Ultra-Wideband Coplanar-Fed Monopoles: A Comparative Study

Jana JILKOVÁ, Zbyněk RAIDA

Dept. of Radio Electronics, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic

xjilko00@stud.feec.vutbr.cz, raida@feec.vutbr.cz

Abstract. *The paper provides an experimental comparison of four types of ultra-wideband coplanar-fed planar monopole antennas. Parameters of the open stub completed by an L-shaped monopole and the cross monopole were adopted from the literature. The forked monopole and the coplanar monopole were fabricated and measured.*

Monopoles were compared from the viewpoint of the impedance bandwidth, gain, directivity patterns and dimensions.

Keywords

Ultra-wideband monopole antennas, coplanar feeding, planar antennas, numerical modeling.

1. Introduction

Thanks to the dynamic development of advanced wireless communication systems, miniaturized planar ultra-wideband antennas are intensively investigated as a potential solution of a small and efficient structure for receiving and transmitting the broadband communication signals. Coplanar-fed planar monopole antennas play an important role here.

In last four years, several interesting concepts of coplanar-fed monopoles were published in IEEE periodicals [1] to [7]:

- An open stub completed by an L-shaped monopole (Fig. 1a) was tuned to cover the frequency band from 3.0 GHz to 11.0 GHz (VSWR < 2.0). The radiation was omni-directional in H-plane and symmetrical in E-plane. The gain varied from 1.4 dBi to 4.6 dBi against operating frequencies [1].

  A generalized version of this antenna was published in [7]: the widths of the open stub and the L-shaped monopole were considered to be different. No advantages compared to the initial design were achieved.

- A meander-shaped monopole (Fig. 1b) was designed as a tri-band antenna (resonances of different antenna segments). The first two bands coalesce to give a wide bandwidth of 62% (1.32 to 2.50 GHz, 1188 MHz). The third band has a bandwidth of 17% (5.13 to 6.08 GHz, 960 MHz).

  The monopole was fabricated on FR4 substrate (ε_r = 4.4 and thickness 1.6 mm). The resonance was at 1.74, 2.34 and 5.58 GHz. Gains of the antenna were not reported in the paper. Small dimensions of the antenna were emphasized as the main advantage [2].

- A coplanar-fed monopole antenna loaded by a dielectric resonator (Fig. 1c) is a quite unique solution of a double-band antenna covering relatively narrow bandwidths [3]. For this design, an FR4 dielectric substrate is chosen (ε_r = 4.4 and thickness 1.6 mm). The dielectric resonator is ceramic with ε_r = 22. This concept is not considered in the paper. The measured bandwidth was 8 % and 35.3 % at the resonant frequencies 2485 and 5600 MHz [3].

- A conventional monopole is completed by multiple sleeves (Fig. 1d). Switches are used to control the length of the monopole and the sleeves and to tune the resonant frequencies of the antenna. Using two sleeves, a double-band antenna is built [4]. The antenna is printed on a Roger 3203 substrate with the thickness of 1.524 mm and ε_r = 3.02.

  When the second sleeve is not connected to the monopole, the antenna has two resonant frequencies, at 2.65 GHz and at 3.17 GHz. When the second sleeve is connected the antenna has three resonant frequencies: the first one at 2.4 GHz, the second one at 2.92 GHz and the third one at 3.35 GHz [4].

- The cross monopole (Fig. 1e) is a wideband antenna, which was designed to cover the frequency band from 3.3 GHz to 10.6 GHz with the gain varying from 0.3 dBi to 4.5 dBi.

  Obviously, parameters of the cross monopole and the open-stub L-shaped monopole are similar [5]. This monopole is fabricated on the RO4350b substrate (ε_r = 3.48 and thickness of 0.762 mm) and the measured bandwidth is 7.25 GHz (104.7 %).

- A conventional monopole completed by a slit feeder (Fig. 1f) was proposed in [6]. Thank to the proper design of slits in the feeder, a multiband behavior was achieved. The design is fabricated on an FR4 substrate, with ε_r = 4.4 and thickness 6.37 mm. The obtained measured bandwidths are 1380 MHz (55%, 1.72 - 3.1 GHz), 340 MHz (8.5 %, 3.78 - 4.12 GHz) and 230 MHZ (4.4 %, 5.13 - 5.36 GHz).

