higher modes are travelling-wave modes [2] and their patterns are improved with symmetry. To achieve a closed curve in CST Microwave Studio, the curve is constructed in the following way. A 'virtual' control point P_{vn} is placed in the middle of each line between two control points. A quadratic Bézier curve is than generated from each adjacent pair of 'virtual' points with the real point between them. The tangent on each of these 'virtual' endpoints is the same for the two curves that meet there, so that a smooth transition between adjacent curve segments is ensured. The virtual points are marked by circles in Fig. 1.

The expression defining the set of quadratic Bézier curves $B_n(t)$, $n \in [0, 7]$ is given by:

$$B_n(t) = (1-t)^2 \begin{bmatrix} P_{vnx} \\ P_{vny} \end{bmatrix} + 2t(1-t) \begin{bmatrix} P_{nx} \\ P_{ny} \end{bmatrix} + t^2 \begin{bmatrix} P_{vn+1x} \\ P_{vn+1y} \end{bmatrix}; t \in [0, 1], n \in [0, 7]$$

where P_{vn} is the 'virtual' control point before P_n, and P_{vn+1} is the 'virtual' control point after P_n. For the case of $n = 7$, P_{vn+1} is P_{v0}. The resulting curve does not pass through any of the endpoints P_n.

Genetic algorithm optimisation: The position of the control points is optimised by a genetic algorithm. The problem is encoded in binary format. Single-point crossover and tournament selection are used. The mutation rate is 1%. The population size was set to 30 and evolved over 20 generations. Multiple objectives are used in the fitness function. The GA operates on points P_1–P_4 (P_5–P_7 are mirrored and not in the scope of the GA). The boundaries of these points are also shown in Fig. 1. The x- and y-co-ordinates of points P_1–P_3 and the x-co-ordinate of point P_4 are encoded in a binary format. Altogether, these seven parameters are encoded to only 35 bits. This is a very small search space considering the complexity of the resulting geometry.

The design goal consists of two parts. The first is to optimise for a wide band between 0 and 20 GHz; this is weighted at 70%. The second goal is to reduce the lower edge frequency; this is weighted with 30%. The FDTD simulation software returns the S_{11} as a list of 1000 frequency points. The fitness function is as follows:

$$\mathit{fitness} = 0.7\mathrm{BW} + 0.3(1000 - f_{\mathrm{LE}})$$

where

$$\mathrm{BW} = \sum_{n=0}^{1000} (S_{11}(n) \leq -10\,\mathrm{dB})$$

and f_{LE} = point of lower edge frequency, i.e. the smallest n where $S_{11}(n) \leq -10$ dB. The final geometry optimised by the GA is shown in Fig. 2. It can be seen that the element curves away smoothly from the feed point. The maximal possible height is exploited as point P_5 is placed 35 mm away from the feed point. The computational time needed for the 600 evaluations amounts to four days on a single computer.

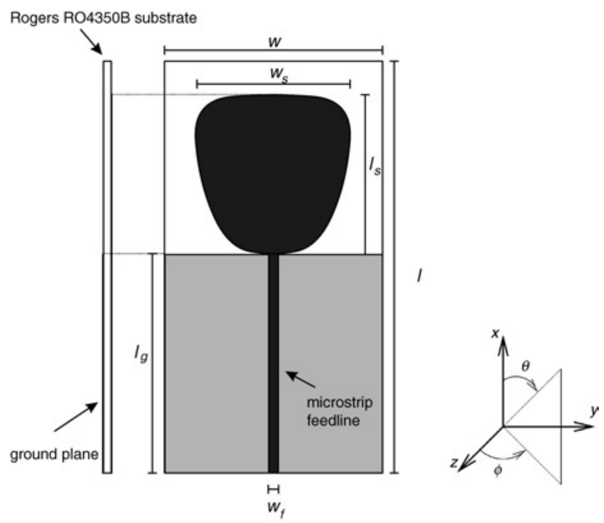

Fig. 2 *Optimised geometry of antenna*

Antenna geometry: The antenna is printed on Rogers microwave laminate RO4350B of 0.762 mm thickness, $\varepsilon_r = 3.48$ and tan d = 0.0037. The substrate has a size of $w = 45$ mm by $l = 85$ mm with the groundplane located on the rearside. The dimension of the groundplane is $l_g = 45$ mm square. The antenna is fed by a w_f = 2.5 mm microstrip feedline. The dimensions of the spline-based radiating element are $l_s = 33$ mm by $w_s = 32$ mm.

