ISSN 0005–1144
ATKAAF 49(1–2), 45–50 (2008)

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Distortion Minimization of Radiated Impulses of Tapered Slot Vivaldi Antenna for UWB Application

UDK 621.396.674
IFAC 4.3.2;3.1.1

Original scientific paper

The paper deals with the optimization of the Vivaldi antenna, which is suitable for the measurement of impulse radiation characteristics. In case of particular ultra wideband applications (i.e. radar, positioning, etc.), it is crucial to know the transient responses of antennas. The optimization process searches for the Vivaldi antenna shape. The optimization accomplishes three required parameters – good matching, minimal distortion and smaller antenna dimensions. The parametric study and the manual step-by-step method were used in the process of antenna optimization. The main part of the paper presents the impulse distortion minimization by the feeding transition design and the overall obtained results, which are compared with the measured characteristics.

Key words: Vivaldi antenna, ultra wideband, impulse radiation characteristic, distortion minimization

1 INTRODUCTION

The ultra wideband (UWB) radio represents an emerging technology that attracts attention of both, industry and academia. An antenna represents the indispensable component of every radio system. Consequently, in this paper, the antenna is studied from the pulse radiation point of view. Firstly, the required ultra wideband antenna should be perfectly matched to the feeding line. Secondly, it should minimally distort transmitted or received impulses.

The ultra wideband technology is defined as any radio technology using signals that have a spectrum occupying a bandwidth either greater than 20 % of the centre frequency or a bandwidth greater than 500 MHz, [1]. The US Federal Communications Commission (FCC) defined the frequency mask that determines the maximum radiated power of the ultra wideband signal. This mask indicates the frequency band ranging from 3.1 to 10.6 GHz within which the ultra wideband signal is transmitted with a maximum power.

For a measurement purposes it is necessary to use an antenna with a minimum distortion of received or radiated impulses. A Vivaldi antenna offers the best solution for the impulse measurement. On the other hand, a double ridged horn antenna has a very similar impedance and radiation characteristics, but its feeding circuitry including the waveguide cavity can (due to the cut-off frequency) substantially distort the radiated impulses.

1.1 Distortion of radiated impulses

The distortion is evaluated using the fidelity factor $F(\theta,\phi)$, which is evaluated as a normalized correlation function of evaluated impulse with the template impulse; see Equation (1), [4].

$$F(\theta,\phi)=\max_{\tau}\left|\frac{\int_{-\infty}^{\infty} e(t,\theta,\phi)T(t+\tau)\,\mathrm{d}t}{\sqrt{\int_{-\infty}^{\infty}|e(t,\theta,\phi)|^2\,\mathrm{d}t\int_{-\infty}^{\infty}|T(t)|^2\,\mathrm{d}t}}\right| \quad (1)$$

where $e(t,\theta,\phi)$ is evaluated impulse radiated or received to/from direction (θ,ϕ) and $T(t)$ is the template impulse.

In cases of the received and transmitted impulses, the template impulse is directly equal to the excitation impulse – e.g. incident plane wave. In case of the radiated impulses, the template impulse stands for the derivative of the excitation impulse (because of derivative characteristics of antennas during the radiation), [5]. The fidelity reaches to very low sensitivity to the impulse shape, see com-

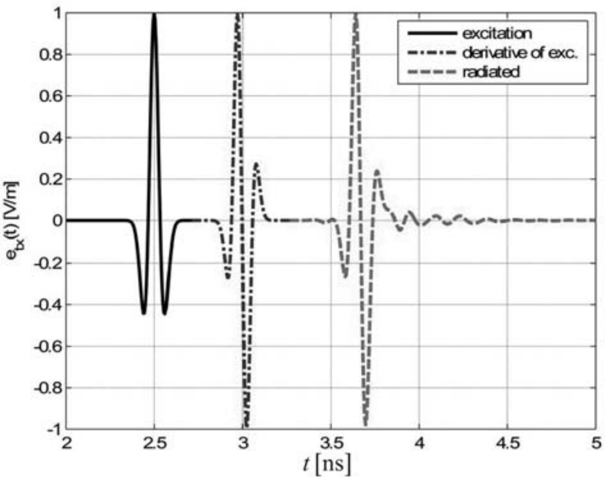


Fig. 1 Excitation impulse, derivative of excitation impulse, radiated impulse to main direction