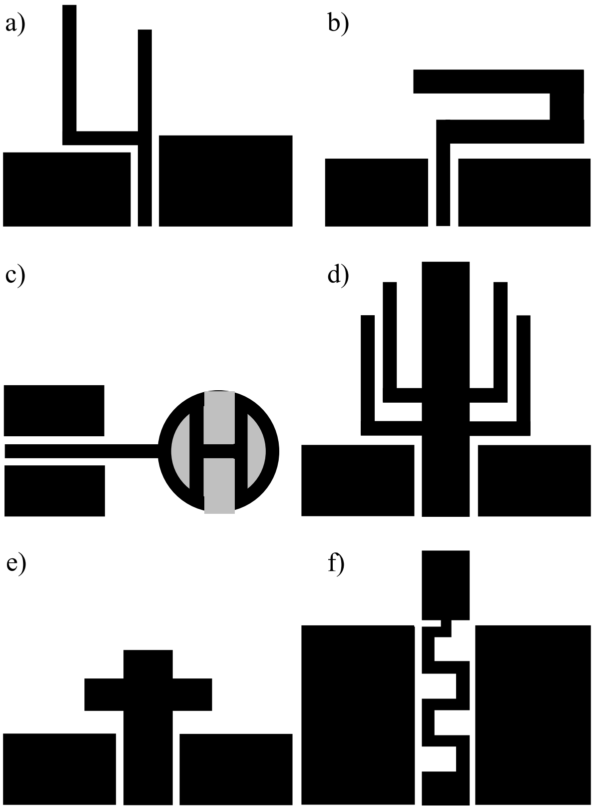

Fig. 1. Coplanar-fed planar monopole antennas: a) open stub completed by L-shaped monopole, b) meander-shaped monopole, c) dielectric loaded monopole, d) multiple-sleeve monopole, e) cross monopole, f) slit-fed monopole.

Since the paper is focused on the comparison of ultra-wideband antennas, novel modifications of such antennas are proposed and compared with the open-stub L-shaped monopole, and the cross monopole.

Numerical models of investigated antennas are developed in CST Microwave Studio. The CST Microwave Studio includes four different solvers. In our investigations, a time-domain solver (general, transient fields), and a frequency-domain solver (harmonic fields) are exploited. CST Microwave Studio is based on the description of electromagnetic problems by differential Maxwell equations those are solved by the finite difference method [8].

2. Simulations

Published parameters of the open stub L-shaped monopole [1] and the cross monopole [5] are compared to the analysis results of the forked monopole (Fig. 2) and the coplanar monopole (Fig. 5). The forked monopole was proposed in [5], the coplanar monopole is the result of our own research.

Designing the forked monopole and the coplanar one, antennas were required to be matched (input impedance matching considered) from the frequency 3.0 GHz to the frequency 15.0 GHz. In the operation band, the maximum possible gain was required. Antennas were also asked to provide an omni-directional radiation pattern in the horizontal plane, and as small dimensions as possible.

2.1 Forked Monopole

The layout of the forked monopole is depicted in Fig. 2. The published antenna was designed for the substrate Rogers Ro450b, and the re-design was done for the substrate Arlon 25N. Antenna parameters for both the substrates are given in Tab. 1.

Substrate	Ro4350b	25N
ε_r [-]	3.48	3.28
h [mm]	0.76	1.50
W [mm]	27.00	27.62
L [mm]	29.00	29.67
A [mm]	4.80	4.91
B [mm]	4.80	4.91
C [mm]	4.80	4.91
D [mm]	5.70	5.83
E [mm]	4.80	4.91
F [mm]	1.50	1.54
G [mm]	0.30	0.31

Tab. 1. Parameters of the forked monopole for the Rogers substrate (the column Ro450b), and for the Arlon substrate (the column 25N).

Wideband properties of the original antenna and the re-designed one were verified by computing the frequency response of the module of the reflection coefficient at the antenna input in CST (Fig. 3). A relatively good agreement between the original antenna properties and the re-designed one can be observed.

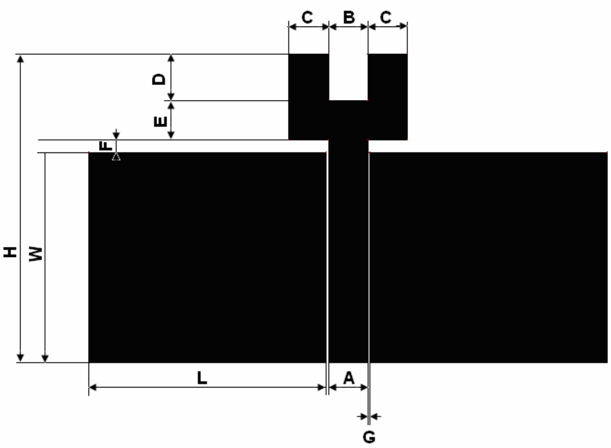

Fig. 2. Layout of the forked monopole.

