CPW-fed UWB monopole antenna optimization

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1. Introduction

In recent years, useful characteristics of ultra wideband (UWB) technology such as high data rate, low interference with other systems, and resistance to multi path fading propounded it as an interesting method of data communication especially for short distances. For this class of applications, design of light weight and portable UWB devices attracts much interest. In this direction, many studies have been done on antenna as an indispensable part of UWB systems. Through different prototypes, planar antennas due to their integration capability and small size attract much attention. In this paper we focus on planar monopole antenna with a coplanar waveguide (CPW) feed. Planar CPW-fed antenna had been investigated from frequency domain aspects such as VSWR and radiated pattern [1]. In impulse radio UWB communication, consistency of signal waveform from transmitter to receiver must be preserved. Antenna, as an analog part of system, may destroy this consistency. Time-domain response of UWB antennas has been investigated for various input waveforms [2]. In our study, in addition to return loss, transient characteristics of antenna for a fixed waveform which satisfies the Federal Communications Commission (FCC) mask [3] are considered. Fidelity factor as a time domain bench mark could be applied to assess transient performance of antenna. A high fidelity factor means high similarity between transmitted and received signals. In other word, a high fidelity factor ensures flatness of transfer function magnitude ($|S_{21}|$) and linearity of transfer function phase ($\angle S_{21}$) in frequency domain. A genetic algorithm (GA) optimizer is aimed at minimization of return loss and maximization of fidelity factor. Fidelity factor is calculated by means of three virtual probes situated at proper locations in far field region. Major parts of optimization variables lies on ground part of CPW.

In the next section, antenna structure and optimization procedure is described. Section III elaborates simulation results of optimized antenna and compares it with a prototype antenna for different criteria such as VSWR, correlation factor (fidelity factor), transfer function and group delay. Finally conclusions are expressed in section IV.

2. Antenna optimization

The antenna structure used in optimization procedure is shown in Fig. 1 (a). As it is observed, the radiator part has an elliptical shape. But a and b could be varied during optimization process. Five points on each half of ground plane controls the ground shape by means of a spline curve. For each control point, two spline factors -expansion and sharpness- are assigned. There are three class of descriptive parameters for antenna: constant values, independent variables and dependent variables. Constant values correspond to feed line and margin of radiating part from substrates edge. independent values take participate in optimization process and dependent variables are constructed from independent variables with some linear equations. Substrate is made from RO4003 ($\varepsilon_r = 3.38$) with 0.813*mm* thickness. Cost function is a weighted sum of two functions F1 and F2 as follows:

$$F_1 = \max_{f \in [3.1GHz, 10.6GHz]} \{S_{11}(f)\} \quad (1)$$

And

$$F_2 = 1 - (\sum_{i=1}^{3} CF(\theta_i))/3 \quad (2)$$

Where $CF(\theta)$ depicts correlation (fidelity) factor and it is defined as follows:

$$CF(\theta) = \max_{\tau} \left\{ \frac{\int s_{in}(t) s_{\theta}(t-\tau) dt}{\sqrt{\int s_{in}^2(t) dt} \sqrt{\int s_{\theta}^2(t) dt}} \right\} \quad (3)$$

$CF(\theta)$ is a measure of similarity between the input signal of antenna s_{in} and the received signal at a specified direction s_{θ}. Three different directions are chosen ($\varphi = 90°,\ \theta = 0°, 30°, 90°$). To achieve an accurate result, received signal must be measured at the output terminal of a receiver antenna. But to reduce the simulation time, virtual probes measuring electric field intensity are used in far-field region of transmitter antenna instead of recording received signal at the output terminal of the receiver [4-5]. This method is fairly equivalent with simulation of just a single antenna and could be used in an iteration based algorithm like GA, easily. The final cost function will be:

$$F = F_1 + \gamma F_2 \quad (4)$$

γ can be changed with respect to importance of each part. In this optimization, γ is selected to be 1. Optimization process is implemented in MATLAB. CST Microwave Studio is applied for simulation of antenna and evaluating cost function [6]. GA settings are as follows: population size: 60, maximum number of generation: 8, crossover rate: 0.8, mutation: adaptive feasible and elite count:2. Thirteen independent variables participate in optimization.