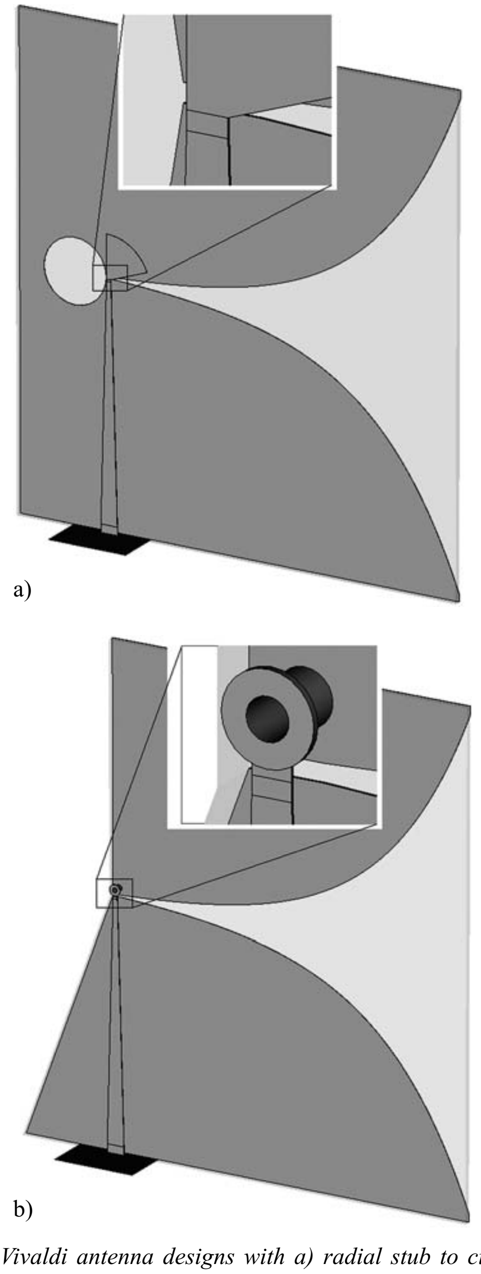
parision in Table 2, Figures 10 and 11. Its value ranges from zero to one (highest fidelity). The value above 0.95 can be considered as a very good result, [6].

In this paper, only the distortion of the radiated impulses is evaluated. Figure 1 shows the impulses used for the antenna excitation (the second derivative of the Gaussian impulse – solid line) and for the distortion evaluation (the third derivative – dash dotted line) of radiated impulses (dashed line). The width of the second derivative of the Gaussian impulse (excitation impulse) is designed for the FCC frequency band.

2 VIVALDI ANTENNAS

The Vivaldi antenna is a planar travelling wave antenna with the end fire radiation. It provides the typical gain 4–8 dBi. The antenna consists of the feeding line, the transition and the radiated structures. The radiated structure is usually tapered exponentially. The exponentially tapered radiated structure is usually made in one, two or three layers, [2, 3].