Let us discuss CST results first. Considering the level s_{11} = = –10 dB to identify the operation bandwidth, the forked monopole exhibits the operation bandwidth from 3.0 GHz to 9.2 GHz if slightly higher values of s_{11} around the frequencies of 4.8 GHz and 7.8 GHz are neglected.

The numeric simulation showed that the gain in the operation band varied from 2.18 dB to 4.11 dB. We can therefore conclude, that the parameters of the simulated forked monopole are comparable to the open stub completed by an L-shaped monopole, and the cross monopole. The forked monopole was therefore fabricated to compare measurement results.

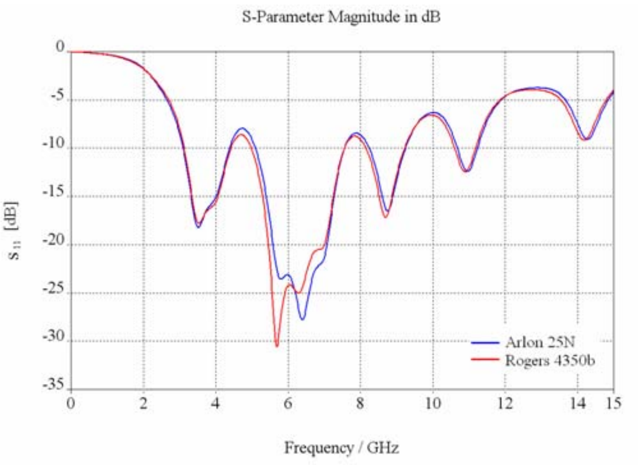

Fig. 3. Frequency response of the module of the reflection coefficient at the forked monopole input. Computed by CST for Rogers 4350b (red) and Arlon 25N (blue).

The influence of changing the number of the hexahedral mesh cells to the simulation results was investigated in CST also. The obtained dependencies are shown in Fig. 4. When increasing the number of cells, the magnitude of the reflection coefficient is slightly lower up to the limit of 30 cells per wavelength; further refinement of the mesh does not influences the obtained results.

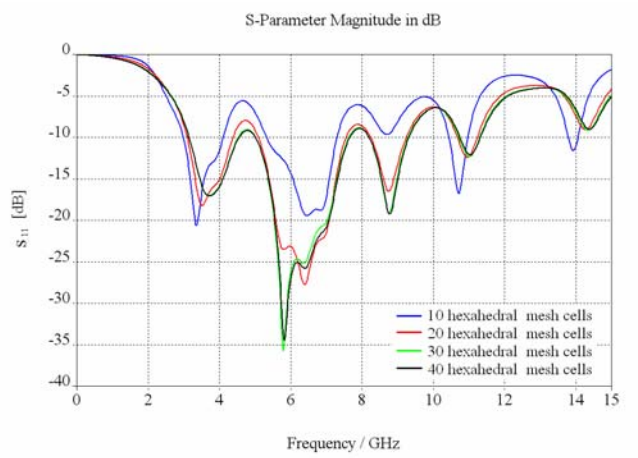

Fig. 4. The influence of the quality of the discretization mesh to the computer magnitude of the reflection coefficient: 10 cells per wavelength (blue), 20 cells per wavelength (red), 30 cells per wavelength (green), 40 cells per wavelength (black). Computed by CST for Arlon 25N.

2.2 Coplanar Monopole

The layout of the coplanar monopole is depicted in Fig. 5. The antenna was originally designed for the substrate FR4, and the re-design was done for the substrate Arlon 25N. Antenna parameters for both the substrates are given in Tab. 2.