The final shape of antenna is illustrated in Fig. 1 (b).

Corresponding values of optimized antenna are as follows:

Constant values:

$w = 4mm, l = 10mm, \Delta y_{mar} = 5mm$

Independent variables:

$x_1 = 4.1,\ x_2 = 14.5,\ x_3 = 20.3, y_0 = 0.18,\ y_1 = -0.08,\ y_2 = 1.6, y_3 = 1.3,\ y_4 = -3.7, g = 24.2,\ q = 0.45,\ a = 18.8,\ b = 14.7$

Dependent variables:

$x_{11} = 3.5,\ x_{12} = 8.9,\ x_{21} = 10,\ x_{22} = 15.5, x_{31} = 16.6,\ x_{32} = 23.1, y_{11} = -6.7,\ y_{12} = 6, \Delta y_{ag} = 0.32$

Also during the optimization process, we maintain expansion and sharpness of each spline curve equal to 1 and 0.5, respectively.

3. Simulation and experimental results

In this section, performance of optimized antenna discussed from matching, Tx/Rx frequency domain transfer function and transient characteristics points of view. These features are also compared with prototype antenna proposed in [1].

3.1 Frequency domain performance

As shown in Fig. 2, the measured return loss agrees reasonably well with the simulated one. Measurement shows maximally a -14dB return loss in the entire UWB band which introduces it as an excellent antenna from matching point of view [7].

To investigate transfer function consistency in frequency domain, two antennas are situated face to face with 60cm distance. The magnitude of S_{21} and the group delay are presented in Fig. 3 (a) and (b) respectively. As it is observed, the maximum variation of $|S_{21}|$ for optimized antenna is 19.78dB while this value for prototype antenna is 28.85dB.

Besides, optimized antenna presents a more linear phase in the frequency band. This is clear in group delay diagram. Fig. 3 (b) shows that the maximum variation of group delay for obtained antenna is 0.23ns whereas this value for prototype antenna is 0.42ns.

The measured and simulated radiation patterns at 4GHz, 7GHz and 10GHz for E-plane and H-plane are shown in Fig. 4 (a) and (b), respectively. As it is observed, both measured co- and cross-polarization field in E-plane and H-plane are very close to simulated ones.

3.2 Time domain performance

As it is observed in previous section, frequency domain characteristics of this antenna is improved in comparison with prototype antenna. But in ultra short pulse transmission and reception, frequency domain characteristics usually are not the definite criteria to assessment of the UWB antenna. On the other hand, there are some alternative parameters in time domain which satisfying them entails having a proper UWB antenna. Two time domain gauge are employed to evaluate resulted antenna: fidelity factor and transient peak power.

As mentioned above fidelity factor was an explicit object in optimization process. Fig. 5 shows fidelity factor pattern in E-plane. It is noticed that the fidelity factor is improved at all angles. Besides, to investigate antenna characteristics in a real situation, the face to face and side by side scenarios were simulated. The corresponding fidelity factors are listed in Table 1. which are truly well in comparison with complicated antennas optimized before [4- 5].

Transient peak power [8-9] pattern is a time domain scheme to capture the maximum value of radiated power in space. This pattern in E-plane is shown in Fig. 6 for optimized and prototype antenna. It is observed that the peak power pattern of optimized antenna is more uniform in comparison with prototype antenna.

4. Conclusion

A CPW-fed monopole antenna has been optimized with genetic algorithm. Targets of optimization were low VSWR and high correlation between transmission and reception signals. To reduce simulation time, correlation (fidelity) factor was calculated between the input signal of transmitter antenna and signals measured by three electric field intensity virtual probes situated in far-field region of antenna. Simulation results show that with few changes in the structure of a prototype antenna, antenna designs with smaller size, excellent matching, flatter transfer function and less group delay variations are achievable. Also time domain characteristics such as fidelity factor and transient peak power patterns are more satisfactory in comparison with prototype antenna. Besides, high and uniform fidelity factor entails low and direction-independent distortion of ultra-short pulses.