The one-layer structure is called the tapered slot Vivaldi antenna – it offers small dimensions and provides a sufficient return loss and a sufficient distortion. The two-layer structure is called the antipodal Vivaldi antenna – it offers minimum distortion in exchange for a larger antenna structure. The three-layer structure is called the balanced antipodal Vivaldi antenna – it reduces the cross-polarization of the antipodal structure. One of the goals of the antenna optimization is to minimize the antenna dimensions. Thus, the tapered slot structure of the Vivaldi antenna was chosen. The tapered slot Vivaldi antenna with feeding circuits is depicted in Figure 2a.


a)

b)

Fig. 2 Vivaldi antenna designs with a) radial stub to circular stub transition, b) via to open slotline transition

2.1 Radiating structure of Vivaldi antenna

The design of the Vivaldi antenna radiating structure is based on the parametric studies. The antenna is designed for the microwave substrate TACONIC TLX-8, whose height equals 0,76 mm. The edges of the radiation structure are exponentially tapered slot, defined by the Equation (2).

$$f(x) = \pm(0.513e^{0.09x} - 0.431) \quad (2)$$

where $f(x)$ describes the edges (slot width is $2f(x)$) of radiating structure in distance x from exponentially tapered slot beginning.

2.2 Feeding circuit of Vivaldi antenna

The feeding circuit of the tapered slot Vivaldi antenna consists of the orthogonal transition from the mostly used microstrip line to the input slotline of the Vivaldi radiating structure. The impedances of both inputs of this transition usually amount to 100 Ω. It is necessary to transform the impedance of the input feeding microstrip line into the input impedance of the transition. The linear microstrip taper (L = 28 mm) was used as the input impedance transformer, see Figure 2.

In comparison to the double Y balun, the orthogonal transition slightly distorts the transformed impulse signal, [2, 3]. The orthogonal transition has many variations. The mostly used variation of this feeding circuit consists of the orthogonal crossing of the microstrip line and the slot line (the slot is located in the ground plane of the microstrip line). The microstrip line is usually terminated by the radial stub (α = 60°, R = 5.3 mm). In addition, the slot line is usually terminated by the circular stub (R = 4 mm), see design in Figure 2a.

2.3 Distortion minimization of feeding circuit of Vivaldi antenna

The microstrip radial stub represents the capacity, whereas the slotline circular stub stands for the inductance. These two electrical and parasitic components accumulate the energy of the impulse for the short time interval and substantially distort the transmitted impulse; for the fidelity see Table 1. This effect is depicted in the Figure 3. The first minimum of the Gaussian doublet is substantially smaller than the second one.

Table 1 **Distortion (as fidelity) for various transitions**

Transition type	Radial Stub + Circular Stub	Via + Circular Stub	Via + Open
Fidelity	0.9663	0.9936	0.9989

The distortion expressed using the fidelity of the standard transition offers a suitable, but not excellent value, see Table 1. In order to improve the fidelity, it is necessary to minimize the influence and values of the parasitic components. Firstly, the capacity represented by the microstrip radial stub termination was replaced by the short (represented by via), which accumulates a substantially smaller amount of energy in comparison to the radial stub; see phases of reflection coefficient in Figure 4. This first improvement of the transition dramatically increases the fidelity factor (by 2.8 %), see Table 1. Secondly, the circular slotline stub was replaced by the open end slotline. The aforementioned improvement of the orthogonal transition increases the fidelity factor by 0.53 %, see Table 1. Both improvements are illustrated in Figure 3. The energy accumulation effect is substantially smaller, which is obvious from the phases of reflection coefficient in Figure 4. The Vivaldi antenna with improved feeding circuit is depicted in Figure 2b.

