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Optimal Design of UWB Antenna Using Differential Evolution

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Abstract

Wireless technology is one of the main areas of research in the world of communication systems today and a study of communication systems is incomplete without an understanding of the operation of antennas. This paper reports the optimization of staircase ultra wideband antenna with an inverted U shaped structure for 5.8 GHz ISM band suppression. Generally antennas are optimized on trial and error techniques, which are time consuming and even after a number of iterations there is no guarantee of achieving optimum result. The optimal design of Ultra Wide Band (UWB) antenna with a large number of dependent variables is achieved using Differential Evolution Metaheuristic. Suitable representation, mutation operator and fitness function have been designed for the purpose and implemented using MATLAB. Twelve dependent antenna variables are optimized in a very efficient way by exploiting dependencies among them in terms of bandwidth, notch band selection and return loss. The UWB antenna with optimized parameters is designed and simulated using CST Microwave Studio a state-of-the-art microwave design and simulation software used in the industry. The antenna covers frequencies from 2.2 to 8.5 GHz and is immune to 5.8 GHz communication by rejecting the frequency.

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Introduction

One of the fundamental attributes of current short-range wireless technologies is the use of high bandwidth to achieve the desired data rates. The high transmission power is not a feasible option to achieve the required high data rates. In recent years, the commercial operations of Ultra Wideband (UWB) technology attracted researchers to contribute in its evolution by proposing various designs. Ultra-wideband (UWB) wireless technology guarantees very high bit rates availability, low power consumption, low costs and location capabilities (Giuliano and Mazzenga, 2006). Therefore, the antennas employed for these applications should be very efficient.

The UWB antennas cover a wide bandwidth which makes them susceptible to interference from other narrowband systems like in 5.8 GHz ISM band, HyperLan and Wi-Fi. To protect the system from such interference, a notch can be introduced in the radiation or receiving characteristics of UWB antennas which eliminate the requirement of any additional high quality band-pass filter structures. Several techniques have been proposed to introduce a notch in the desired band, such as a tuning fork shaped antenna (Ryu and Kishk, 2009), printed monopole antenna with slots (Movahedinia and Azarmanesh, 2010), antenna with inverted L shaped slot in the ground plane (Movahedinia *et al.*, 2011), antenna with parasitic elements on the patch (Abbosh and Bialkowski, 2009), *etc*. One of the basic techniques is the use of inverted U shaped slot in the patch antenna to create the notch (Kerkhoff and Hao, 2004). This technique of inverted U shaped slot has been adopted to introduce the band rejection characteristics in this work.

In general, it is rare to achieve the desired characteristics with mere theoretical calculations; the optimization process is thus required which involves various variables whose inter-dependencies are not well established. Sequential search techniques for optimizing these parameters consume time and valuable resources. Hence a random search in the solution space is highly beneficial in terms of temporal cost as well as convergence to the optimal/ near optimal solution. This reduces significant amount of time and resources as compared to techniques used otherwise.

Differential evolution (DE) is one of the most powerful stochastic real-parameter optimization algorithms. DE operates through similar computational steps as employed by a standard evolutionary algorithm (EA) (Das and Suganthan, 2010). One of the advantages of DE algorithm compared to GA is that this method does not require the transformation of the variables into binary strings (Shamekhi, 2013). DE maintains a population of agents which are iteratively combined and updated using simple formulae to form new agents (Pedersen, 2010). The algorithm evolves towards an optimum solution by randomly searching a population of candidate solutions called parent population, and then applying mutation operators to generate mutant population. With the help of a pre-defined fitness function, the algorithm advances in a step wise iterative manner until a desired termination condition is reached. The fitness function is defined on the basis of desired antenna attributes like bandwidth, gain, reflection coefficients, and return loss and antenna dimensions.

The UWB antenna with optimized parameters is designed and simulated using CST Microwave Studio (CST MWS). This tool is based on the finite integration technique (FIT), a very general approach, which describes Maxwell's equations on a grid space and can be written in time domain as well as in frequency domain and is not restricted to a certain grid type. It is possible to handle large radiating structures and even complete arrays with more than some hundreds of radiating elements in this software (Hirtenfelder, 2007).

