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Ultra Wideband Dipole Antenna Optimization

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This paper describes optimization of the planar ultra wideband dipole antennas, which are optimized for perfect matching and perfect impulse radiation characteristics. The optimization of the dipole shapes starts from the classical wideband dipoles, especially from elliptical and diamond shapes. These wideband dipoles have been analyzed and optimized with unsatisfactory parameters performance. This paper proposes two optimized dipole structures fulfilling required parameters. Designed antennas could be used as an impulse-shaping filter for forming of transmitted UWB impulse.

Key words: antennas, ultra wideband, impulse radiation characteristic, elliptical dipole, diamond dipole

1 INTRODUCTION

Ultra wideband (UWB) radio represents an emerging technology that attracts attention of industry and academia alike. An antenna is an indispensable component of every radio system, thus the antenna is studied in this paper from the pulse radiation point of view with the omni-directional radiation pattern. The required ultra wideband antenna should be perfectly matched to the feeding line, serve as a Gaussian impulse-shaping filter and radiate impulse similar to the higher orders of the Gaussian impulses.

1.1 Ultra wideband technology

Ultra wideband (UWB) technology is defined as any radio technology using signals having a spectrum that occupies a bandwidth greater than 20 % of the center frequency or a bandwidth greater than 500 MHz. This differs from narrow band technologies where the bandwidth is typically 10 % or less of the center frequency.

European Telecommunications Standards Institute (ETSI) and US Federal Communications Commission (FCC) defined the frequency mask, which determinates the maximal radiated power of the UWB signal. This mask indicates the frequency band from 3.1 to 10.6 GHz within which the UWB signal is transmitted with a maximum power. The first derivative or higher of the Gaussian impulse is mostly used for the UWB signals.

2 WIDEBAND DIPOLE ANTENNAS

The ultra wideband antennas with flat amplitude and linear phase of the transmission coefficient radiate the applied impulse without any distortion. These antennas are predominantly directional and could be used as measurement antennas. On the other hand, the dipoles have omni-directional radiation patterns and are more suitable for the above-mentioned purposes.

The following ultra wideband dipoles can be distinguished: thick, bow tie, diamond, elliptical, rhombus etc. The analysis of the above-mentioned dipoles has been carried out. Their unsatisfactory parameters in the basic configuration were improved with the help of the optimization. Unfortunately, these parameters are still insufficient, but elliptical or diamond dipoles fulfill at least one required parameter (suitable reflection coefficient or radiated impulse). These two dipoles are described in detail in the following sections.

The thick rotational dipole has reflection coefficient less than –8 dB above frequency 2.6 GHz. The radiated impulse is slightly distorted in comparison with the first or the second derivative of the Gaussian. The reference impedance of the differential port is 80 Ω.

The planar bow-tie dipole has reflections better than –10 dB above 3 GHz, but, in comparison with radiation to the normal direction, it radiates much

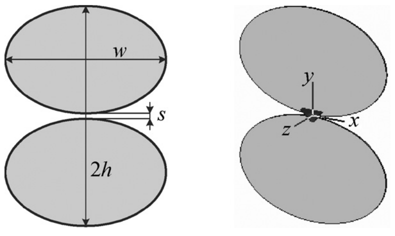

Fig. 1 Elliptical dipole

more distorted impulses to the side direction. The reference impedance is 180 Ω.

The planar rhombus dipole has reflections better than –7 dB above 3.8 GHz and the radiated impulses are also slightly distorted. The reference impedance is 100 Ω.

