Planar UWB monopole antenna optimization to enhance time-domain characteristics using PSO

#Somayyeh Chamaani, Seyed Abdullah Mirtaheri
[1] Electrical engineering department, K. N. Toosi University
P.O. Box 16315-1355, Tehran, Iran,
chamaani@eetd.ktu.ac.ir, mirtaheri@eedt.kntu.ac.ir

1. Introduction

In recent years, interesting characteristics of UWB technology such as high data rate support, simplicity and low cost, high data resolution, robustness to multi-path fading and very low interference, propose it as a good candidate for wireless communication systems Such as Body Area Networks (BANs), Radar and other applications.

Although generally UWB covers multi carrier systems such as OFDM, MC-CDMA and DS-CDMA [1]-[2], in this study, focus is on impulse radio communication systems. In these systems UWB spectrum, is occupied by spectra of a single or several impulses [3]. In impulse radio, transient characteristics of the system are very important. In other words, the transmitted signal must be received at receiver with minimum distortion. In this way, antenna as a vital part of any wireless system must be as distortion less as possible. Also due to power limitations of FCC mask for indoor UWB communications, antennas must provide a good matching with feed section.

In this study a modified version of Particle Swarm Optimization is used to minimize return loss (S_{11}) and maximize fidelity factor. A high fidelity factor accounts for both of $|S_{21}|$ and group delay flatness in frequency domain (when Tx/Rx system is considered). Thus using fidelity factor in cost function, frees us from calculation of S_{21} in the entire frequency domain [4], [5].

This paper is organized as follows: section 2 describes antenna structure and optimization procedure. Section 3 focuses on numerical and experimental results and comparison of the optimum antenna with a prototype one (Fig. 3). Prototype antenna is a Planar Circular Disk Monopole (PCDM) one which was introduced as a well candidate for UWB applications, before [6]. Finally conclusions are discussed in section 4.

2. Antenna optimization

The antenna structure is shown in Fig. 1 [7]. A finite ground microstrip line (FGMSL) is used to feed this antenna. FGMSL is a modified version of microstrip line. It has been recently gaining a potential application in exploration of high-performance hybrid microwave integrated circuits [8].

As it is noticed, the bottom part of radiator is a semi-disc. Some researches about shape optimization of UWB antennas show this form leads us to a low VSWR [9] in UWB frequency range. Also, since current distribution on upper part of antenna is low, forming of it sounds a nondestructive procedure.

This antenna structure recently have been used to optimization of UWB antenna for some objects: low VSWR, small size, pattern uniformity and gain consistency [7]. But, in impulse radio, transient characteristics are more critical than traditional frequency domain definition of pattern and gain. Thus in this study, optimization carried out for VSWR and correlation factor (fidelity factor) objects simultaneously.

The cost function F used in optimization is a weighted sum of two functions F_1 and F_2 as following as:

$$F_1 = \max_{f \in [3.1,10.6]} \{VSWR\}, F_2 = 1 - CF_{av}(\theta,\varphi) \tag{1}$$

Where

$$CF(\theta,\varphi) = \max_{\tau} \left\{ \frac{\int s_{in}(t) s_{\theta,\varphi}(t-\tau) dt}{\sqrt{\int s_{in}^2(t) dt} \sqrt{\int s_{\theta,\varphi}^2(t) dt}} \right\} \tag{2}$$

$CF(\theta,\varphi)$ is the correlation factor between excitation signal $s_{in}(t)$ and signal $s_{\theta,\varphi}(t)$. To reduce simulation time, $s_{\theta,\varphi}(t)$ in our simulation is the electric field intensity picked with some virtual probes [4-5] at far field region of transmitter antenna. Then the mean value of resulted correlation factors CF_{av} is used in calculation of cost function. Three probes situated at ($\varphi = 90, \theta \in \{0,30,60\}$) are used for electric field intensity recording. Finally CF_{av} and F will be as following as:

$$CF_{av} = \frac{1}{3} \sum_{i=1}^{3} CF(\theta_i, \varphi = 90), F = F_1 + \gamma F_2 \tag{3}$$

The relative importance of each part determines the γ. In our design, γ equals 1. A modified version of PSO (MLPSO) is used for optimization [10]. This version of PSO, divides total population to some sub swarms which they search the space in parallel and share their results after each generation. Previous studies show this method searches the space more effective than basic PSO [10]. In MLPSO, we set population_size=15 and maximum_generation=40. Population is divided to 3 sub-swarm with 5 particle in each of them. The antenna is printed on a Rogers Ro4003 substrate ($\varepsilon_r = 3.38$) with the thickness of $t = 0.813mm$.

3. Simulation and experimental results

In our optimizations the fifth derivative of Gaussian pulse is used for excitation which complies the FCC mask very well [11].