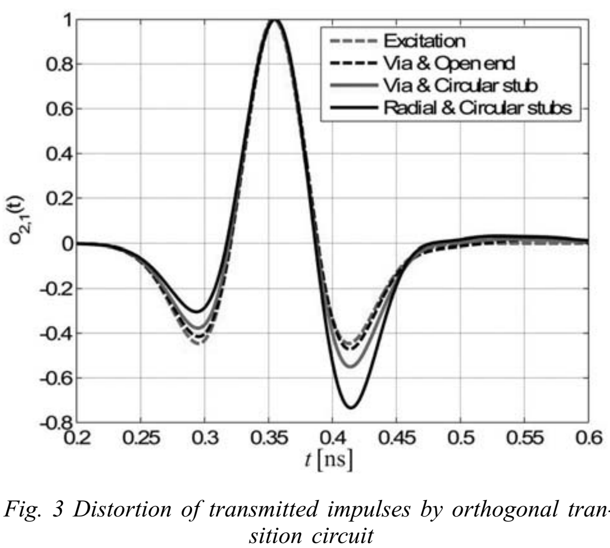


Fig. 3 Distortion of transmitted impulses by orthogonal transition circuit

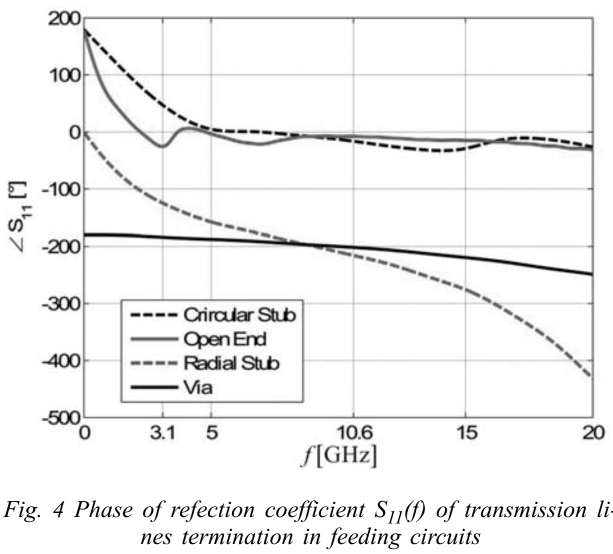


Fig. 4 Phase of refection coefficient $S_{11}(f)$ of transmission lines termination in feeding circuits

3 CHARACTERISTICS OF OPTIMIZED VIVALDI ANTENNA

3.1 Simulation results of transient radiation characteristics

The antenna transition, impedance transformer and radiation structure were simulated in 3D full-wave simulator CST Microwave Studio®, the structures were excited by the Gaussian doublet with parameter σ = 48 ps, see Figure 1.

Table 2 involves comparisons of simulated fidelity factors for designed Vivaldi antennas among via (short) to open end transition, microstrip radial stub to slot circular stub transition and Vivaldi antenna design by Piksa-Sokol [3]. The Figure 1 depicts the radiated impulse by the Vivaldi antenna with via to open end transition to the main direction (dashed line) and the template impulse (dash dotted line) used for the fidelity evaluation. The spatial distribution of the fidelity (impulse distortion) is shown in Figure 5. Cross sections of fidelity in θ and ϕ planes are depicted in Figure 6.

Table 2 **Distortion (as fidelity) for various transitions and two excitation impulses, modulated Gaussian impulse is defined in CST in band (3.1–10.6 GHz)**

Excitation Impulse	Via + Open V.	Radial Stub + Circular Stub V.	Piksa Vivaldi
Doublet	0.9652	0.9633	0.9552
Modulated Gauss	0.9944	0.9953	0.9874

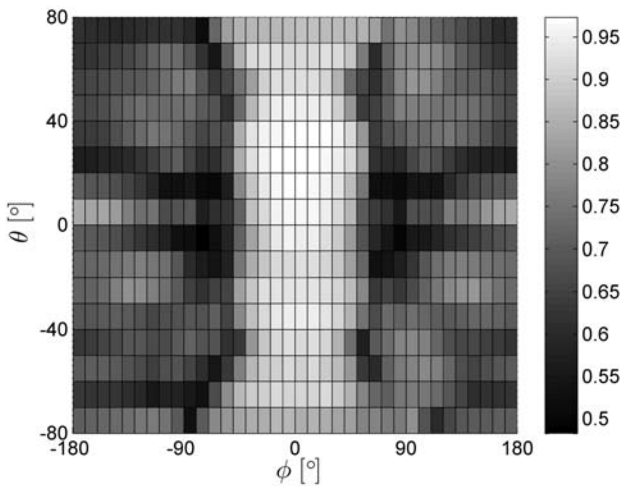


Fig. 5 Spatial distribution of fidelity of radiated impulses

3.2 Experimental results

The Vivaldi antennas with the via to open end transition and the microstrip radial stub to slot circular stub transition were manufactured, their parameters were measured and compared with the simulated ones. Figure 7 and Figure 8 depict the comparison of the simulation and the actual measurement of the reflection coefficients of the fabricated Vivaldi antennas with both transitions. Figure 9 shows the measured excitation impulse $s_{tx}(t)$ used in the time domain measurement. This impulse is generated by the step recovery diode (SRD) generator, developed at our department.