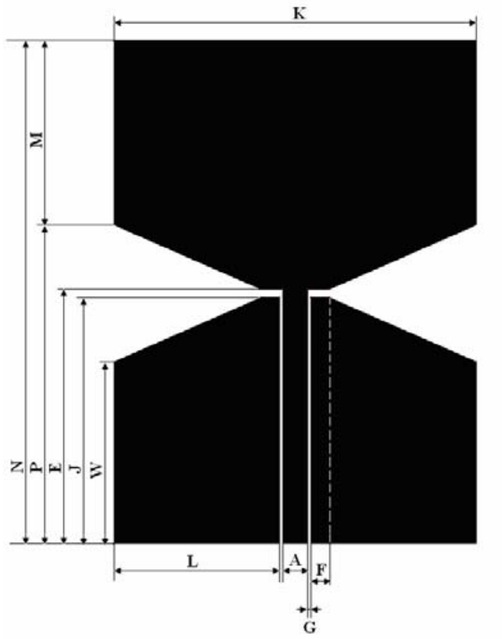

Fig. 5. Layout of the coplanar monopole.

A wideband behavior of the coplanar antenna on both the substrates was verified by computing the frequency response of the module of the reflection coefficient at the antenna input in CST (Fig. 6). An agreement between those two designs is worse compared to the forked monopole (see Fig. 3).

Substrate	FR4	25 N
ε_r [-]	4.40	3.28
h [mm]	1.50	1.50
W [mm]	11.74	13.14
L [mm]	10.03	11.23
A [mm]	1.50	1.68
J [mm]	15.65	16.98
N [mm]	31.30	35.06
M [mm]	11.24	12.59
P [mm]	20.06	22.47
E [mm]	16.15	18.09
G [mm]	0.22	0.25
K [mm]	22.00	24.64

Tab. 2. Parameters of the coplanar monopole for the FR4 substrate and for the Arlon 25N substrate.

Observing Fig. 6, the operation bandwidth of the coplanar monopole (the level s_{11} = –10 dB is considered) is from

2.5 GHz to 15.0 GHz if slightly higher values of s_{11} between frequencies 7.2 GHz and 12.5 GHz are neglected. Hence, the coplanar antenna exhibits the widest bandwidth of all the compared antennas.

The numeric simulation showed that the gain in the operation band varied from 2.46 dB to 5.20 dB. We can therefore conclude, that the parameters of the simulated coplanar monopole are comparable to the open stub completed by an L-shaped monopole, and the cross monopole. The coplanar monopole was therefore fabricated to compare measurement results.

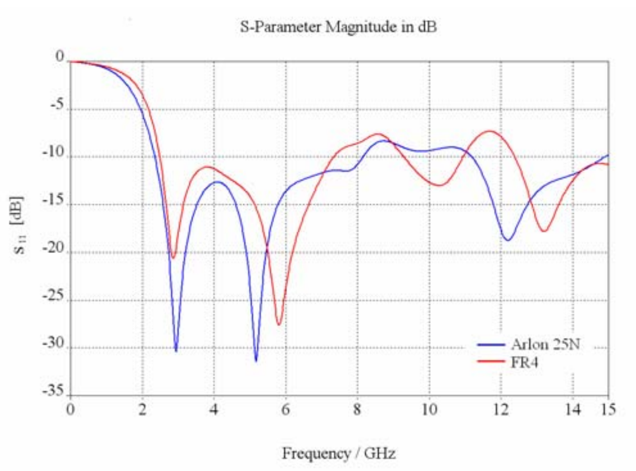

Fig. 6. Frequency response of the module of the reflection coefficient and the coplanar monopole input. Computed by CST MS for Arlon 25N (blue) and FR4 (red).

f [GHz]	Forked monopol		Coplanar monopol	
	RO4350b	Arlon 25N	FR4	Arlon25 N
	G [dB]	G [dB]	G [dB]	G [dB]
3	1.997	1.974	2.402	2.462
4	3.310	3.355	3.416	3.625
5	4.446	4.222	4.298	4.562
6	4.002	4.057	3.769	3.638
7	3.985	4.012	3.836	3.295
8	4.333	4.395	4.199	3.316
9	4.734	4.736	3.592	3.068
10	5.399	5.524	4.703	4.004
11	5.698	5.716	6.246	5.202
12	5.349	5.397	4.222	3.759
13	5.302	5.527	4.929	3.912
14	4.957	5.132	5.047	3.749
15	5.695	5.795	4.714	4.270

Tab. 3. The influence of the gain of the antennas to the frequency and to the type of the substrates (computed by CST MS).