After the optimization, values listed in Table 1 are obtained for the optimized antenna (Fig.2). Antenna performance is investigated from two aspects: frequency-domain characteristics and time-domain radiation patterns as following as:

3.1 Frequency domain characteristics

Simulated and measured value of $|S_{11}|$ are shown in Fig.3. As it is noticed, the optimized antenna presents a good matching in the entire desired frequency.

Since virtual probes are situated in elevation plane ($\varphi = 90^\circ$), we expect the frequency domain transfer function in face to face scenario become more flat. So transfer function in face to face configuration examined for optimized antenna. Maximum variation of $|S_{21}|$ and group delay are reduced noticeably for optimized antenna in comparison with PCDM [12]. As it shown in Fig. 5 the measured value of $|S_{21}|$ agrees reasonably in well with the simulated one.

3.1 Time domain radiation patterns

Radiation pattern presentation is a useful tool to investigate direction dependent performance of antennas. But whereas the ultrawide bandwidth of ultra short pulses, restrict us to apply conventional frequency domain radiation pattern descriptors, some pattern descriptors are defined in time-domain. For example fidelity factor is a time-domain pattern (Fig.6). In addition to fidelity factor three following types of radiation patterns are used to evaluate the antenna time-domain performance [13]:

1) Energy pattern

$$P_{energy}(\theta,\varphi)=\int_{0}^{\infty}\left|s(\theta,\varphi)\right|^{2}dt \tag{4}$$

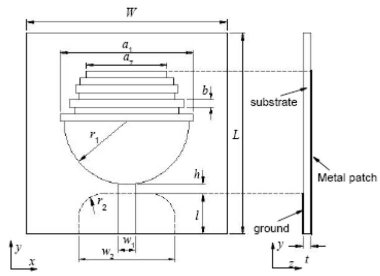

Fig.1 Antenna Structure [5].

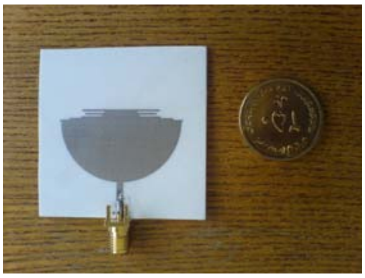

Fig.2 Optimized antenna

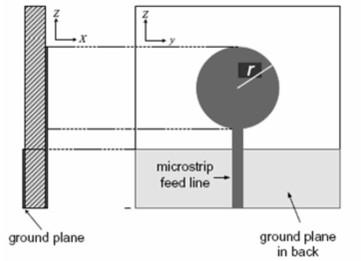

Fig.3 PCDM Antenna [11].

2) Peak power pattern

$$P_{peak}(\theta,\varphi)=Max\{s(t,\varphi)\} \tag{5}$$

3) Correlated energy pattern

$$P_{correlated}(\theta,\varphi)=\int_{0}^{\infty}s(t,\theta,\varphi)b(t)dt \tag{6}$$

$b(t)$ is a template pulse and in this work selected to be excitation signal. Resulted pattern are shown in Fig. 7.

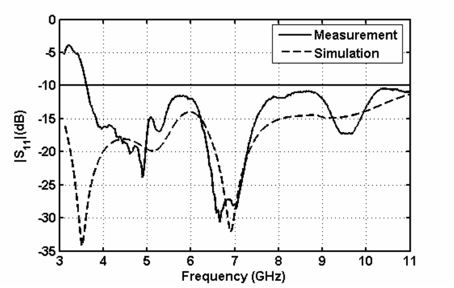

Fig. 4 Return loss of optimized antenna

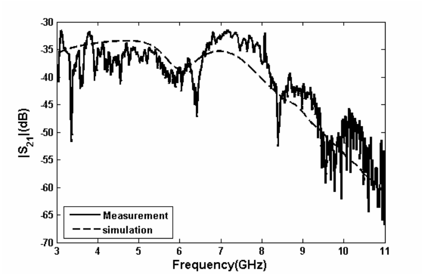

Fig. 5 Measurement result of $|S_{21}|$ in face to face scenario.

Table1. Optimized antenna dimensions.

w_1	w_2	l	b	h	r_1	r_2
1.85	30	10	0.5	0.5	17.7	6.1
a_1	a_2	a_3	a_4	a_5	a_6	a_7
36.2	30.5	23.3	11	21	9.6	22.8

As results show, since low VSWR and high fidelity factor constitute the objective function, CF pattern is improved obviously. Also in other patterns such as energy pattern, transient peak power pattern and correlated energy pattern, optimized antenna exhibits satisfactory uniformity in different angles in the interval of $\theta\in[0^{\circ},50^{\circ}]$ which have the most practical importance.