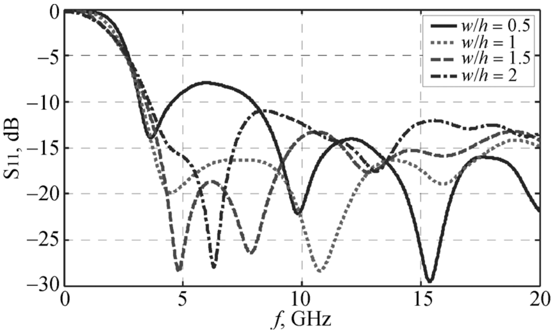

Fig. 2 Elliptical dipole – reflection coefficients

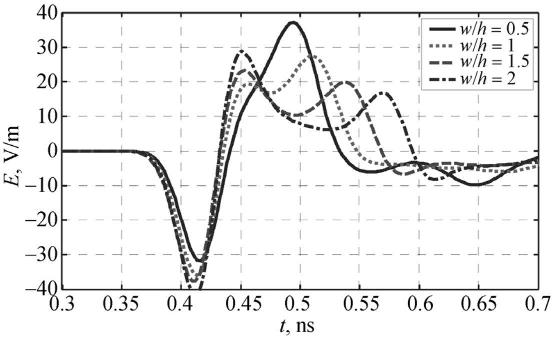

Fig. 3 Elliptical dipole – radiated impulses

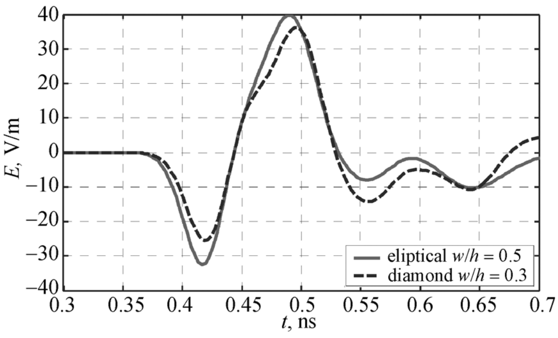

Fig. 4 Radiated impulses – normal direction

All dipole elements described in the paper have the same elements-height $h = 20$ mm (for reliable comparison), all presented parameters and characteristics were performed by means of the full-wave time domain electromagnetic fields simulator CST Microwave Studio® and all compared structures were excited by the standard Gaussian impulse (in CST with parameters 0–20 GHz). All dipoles are oriented in the same way; see Figure 1. Axis x corresponds to the side radiation and the axis z corresponds to the normal direction of radiation.

2.1 Elliptical dipole

Dipoles with elliptical elements offer good dipole performance over nearly two octaves. They also exhibit –10 dB return loss for 0.40 λ elliptic dipole height ($2h$) in comparison with traditional dipoles whose height must equal approximately half-wave-length, [1] or [2].

Arrangement and dimensions of the elliptical dipole is depicted in Figure 1. Parametric analysis results of optimized elliptical dipoles are shown in the following charts. The reflection coefficients are presented in Figure 2 for few different ratios of major to minor axes w/h. The radiated impulses (electric intensity) to the side direction of these elliptical dipoles are shown in Figure 3 and to the normal direction in Figure 4. The reference impedance is 100 Ω.

2.2 Diamond dipole

The diamante dipoles offer very good impulse performance, but unfortunately in relatively narrow frequency band – a bit more than an octave of bandwidth, or roughly a 70 % fractional bandwidth, [3] or [4].

Arrangement and dimensions of the diamond dipole is depicted in Figure 5. Two small feeding rectangular elements, improving the return looses, were added to the diamond dipole structure. Results of parametric analysis of these optimized diamond dipoles are shown in the following charts.