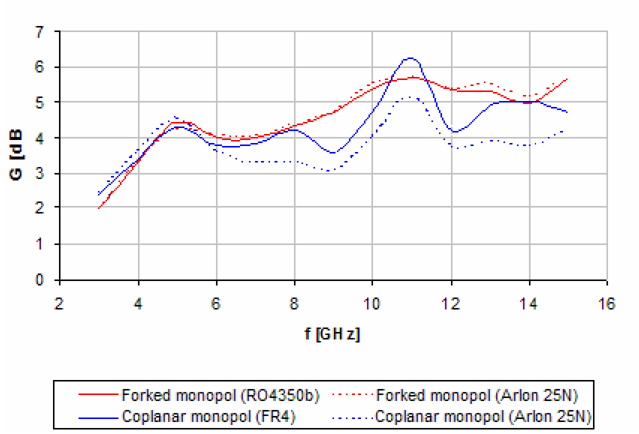

Fig. 7. The influence of the gain of the antennas to the frequency and to the type of the substrates (computed by CST MS).

3. Optimization and Measurements

In order to improve the initial design of the antennas (Tab. 1 and Tab. 2), CST Microwave Studio was connected to MATLAB: CST provided the computational kernel, and MATLAB was used for performing an optimization routine.

The optimization was aimed to tune the initial design of the forked monopole and the coplanar one by Particle Swarm Optimization (PSO) as described in [9]. The optimization was intended to reach the prescribed impedance matching of antennas; other objectives (radiation properties, gain, dimensions) were not included into the optimization process.

In order to perform the experimental comparison of the optimized wideband monopole antennas, the forked monopole was built on the substrate Arlon 25N (Fig. 8), and the coplanar monopole was fabricated on the substrate FR4 (Fig. 9). Frequency responses of the antenna prototypes were measured using the vector analyzer Agilent E8364B. Directivity patterns of the investigated antennas were measured in the anechoic chamber of the ERA company in Pardubice.

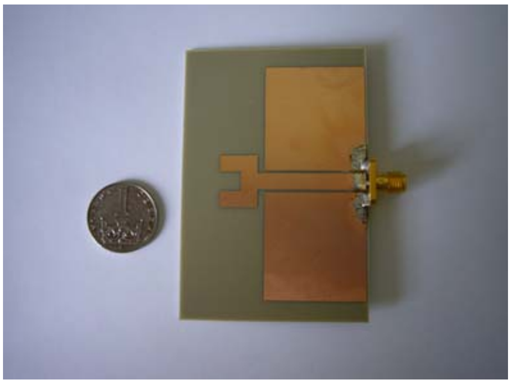

Fig. 8. The fabricated forked monopole on the substrate Arlon 25N.

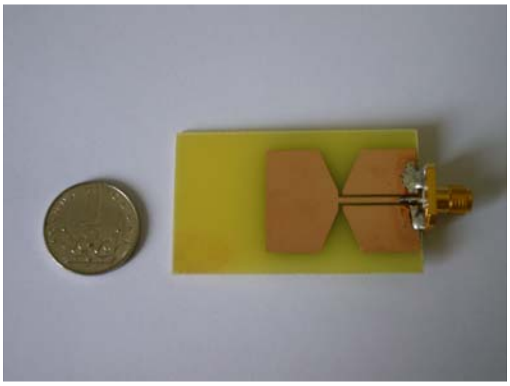

Fig. 9. The fabricated coplanar monopole on the substrate FR4.

Figs. 10 and 11 provide comparisons of the frequency responses of the reflection coefficient module.

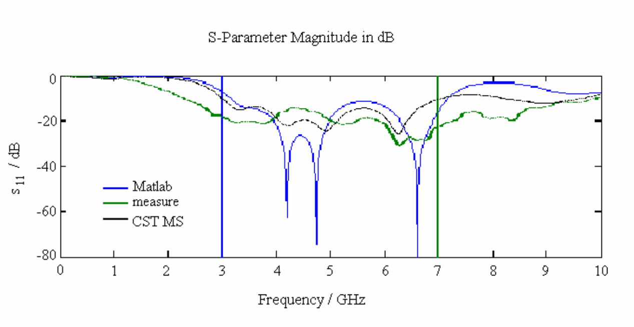

Fig. 10. Frequency response of the reflection coefficient at the input of the forked monopole: MATLAB optimization (blue), measurement (green), and CST Microwave Studio (black).