The transmission between the pair of identical Vivaldi antennas with the given excitation impulse represents a basis for the comparison of the time domain radiation characteristics. The first characteristic is directly measured using the SRD gene-

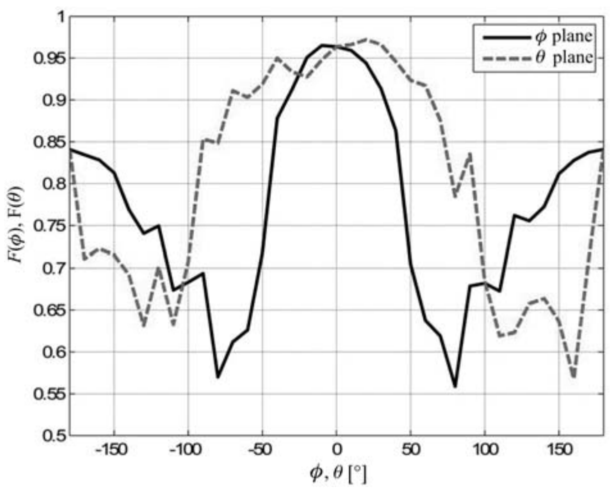


Fig. 6 Directional distribution of fidelity in the θ and ϕ planes of radiated impulses

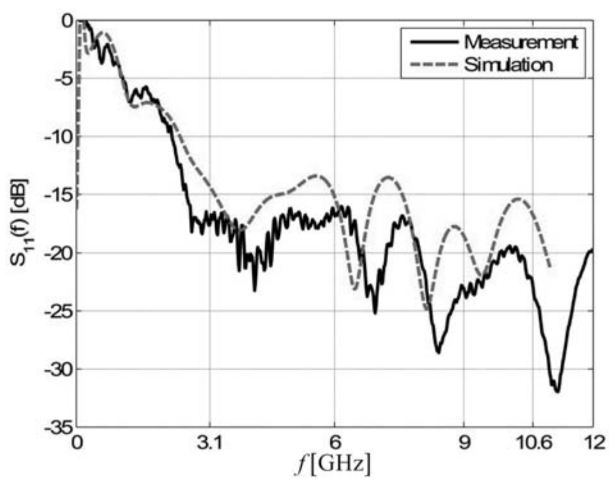


Fig. 7 Measurement of reflection coefficient of Vivaldi antennas with via to open end transition

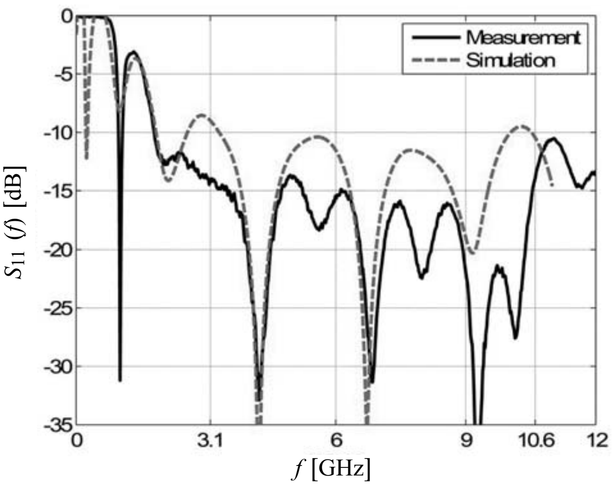


Fig. 8 Measurement of reflection coefficient of Vivaldi antennas with microstrip radial stub to slotline circular stub transition