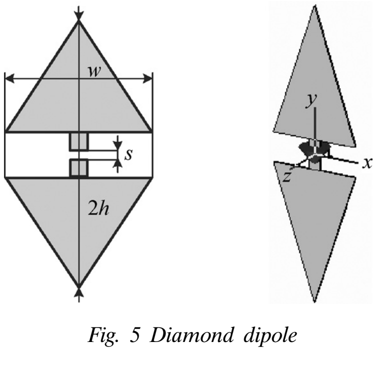

Fig. 5 Diamond dipole

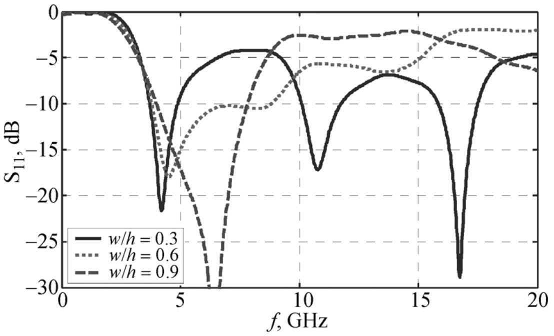

Fig. 6 Diamond dipole – reflection coefficients

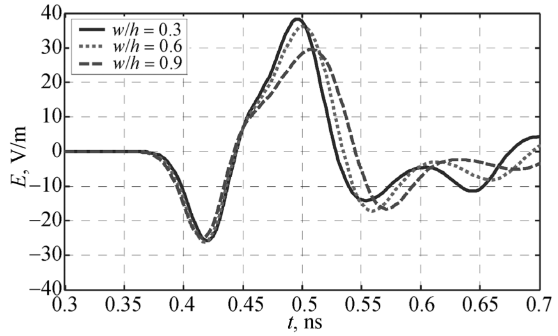

Fig. 7 Diamond dipole – radiated impulses

The reflection coefficients for few different *w*/*h* are shown in Figure 6.

The impulses (electric intensity) radiated to the side direction of these diamond dipoles are depicted in Figure 7 and to the normal direction in Figure 4. The reference impedance is 100 Ω.

3 DIPOLE OPTIMIZATION

The elliptical dipole antenna provides very good matching to 100 Ω from frequency 3 GHz to minimally 20 GHz with exception of axial ratio 0.5. Contrary to the characteristics of the diamond dipole, the elliptical dipole distorts substantially radiated impulses, mainly for higher axial ratios. The diamond dipole radiates impulses that are very similar to the second derivative of the Gaussian impulse. The reflections are also perfect, but only in narrow frequency band 3.8–8.8 GHz for triangular elements width $w = 12$ mm.

It is obvious that the elliptical dipole is perfectly matched; the diamond dipole is suitable for impulse radiation in case of the narrower (in width) structure. By studying of the spectral content of the radiated impulses, it was observed that the side radiation carries more power at higher frequencies. It is possible to describe this effect by two slotline 100 Ω to 377 Ω transformers situated between the feed and a circular boundary.

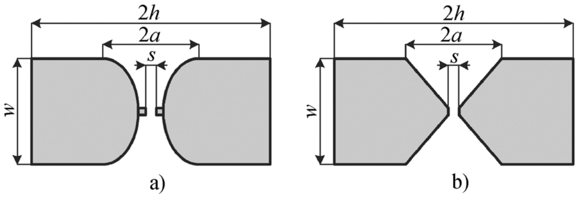

Fig. 8 Variants of the rectangular dipoles

It is possible to suppress this effect using shorter structure (in axis x) and by shifting of the cut-of frequency. It corresponds to the narrowing of the slot situated between elliptical elements at their ends (distance $2a$ in Figure 8a). Furthermore, the wider ends of the dipole show positive effect on the return losses at low frequencies. The optimization procedure, step by step, using parametric studies in CST was performed. Two suitable structures are described in the next section and are shown in Figure 8.

3.1 Optimized dipole antennas performance

The above-mentioned structures have been selected and optimized. These dipole structures consist of two rectangular elements with different bases and feedings. The final dimensions of optimized dipoles are indicated in Table 1. The first structure is shown in Figure 8a. Two small feeding rectangular elements improving the reflections were added to this dipole. This dipole with elliptical basis is also known as a square monopole antenna with semi-circular basis, see [5]. This structure was changed and optimized. The second structure is depicted in Figure 8b. This dipole with triangular basis is also known as the planar fat (thick) dipole.