This paper provides prime solution for optimizing UWB antennas which saves time and resources. Optimizing band rejection characteristics of an antenna using DE will help to achieve a global optimum solution efficiently for any desired radiation characteristics. In this work, a staircase UWB antenna with inverted U shaped slot for 5.8 GHz band suppression is proposed. The bandwidth, notch band, and return loss were selected as the core components of the fitness function for establishing dependencies and optimizing the selected parameters. In section II, the selected antenna design, its inter-dependent parameters and DE algorithm is discussed. A parametric analysis of this design and its optimization using DE is proposed in Section III. In Section IV, the simulated results obtained by DE and CST MWS are discussed. Finally in section V, paper is concluded.

System Model

The proposed antenna consists of a rectangular patch with staircase on the feeding edge. The patch has an inverted U shaped slot which creates the notch at the desired frequency. The ground plane of the antenna has a slot beneath the feeding line

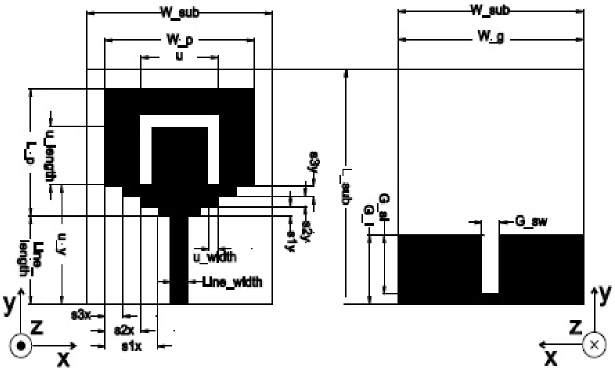

Fig. 1 Layout of proposed antenna

which helps in better impedance matching. The layout is shown in Fig 1. The design is symmetric along Y axis from center which helps in reducing the complexity of the optimization process.

Various antenna parameters from Fig 1 were analyzed to define the variable set for optimization. It was observed that the inverted U shaped slot affects the notch position and attenuation at the rejection band. Larger slot length brings the notch to lower frequencies and vice versa. The position of the slot with reference to the feeding line, referred to as u_y, directly affects attenuation and the quality factor of the notch. Apart from the parameters related to the slot, the impedance matching is very important to achieve the desired in-band rejection and out-of-band transmission. The parametric analysis including various tests concluded that overall 12 parameters required optimization to achieve the desired response. These parameters are listed in Table 1 with their initial values, optimization range and their optimized values.

The main stages of the proposed evolutionary algorithm are shown in Fig 2. Firstly, a randomly initiated population vector, known as genome/chromosome, forms a candidate solution to the optimization problem. Then, a mutant vector, known as donor vector, is obtained through the differential mutation. In Crossover, the donor vector exchanges its components with the target vector. During Selection, the population either gets better or remains the same in fitness status by determining whether the target vector survives to the next generation or not.

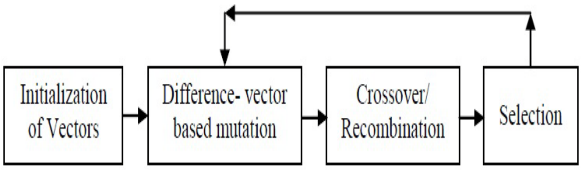

Fig. 2: Main Stages of DE Algorithm

Proposed Methodology

Differential Evolution was implemented in MATLAB. There are 12 genes in the solution string of the UWB antenna design problem with respect to each inter-dependent antenna parameter. In DE, each individual gene represents the design parameters range. Initially, the parent population consists of a single solution string containing initial values of each parameter. The mutation operator generates the mutant population from parent population.

The fitness value is calculated by summation of alpha (α), beta (β) and gamma (γ):

$Fitness = \alpha + \beta + \gamma$

where, α is bandwidth

β is notch band existence

γ is return loss

Bandwidth (α) is calculated by:

$$\alpha = \frac{\sum_{i=1}^{n} xi}{n} \times SF$$

where, n is number of points

SF is scaling factor

x_i is vector of reflection coefficients

Notch band existence (β) is given by:

$$\beta = \begin{cases} 3, & \text{if spike exists} \\ 0, & \text{otherwise} \end{cases}$$

Return loss (γ) is given by:

$$\gamma = \begin{cases} 1, & \text{if } S_{11} > -15\text{dB} \\ 2, & \text{if } -15 > S_{11} > -25\text{dB} \\ 3, & S_{11} < -25\text{dB} \end{cases}$$

The value of alpha is based on the reflection coefficients which are calculated at different frequencies (in the operating range). The value of beta is based on the spike of the S_{11} parameter (reflection coefficient) and gamma also depends on S_{11} parameter.