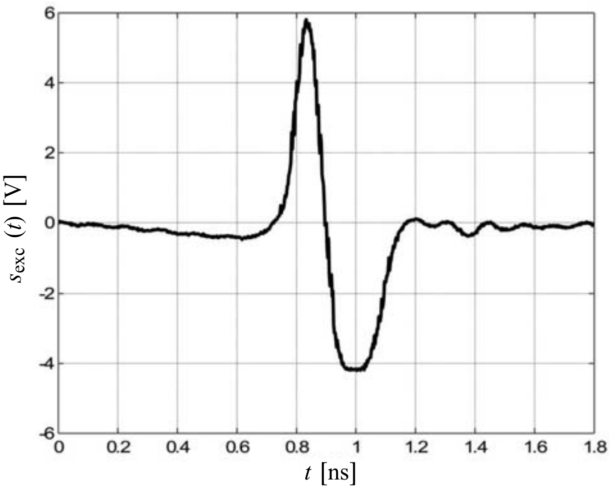


Fig. 9 Measurement of excitation impulse used in time domain measurement

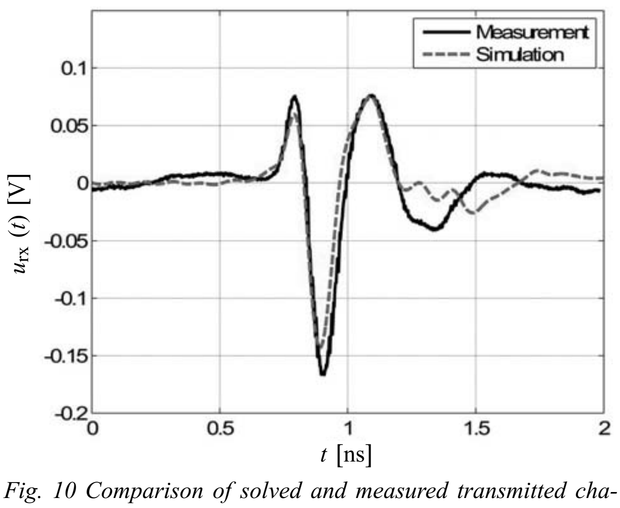


Fig. 10 Comparison of solved and measured transmitted characteristics of Vivaldi antenna with via to open end transition

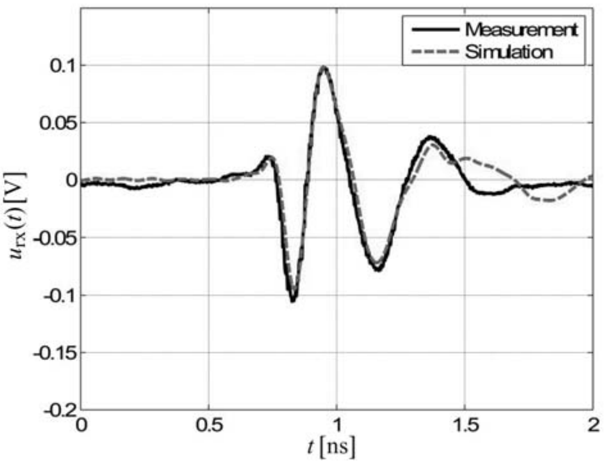
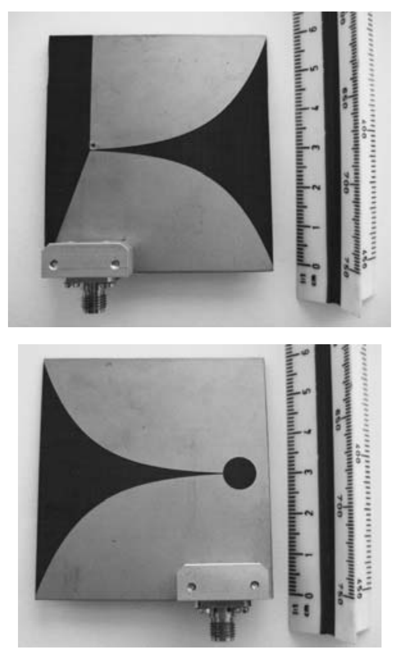