Table 1 **Final dimension of optimized dipoles**

basis	*w* mm	*a* mm	*s* mm
triangular	15	5	0.2
elliptical	14	6	0.4

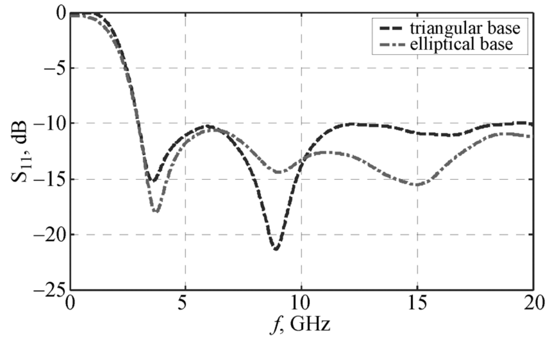

Fig. 9 Rectangular dipoles – reflection coefficients

Reflection coefficients of both optimized dipoles are depicted in Figure 9. Reflections below –10 dB above frequency 3 GHz were achieved. Impulses radiated by these optimized dipoles as directional characteristics are depicted in Figure 10 and Figure 11. Shapes of these radiated impulses are very similar to the first derivative of the Gaussian impulse.

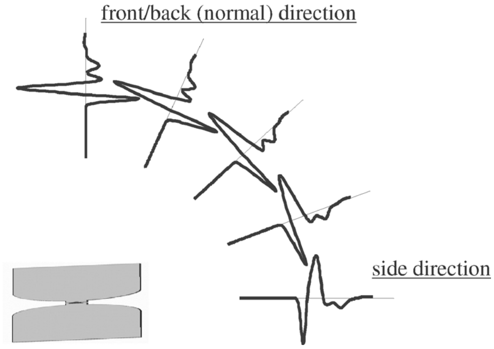

Fig. 10 Rectangular dipole (a) – radiated impulses

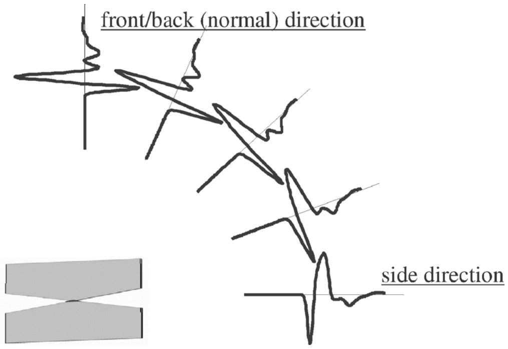

Fig. 11 Rectangular dipole (b) – radiated impulses

Peak value of impulses radiated to the side direction is approximately 65 % of those radiated to the normal direction. Width of the positive parts of impulses radiated to the normal direction is approximately 85 % of those radiated to the side direction.

4 OPTIMIZED ANTENNAS MEASUREMENT

It can be expected that if a dipole antenna were perfectly matched to the 100 Ω, the corresponding antenna in monopole configuration would have characteristic impedance around 50 Ω. Because of the better elements feeding in the asymmetrical 50 Ω system, antenna prototypes with elliptical and triangular basis have been manufactured and measured in the monopole configuration. Measurements were performed using the Agilent vector network analyzer E8364A in frequency band from 45 MHz to 20 GHz.

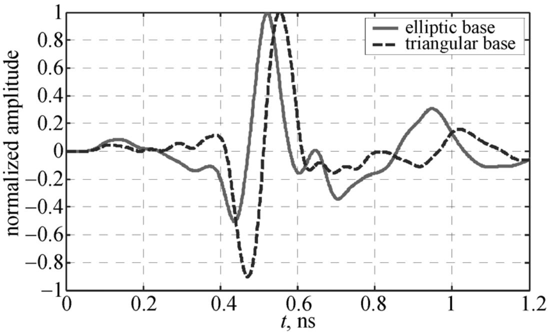

Fig. 12 Measurement – reflection coefficients

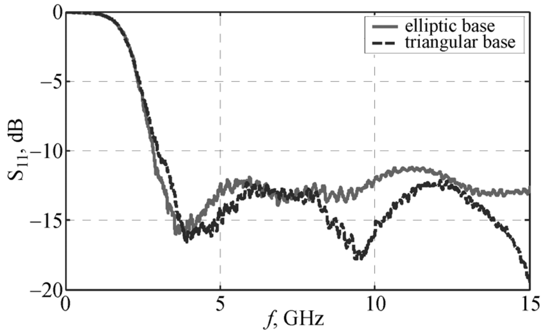

Fig. 13 Calculation – radiated impulses

The measured reflection coefficient is shown in Figure 12 for both rectangular monopole variants. These reflections are better than –10 dB in the frequency range 3–15 GHz.