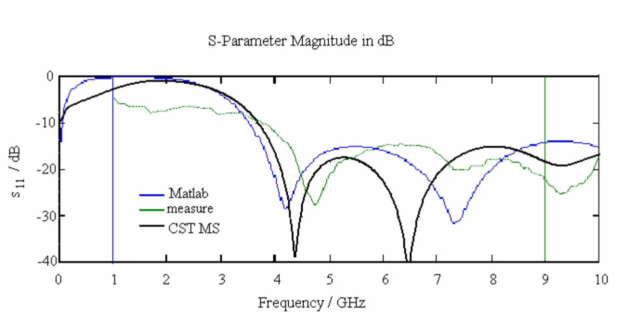

Fig. 11. Frequency response of the reflection coefficient at the input of the coplanar monopole: MATLAB optimization (blue), measurement (green), and CST Microwave Studio (black).

Directivity patterns of the forked monopole and the coplanar one are depicted in Fig. 12.

Obviously, directivity patterns in the horizontal plane can be considered as omni-directional ones at lower frequencies. At higher frequencies, patterns are corrupted in case of the coplanar monopole, especially. This corruption might be caused by the Vivaldi-like slot between the monopole and the ground plane.

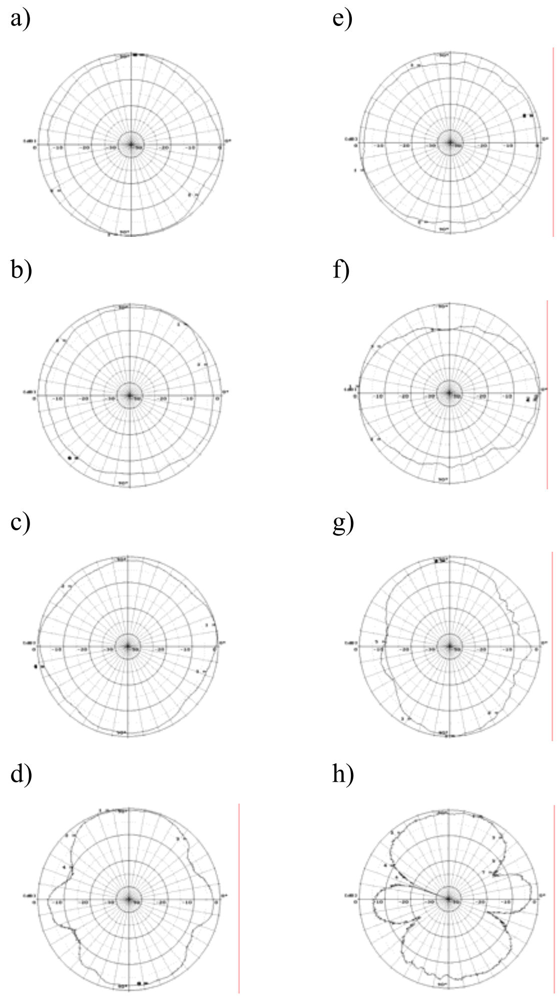

Fig. 12. Directivity patterns in the horizontal plane. Left: the forked monopole at the frequencies a) 3.9 GHz (offset: 0.0°), b) 5.7 GHz (offset: 0.0°), c) 6.6 GHz (offset: 0.0°), and d) 8.5 GHz (offset: 0.0°). Right: the coplanar monopole at the frequencies e) 4.7 GHz (offset: 25.3°), f) 7.4 GHz (offset: 41.1°), g) 9.3 GHz (offset: 0.0°), and h) 13.4 GHz (offset: 0.0°). (Data of the graph: scale 35 dB, orientation normal, type of graph normalized.)

4. Conclusions

The paper deals with the experimental comparative study of planar coplanar-fed wideband monopole antennas. The antennas were compared from the viewpoint of the bandwidth, gain, directivity pattern, and dimensions.

In the study, the open stub completed by an L-shaped monopole, the cross monopole, the forked monopole, and the coplanar monopole were considered.

All the investigated antennas provided omni-directional radiation in the horizontal plane. In case of the coplanar antenna, the pattern was corrupted at higher frequencies due to the Vivaldi-like slot between the monopole and the ground plane.

The measured bandwidth and gain of antennas is listed in Tab. 4. The coplanar monopole exhibits the widest bandwidth and the highest gain.

Antenna	Bandwidth	Gain
L-shaped	3.0 GHz to 11.0 GHz	1.4 dBi to 4.6 dBi
Cross	3.3 GHz to 10.6 GHz	0.3 dBi to 4.5 dBi
Forked	3.0 GHz to 11.8 GHz	4.1 dBi to 6.0 dBi
Coplanar	4.1 GHz to 14.0 GHz	2.9 dBi to 6.2 dBi

Tab. 4. Comparison of the measured parameters of the investigated antennas.