Fig. 11 Comparison of solved and measured transmitted characteristics of Vivaldi antenna with microstrip radial stub to slotline circular stub transition



a)

b)

Fig. 12 Photo of fabricated Vivaldi antennas

rator and the wide bandwidth oscilloscope Agilent 86100C equipped by TDR/TDT module 54754A. The second characteristic $s_{rx}(t)$ is solved as the convolution of the excitation impulse, of the radiated impulse response and of the receiving impulse response; see equation (3).

$$s_{rx}(t) = s_{rx}(t) \cdot h_{tx}(t) \cdot h_{rx}(t) \tag{3}$$

where $s_{tx}(t)$ is the excitation impulse, $h_{tx}(t)$ is the radiated impulse response (including derivative) and $h_{rx}(t)$ is the receiving impulse response.

The radiated impulse response $h_{tx}(t)$ is computed as a deconvolution of the radiated impulse with the excitation impulse (both from the simulation). The received impulse response $h_{rx}(t)$ is computed similarly as a deconvolution of the received impulse with plane-wave excitation impulse (both from the simulation).

Figure 10 and Figure 11 depict the comparison of solved impulses (using equation (3)) and the measured transmitted impulses by pair of Vivaldi antennas with both types of transitions. Figure 12 shows the fabricated Vivaldi antennas with both transitions.

4 CONCLUSION

The manual step-by-step optimization as well as improvements of the Vivaldi antennas including two types of microstrip line to slotline transitions (via to open end and microstrip radial stub to slot circular stub) have been presented. Moreover, the simulated and measured antenna characteristics (reflection coefficients and transmitted impulses) were shown.

The paper proposes the improvement of the feeding transition (including via to open end) of the tapered slot Vivaldi antenna. In comparison to the transition including microstrip radial stub to slotline circular stub, the aforementioned improvement increases the fidelity factor of the radiated impulses in case of the Gaussian doublet excitation.

The paper also proposes the new design of the Vivaldi antenna based on the new feeding transition. In comparison to the design Piksa-Sokol, [3], the above-mentioned antenna design shows approx. half as large dimensions, but at the same time a smaller distortion.

5 ACKNOWLEDGEMENT

The research is a part of the activities of the Department of Electromagnetic Field of the Czech Technical University in Prague within the research project of the Ministry of Education, Youth and Sports of the Czech Republic No. LC06071 Centre of Quasi-Optical Systems and Terahertz Spectroscopy. The measurement was supported by the project Research in the Area of the Prospective Information and Navigation Technologies MSM 6840770014.

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Minimizacija izobličenja impulsa zračenih ugođenom proreznom Vivaldijevom antenom za UWB primjene. Riječ je o optimizaciji Vivaldijeve antene, koja je prikladna za mjerenje karakteristika zračenja impulsa. U određenim UWB (ultraširokopojasnim) (npr. radari, pozicioniranje i dr.) ključno je poznavati tranzijentne odzive antena. Oblik Vivaldijeve antene dobiva se procesom optimizacije. Optimizacijom se postižu tri potrebna svojstva: dobra prilagodba, minimalna izobličenja i manje dimenzije antene. U procesu optimizacije rabi se automatsko variranje parametara i metoda korak po korak. Glavni dio rada prikazuje proces minimiziranja izobličenja impulsa primjenom prijelaza u pobudnoj strukturi te ukupne rezultate koji su uspoređeni s izmjerenim karakteristikama.

Ključne riječi: Vivaldi antena, ultraširokopojasno (UWB), karakteristike zračenja impulsa, minimizacija izobličenja

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Received: 2008-5-5