The impulse radiated to the normal direction is depicted in Figure 13. These calculated impulses differ a bit from modeled characteristics. In case of the dipole with elliptical base, the radiated impulse is similar to the second derivative of the Gaussian impulse and for the dipole with triangular base is similar to the first derivative.

Because of impossibility of the time domain measurement, the radiated impulse is not directly measured, but is calculated using the following method, which is based on the transmission coefficient measurement (in frequency domain) between two monopole antennas.

In order to attain reliable comparison, the distance of measured antennas was chosen 200 mm, which is the double distance of the antenna and the capturing probe. The model of two dipole antennas can be cut on two identical parts (*antenna–cut plane*; *cut plane–antenna*). The transmission coefficient of part *antenna–cut plane* can be calculated from the measured transmission coefficient similarly (e.g. by using the square root function). The calculated radiated impulse is obtained by convolution of the applied excitation impulse (used in CST) and the impulse response of the *antenna–cut plane* part. This impulse response is obtained by means of the Fourier transformation applied on the transmission coefficient of part *antenna–cut plane*.

5 CONCLUSION

The analysis of the planar wideband dipoles (rotational thick, bow-tie, rhombus, elliptical and diamond) has been performed and its results have been presented. These dipole shapes have been optimized. Two optimal rectangular monopole structures with different feeding basis have been found, manufactured and measured. The reflection coefficients of optimized antennas are bellow –10 dB in the required frequency band and antennas radiate suitable impulses similar to the Gaussian impulse derivatives. With regard to the obtained results, the optimized antennas discussed in this paper are likely to gain their ground in impulse radiating antennas and in the UWB technology.

6 ACKNOWLEDGEMENT

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REFERENCES

[1] H. G. Shantz, **Planar Elliptical Element Ultra-Wideband Dipole Antennas.** IEEE APS/URSI Conference, 2002.

[2] P. Cerny, M. Mazanek, **Elliptical Dipole Antenna for UWB.** Radioelektronika 2005 conference, vol. 1, pp. 207–210, Brno, May 2005.

[3] H. G. Shantz, L. Fullerton, **The Diamond Dipole: A Gaussian Impulse Antenna.** Antennas and Propagation Society International Symposium, IEEE, vol. 4, pp. 100–103, July 2001.

[4] X. H. Wu, Z. N. Chen, **Design and Optimization of UWB Antennas by a Powerful CAD Tool: PULSE KIT.** Antennas and Propagation Society Symposium, IEEE, vol. 2, pp. 1756 –1759, June 2004.

[5] P. V. Anob, K. P. Ray, G. Kumar, **Wideband Orthogonal Square Monopole Antennas with Semi-circular Base.** Antennas and Propagation Society International Symposium, vol. 3, pp. 294–297, July 2001.

Optimizacija ultra-širokopojasnih dipol-antena. Ovaj rad opisuje optimizaciju planarnih ultra-širokopojasnih dipol antena, koje su optimizirane za savršenu prilagodbu impedancije i savršena obilježja zračenja impulsa. Optimizacija oblika dipola počinje na klasičnim širokopojasnim dipolima, posebno onih eliptičnog oblika i oblika kristala dijamanta. Ti su širokopojasni dipoli analizirani i optimizirani s nezadovoljavajućim performancama parametara. Stoga su u ovom radu predložene dvije optimirane dipole strukture zadovoljavajućih performanca. Projektirane se antene mogu upotrijebiti kao filtri za oblikovanje impulsa u ultra širokom pojasu frekvencija.

Ključne riječi: antene, ultra široki pojas, zračenje impulsa, eliptični dipol, dijamantni dipol

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