After a number of iterations and crossover, a solution string is obtained with minimum fitness and has optimized design variables of the antenna. These variables are used for designing and simulating antenna using CST Microwave Studio.

Simulation Results

The optimized inter-dependent variables are obtained using DE which is shown in Table 1 with their initial values, optimization range and optimized values. These variables are used for designing the antenna in CST MWS, shown in Fig 3 and Fig 4. Rogers's 4533 substrate with thickness of 1.524 mm, relative permittivity of 3.3 and loss tangent of 0.0023 was used for optimized design. The antenna covers the frequency band of 2.2 – 8.5 GHz and the notch band is achieved at 5.8 GHz, presented in Fig 5. The radiation pattern at 5.8 GHz frequency is shown in Fig 6.

S. No.	**Inter-dependent Variable**	**Initial Value (in mm)**	**Optimization Range (in mm)**	**Optimized Value (in mm)**
1.	s1x	6	5 – 7	5.11
2.	s1y	1	0 – 2	1.90
3.	s2x	4	3 – 5	4.05
4.	s2y	1	0 – 2	1.81
5.	s3x	2	1 – 3	2.25
6.	s3y	1	0 – 2	0.28
7.	u_y	13	12 – 14	13.16
8.	u_width	1	0 – 2	1.97
9.	U	6.5	5.5 – 7.5	7.48
10.	U_length	6	5 – 7	6.02
11.	ground_sw	2	1 – 3	1.93
12.	ground_sl	6	5 – 7	5.47

Table 1: Optimized Values Of Inter-Dependent Variables

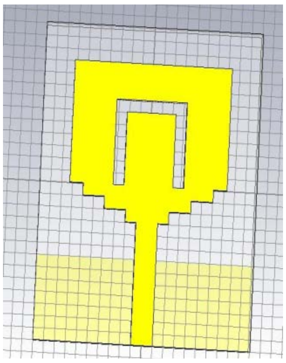

Fig 3: Front View

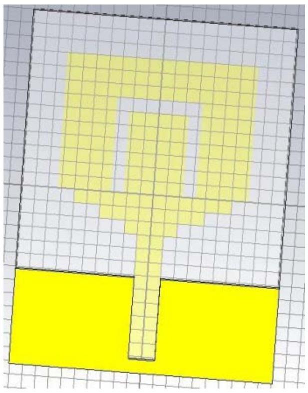

Fig. 4: Back View

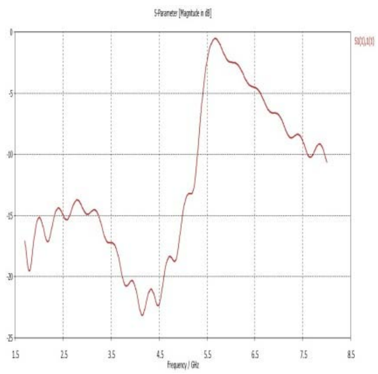

Fig 5: S_{11} Graph

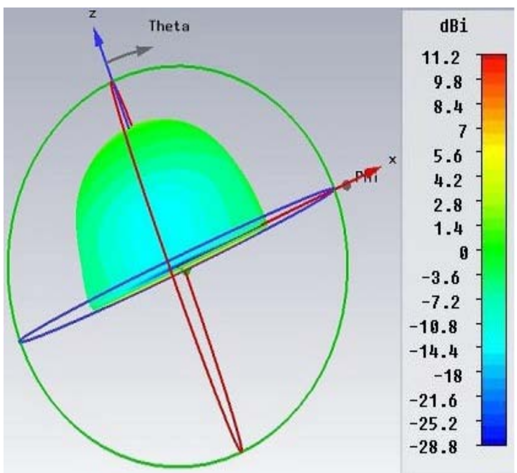

Fig. 6: Radiation Pattern

Conclusion

The optimization process of an UWB antenna has been proposed with notch band characteristics to reject the narrow band communications at 5.8 GHz. A rectangular patch, having inverted U shaped slot, with staircase on the feeding edge was used to achieve the desired specifications. DE has been applied on the initial design to optimize the radiation characteristics and antenna variables. The UWB antenna is designed and simulated in CST MWS using these variables. The antenna covers frequencies from 2.2 GHz to 8.5 GHz with rejection 5.8 GHz.

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