Acknowledgments

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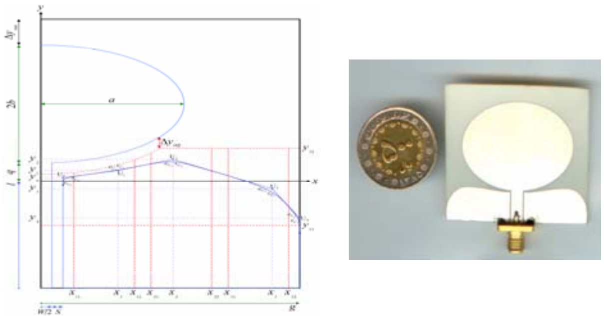


(a) (b)

Figure 1: Geometry of optimizing structure (a), Optimized antenna structure (b).

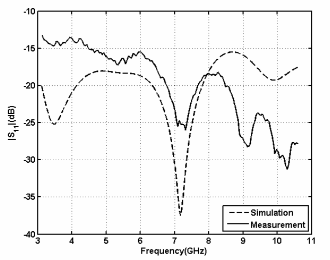
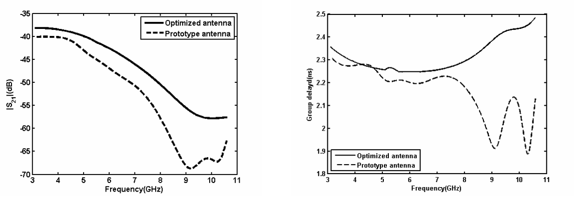


Figure 2: Return loss of optimized antenna and prototype antenna.

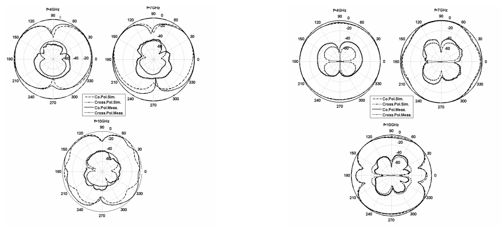


(a) (b)

Figure 3: Magnitude of transfer function for optimized and prototype antenna (a), Group delay of optimized antenna and prototype antenna.

Table 1: Fidelity factor for the two scenarios

Scenario	CF
Face to face	0.84
Side by side	0.78



(a) (b)

Figure 4: Radiation patterns in E-Plane $(\varphi = 90^\circ)$ (a), Radiation patterns in H-Plane $(\varphi = 0^\circ)$ (b).

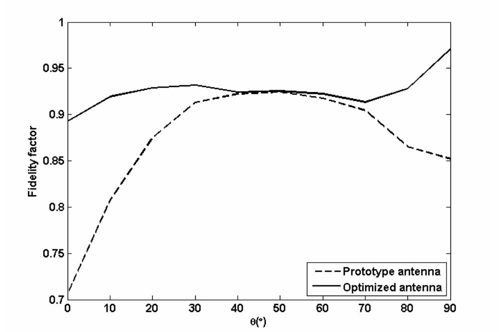
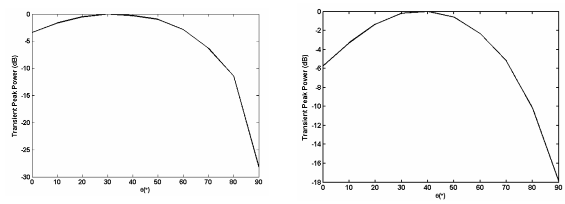


Figure 5: Fidelity factor in E-plane $(\varphi = 90^\circ)$.



(a) (b)

Figure 6: Transient peak power pattern for optimum antenna (a), and prototype antenna (b)