4. Conclusion

Optimization of a FGMS fed UWB planar monopole antenna has been done by a modified version of PSO. The optimization aims good matching and high similarity between transmitted and received signals. To quantize similarity, fidelity factor which is a time-domain parameter was applied. To reduce simulation time, virtual probes in far-field region of transmitter antenna were used instead of simulating two antennas Tx/Rx system. Correlation factor is calculated between excitation signal and electric field intensity recorded by far-filed probes. Obtained antenna presents not only a high CF pattern but also a flatter magnitude of transfer function $|S_{21}|$ and group delay in the entire frequency band of UWB. Some time-domain pattern descriptors investigate radiation characteristics of optimized antenna. Obtained results show time-domain patterns of the optimized antenna is satisfactorily uniform in E-plane.

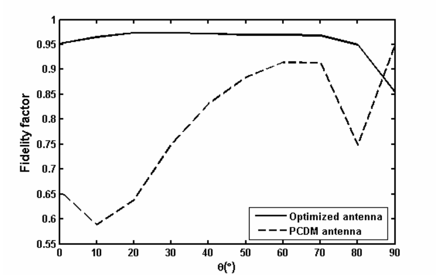

Fig. 6 Fidelity factor in E-plane ($\varphi = 90^\circ$).

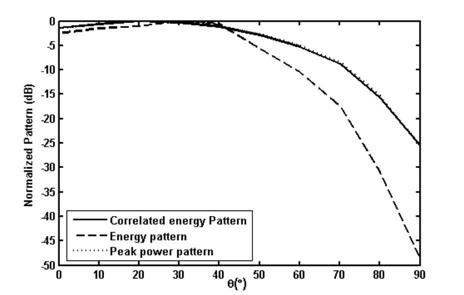

Fig. 7 Time domain radiation patterns in the E-plane ($\varphi = 90^\circ$).

Acknowledgments

The authors gratefully thank Iran telecommunication research center for its helpful support.

References

[1] M. Schmidt. F. Jondral, "Ultra wideband transmission based on MC-CDMA", Proc. IEEE Global Telecommunications Conference, pp. 749-753, 2003.

[2] Y. B. Park, C. S. Kim, K. K. Chu, C. J. Lee, H. K. Lee, J. M, Kim, K. S. Kwak, " Performance of UWB DS-CDMA/OFDM/MC-CDMA system", Proc. 47th Midwest Symposium on circuits and Systems, pp. 37-40, 2004.

[3] B. Alen, M. Dohler, E. E. Okon, W. Q. Malik, A. K. Brown, D. J. Edwards, *Ultra-wideband antennas and propagation for communications, radar and imaging*, Wiley, chapter 7, pp. 147-161, 2007.

[4] N.Telzhensky and Y.Leviatan, "Novel method of UWB antenna optimization for specified input signal forms by means of genetic algorithm," IEEE Transactions on Antenna and Propagat., vol. 54, no. 8, pp. 2216-2225, August 2006.

[5] N. Telzhensky and Y.Leviatan, "Planar Differential Elliptical UWB Antenna Optimization", *IEEE Trans. Antennas Propag.*, vol. 54, no. 11, pp. 3400-3406, November 2006.

[6] J. Liang, L. Guo, C.C. Chiau, X. Chen, and C.G. Parini, "Study of a Printed Circular Disc Monopole Antenna for UWB Systems," IEEE Transactions on Antennas and propagation, VOL. 53, NO. 11, November 2005.

[7] X. S. Yang, K. F. Man, S. H. Yeung,J. L. Li, B. Z, Wang, "Ultra-wideband planar antenna optimized by a multi-objective evolutionary algorithm," Proc. IEEE Asia-Pacific Microwave conference, pp. 649-652, Dec. 2007.

[8] S. Sun, L. Zhu, "Unified equivalent circuit model of finite-ground microstrip line open-end discontinuities using MoM-SOC technique", IEICE Trans. Electron., Vol. E87-C, No. 5, pp. 828-831, May 2004.

[9] A. J. Kerkhoff, R. L. Rogers,H. Ling, "Design and analysis of planar monopole antennas using a genetic algorithm approach ", IEEE Trans. Antennas Propagat., Vol.52, No.10, pp.2079-2718, Oct. 2004.

[10] S. Chamaani, S. A. Mirtaheri, M. A. Shooredeli, "Design of very thin wideband electromagnetic absorber using modified local best particle swarm optimization," Int. J. Electron. Commun. (AEÜ) 62, pp. 549 – 556, 2008.

[11] H. Sheng, P. Orlik, A. M. Haimovich, L. J. Cimini, J. Zhang, "On the spectral and power requirements for Ultra-Wideband transmission", Proc. of IEEE international Conf. on Communications (ICC), December 2003.

[12] J. Liang, L. Guo, C.C. Chiau, X. Chen, " Time domain characteristics of UWB disk monopole antennas, " Proc. European Microwave Conference, Oct. 2005.

[13] X. H. Wu, A. A. Kishk, and Z. N. Chen Z. N., "A linear antenna array for UWB applications, " Proc. IEEE Antennas and Propagation Society International Symposium, pp. 594-597, 2005.