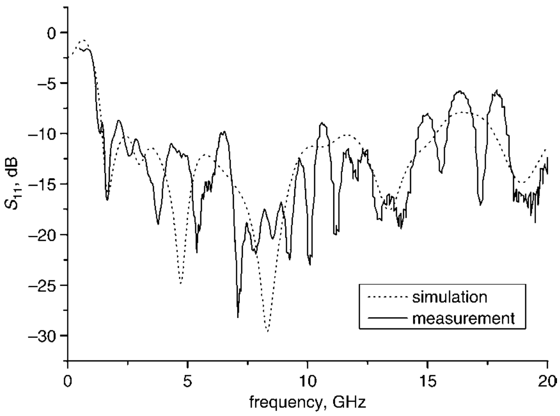

Fig. 3 *Simulated and measured return loss*

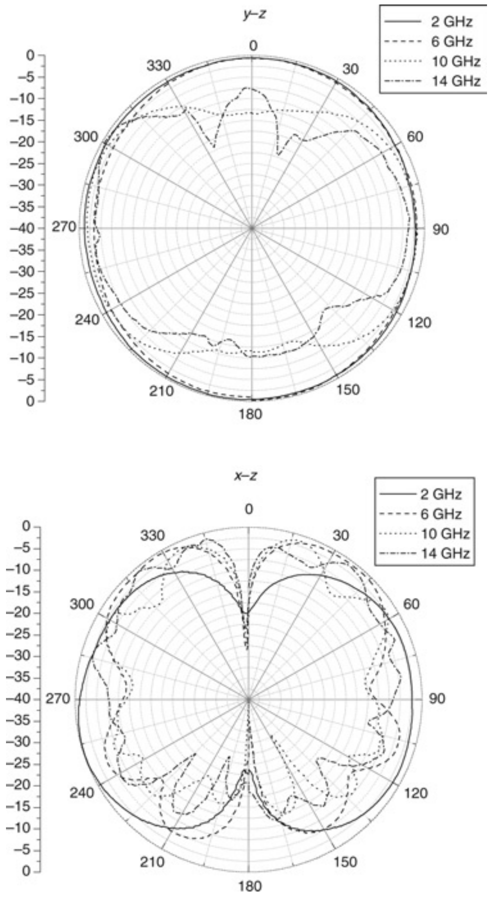

Fig. 4 *Measured radiation patterns in y–z and x–z planes*

Results: The simulated and measured return losses are shown in Fig. 3. It can be seen that the measured return loss is greater than 10 dB from 1.44 to 14.7 GHz. This is an impedance bandwidth ratio of 10.2:1, which is very wide for a printed monopole. Measured radiation patterns are shown in Fig. 4. The H-plane patterns are omnidirectional up to about 8 GHz. The gain is 2.8 dBi at 2 GHz, 4.3 dBi at 6 GHz, 4.8 dBi at 10 GHz and 5.3 dBi at 14 GHz. The radiation efficiency at these frequencies is 91, 96, 92 and 89%, respectively. The antenna is proposed for multimode use in higher cellular, WLAN and UWB systems.

Conclusions: A novel Bézier spline-based technique for the design of printed monopole antennas has been presented. Only seven parameters are necessary to define the geometry; this also allows for a small 35 bit search space for the GA. It has been shown that this technique can give very wide bandwidths of 10.2:1.

Acknowledgment: This work is supported by Science Foundation Ireland.

11 December 2006
Electronics Letters online no: 20073802
doi: 10.1049/el:20073802

M. John and M.J. Ammann (*Centre for Telecommunications Value-Chain Research, School of Electronic & Communications Engineering, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland*)

E-mail: max.ammann@dit.ie

References

1 Chen, H.D., Li, J.N., and Huang, Y.F.: 'Band-notched ultra-wideband square slot antenna', *Microw. Opt. Technol. Lett.*, 2006, **48**, (12), pp. 2427–2429
2 Liang, J., Chiau, C.C., Chen, X., and Parini, C.G.: 'Study of a printed circular disk monopole antenna for UWB systems', *IEEE Trans. Antennas Propag.*, 2005, **53**, (11), pp. 3500–3504
3 Angelopoulos, E.S., *et al.*: 'Circular and elliptical CPW-fed slot and microstrip-fed antennas for ultrawideband applications', *IEEE Antennas Wirel. Propag. Lett.*, 2006, **5**, pp. 294–297
4 Chen, Z.N., *et al.*: 'Planar antennas: promising solutions for microwave UWB applications', *Microw. Mag.*, 2006, **7**, (6), pp. 63–73
5 Karacolac, T., and Topsakal, E.: 'A double-sided rounded bow-tie antenna (DSRBA) for UWB communication', *IEEE Antennas Wirel. Propag. Lett.*, 2006, **5**, pp. 446–449
6 Haupt, R.L.: 'An introduction to genetic algorithms for electromagnetics', *IEEE Antennas Propag. Mag.*, 1995, **37**, (2), pp. 7–15
7 Johnson, J.M., and Rahmat-Samii, Y.: 'Genetic algorithms in engineering electromagnetics', *IEEE Antennas Propag. Mag.*, 1997, **39**, (4), pp. 7–21
8 Griffiths, L.A., Furse, C., and Chung, Y.C.: 'Broadband and multiband antenna design using the genetic algorithm to create amorphous shapes using ellipses', *IEEE Trans. Antennas Propag.*, 2005, **54**, (10), pp. 2776–2782
9 John, M., and Ammann, M.J.: 'Optimisation of a wide-band printed monopole antenna using a genetic algorithm'. LAPC - Loughborough Antennas & Propagation Conf., April 2006, pp. 237–240