The dimensions of the investigated antennas are given in Tab. 5. The coplanar dipole occupies the minimum surface of the substrate.

Antenna	Width	Height
L-shaped	30.0 mm	25. 0 mm
Cross	40.0 mm	22.5 mm
Forked	64.6 mm	38.4 mm
Coplanar	22.4 mm	25.7 mm

Tab. 5. The dimensions of the investigated antennas.

Acknowledgements

The research was supported by the Czech Grant Agency under the grant 102/07/0688, and by the Czech Ministry of Education under the research plan no. MSM 0021630513. The described research is also a part of the COST project IC0603 ASSIST.

References

[1] KIM, J. I., JEE, Y. Design of ultra-wideband coplanar waveguide-fed LI-shape planar monopole antennas. *Antennas and Wireless Propagation Letters*. 2007, vol. 6, p. 383–387.

[2] DEEPU, V. D. V., RAJ, R. K., JOSEPH, M., MOHANAN, P. Compact asymmetric coplanar strip fed monopole antenna for multiband applications. *IEEE Transactions on Antennas and Propagation*. 2007, vol. 55, no. 8, p. 2351–2357.

[3] LIN, Y. F., LIN, C. H., CHEN, H., M., HALL, P. S. A miniature dielectric loaded monopole antenna for 2.4/5 GHz WLAN applications. *Microwave and Wireless Components Letters*. 2006, vol. 16, no. 11, p. 591–593.

[4] ZACHOU, V., CHRISTODOULOU, C. G., CHRYSSOMALLIS, M. T., ANAGNOSTOU, D., BARBIN, S. Planar monopole antenna with attached sleeves. *IEEE Antennas and Wireless Propagation Letters*. 2006, vol. 5, p. 286–289.

[5] KIM, J., YOON, T., JAEMOUNG, K., CHOI, J. Design of an ultra wide-band printed monopole antenna using FDTD and genetic algorithm. *Microwave and Wireless Components Letters*. 2005, vol. 15, no. 6, p. 395–397.

[6] LIU, W. C. Design of a multiband CPW-fed monopole antenna using a particle swarm optimization approach. *IEEE Transactions on Antennas and Propagation*. 2005, vol. 53, no. 10, p. 3273–3279.

[7] CHEN, H. D., CHEN, H. T. A CPW-fed dual-frequency monopole antenna. *IEEE Transactions on Antennas and Propagation*. 2004, vol. 52, no. 4, p. 978–982.

[8] *CST Microwave Studio User's Guide*. Darmstadt: CST Gmbh, 2007.

[9] ROBINSON, J., RAHMAT-SAMII, Y. Particle swarm optimization in electromagnetics. *IEEE Transactions on Antennas and Propagation*. 2004, vol. 52, no. 2, p. 397–407.

About Authors...

Jana JILKOVÁ was born in Kaplice, Czech Republic, in October 1977. She graduated at the Faculty of Electrical Engineering and Communication (FEEC), Brno University of Technology (BUT), in 2007. Since 2007, she has been a post-graduate at the Dept. of Radio Electronics, BUT.

Zbyněk RAIDA received Ing. (M.Sc.) and Dr. (Ph.D.) degrees from the Brno University of Technology (BUT) in 1991 and 1994, respectively. Since 1993, he has been with the Dept. of Radio Electronics of BUT as the assistant professor (1993 to 98), associate professor (1999 to 2003), and professor (since 2004). From 1996 to 1997, he spent 6 months at the Laboratoire de Hyperfrequences, Universite Catholique de Louvain, Belgium as an independent researcher.

Prof. Raida has authored or coautored more than 80 papers in scientific journals and conference proceedings. His research has been focused on numerical modeling and optimization of electromagnetic structures, application of neural networks to modeling and design of microwave structures, and on adaptive antennas.

Prof. Raida is a member of the IEEE Microwave Theory and Techniques Society. From 2001 to 2003, he chaired the MTT/AP/ED joint section of the Czech-Slovak chapter of IEEE. In 2003, he became the Senior Member of IEEE. Since 2001, Prof. Raida is editor-in-chief of the Radioengineering journal (publication of Czech and Slovak Technical Universities and URSI committees).