A NON-OVERLAPPED PRINTED MONOPOLE ANTENNA FOR UWB APPLICATIONS

ABDELHADI ASSIR
Electronics and Communications Laboratory, Mohammadia School of Engineers, Mohammed V University
EMI, Av. Ibn Sina, Agdal, BP 765 – Rabat/ Morocco
abdelhadi.assir@gmail.com

ABDELMAJID OUMNAD
Electronics and Telecom. Systems Group, Electrical Engineering Depart., Mohammadia School of Engineers
EMI, Av. Ibn Sina, Agdal, BP 765 – Rabat/ Morocco
aoumnad@menara.ma

Abstract:
In this paper, a novel small ultra-wideband (UWB) printed monopole antenna, designed to operate in 3.1-10.6 GHz frequency band, is presented. The antenna is composed of five non-overlapped rectangular patches, a partial ground plane and a standard 50-Ω microstrip feed line. The overall size of the proposed antenna is 22.8 mm × 29.5 mm × 0.813 mm. The design procedure that we have used is based on a mixed integer genetic algorithm (GA) and the finite-difference time-domain (FDTD) method with uniaxial perfectly matched layer (UPML) absorbing boundary condition. The optimized printed monopole antenna is analyzed using our own FDTD code and the high frequency structure simulator (HFSS).

Keywords: UWB printed monopole antenna; Genetic Algorithms; Finite-Difference Time-Domain method.

1. Introduction
Since its adoption by the United States Federal Communications Commission (FCC) in 2002, there has been a considerable research both in academia and industry in the development of ultra-wideband (UWB) technology [FCC (2002)]. The basic idea for UWB technology is to directly transmit and receive trains of extremely short baseband pulses that spread over bandwidth of several GHz. UWB technology promotes extensive employment in various modern wireless systems, such as: through wall imaging, medical imaging, vehicular radar, indoor, and hand-held UWB systems, and so on [Allen et al. (2007)] [Chong et al. (2006)] [Oppermann et al. (2004) [Porcino and Hirt (2003)]. This is due to its potential advantages, such as high data rate, high resolution positioning, excellent immunity to multipath interference, high transmission security, low power consumption and reduced hardware complexity. According to FCC Report and Order, UWB system is required to have either more than 20% fractional 10-dB bandwidth or more than 500 MHz absolute 10-dB bandwidth. For indoor and hand held devices, that encompass a wide variety of applications including high-speed home and business networking devices, the FCC required that the UWB bandwidth must be contained between 3.1 and 10.6 GHz.

The antenna is a critical component in UWB systems, and affects their overall performance. The design of UWB antenna is a challenging task since the compromise between low-profile feature, low manufacturing cost, good matching characteristics over the whole UWB frequency range and an appropriate radiation pattern has to be achieved. Recently, an UWB microstrip-fed printed monopole antenna has been extensively developed for UWB applications [Ammann and John (2007)] [Azer et al. (2010)] [Choi et al. (2004)] [Islam et al. (2010)] [Low et al. (2005)] [Rambabu et al. (2006)] [Zainud-Deen et al. (2010)]. This kind of UWB antenna is a suitable candidate for integrated with portable devices and can realize smaller dimensions. To enhance the impedance bandwidth of small microstrip-fed printed monopole antenna, several techniques have been proposed, including the use of a partial ground plane, an asymmetrical feed arrangement, adjusting the gap between radiator and ground plane, beveling radiating element and/or ground plane, cutting slot on the ground plane beneath the microstrip line, cutting two notches in the radiator or using steps to control the impedance matching. For example, the UWB printed monopole antenna proposed in [Zainud-Deen et al. (2010)] used three
overlapped rectangular patches, slitted partial ground plane and three overlapped slots on the radiator. It is worth mentioning that these techniques allow not only to broaden the impedance bandwidth of the microstrip antenna, but also to reduce their size [Chen et al. (2007)] [Ramadan et al. (2009)]. In [Chen et al. (2007)], UWB performance and size minimization are achieved by cutting a rectangular notch vertically from the rectangular patch, asymmetrically attaching a strip to radiator fed by an asymmetrically arranged microstrip line with a partial ground plane, beveling the two bottom edges of the radiating element and adjusting the gap between radiator and ground plane. An overall size of this antenna is 25 mm × 25 mm × 1.5 mm. The small (20 mm × 40 mm × 1.6 mm) printed monopole antenna proposed in [Ramadan et al. (2009)] is based on a tapered connection between a semi-elliptical patch and a trapezoidal feed line with a partial ground plane.

In this paper, a novel UWB microstrip line-fed patch antenna with a partial ground plane is proposed. The patch is composed of five non-overlapped rectangular patches, which are vertically and symmetrically arranged. Each one is defined by three parameters: its length and width and its distance from the ground plane. This topology is adopted to satisfy UWB performance, low profile feature and easy fabrication. As far as the design process, an efficient global optimization technique, based on a mixed integer genetic algorithm (GA) [Haupt (2007)] and the finite-difference time-domain (FDTD) method [Taflove and Hagness (2000)] with an uniaxial perfectly matched layer (UPML) absorbing boundary condition [Gedney (1996)] is employed.

2. Design Procedure

To achieve UWB operation, a microstrip line-fed patch antenna with a partial ground plane is employed. As shown in Fig. 1, the patch is composed of five non-overlapped rectangular patches. Each one is defined by three parameters which are: Length (L_i, i = 1 to 5), width (W_i) and the gap (H_i) defined by its position from the ground plane. The proposed antenna is printed on a RO4003 substrate of thickness of h = 0.813 mm (32 mil) and relative permittivity of ε_r = 3.38. The width of the microstrip line is W_f = 1.9 mm that is required to ensure 50-Ω characteristic impedance [Garg et al. (2001)]. The dimensions of the ground plane are L_g = 14 mm and W_g = 12W_f.

![Fig. 1. Basic configuration of the proposed UWB printed monopole antenna.](image-url)

The fifteen geometric parameters of the basic antenna topology under investigation give a large freedom-degree conception that assures a satisfactory UWB performance as well as size reduction. The main idea of this configuration design is to elaborate a parameterized geometry that is inspired from some already known geometries, for example, those presented in [Choi et al. (2004)] [Rambabu et al. (2006)]. In [Choi et al. (2004)], the proposed antenna consists of a rectangular patch with two steps, a single slot on the patch, and a partial ground plane. The antenna in [Rambabu et al. (2006)] features a stepped patch with resonators arranged both vertically and horizontally, and partial ground plane. The imposed symmetry and the desired small size of the antenna form two important constraints which are taken in consideration to obtain an omnidirectional radiation...
pattern. On the other hand, as a consequence of its symmetrical arrangement, the five rectangular patches are completely defined by only nine geometrical parameters.

Broadly speaking, this antenna topology is adopted to satisfy UWB performance, low profile feature and easy fabrication. The challenge is thus to determine the nine geometric parameters. Such problem can be carried out either by parametric study or by an optimization technique. The former is more used though it is not systematic. The latter forms a strong approach that allows finding an optimum design satisfying the required performances. Here, an efficient optimization technique is employed to optimize the proposed configuration. The design process is based on genetic algorithm (GA) as the global optimizer, and the finite-difference time-domain (FDTD) as the full-wave analysis method. Our goal is to determine a set of the nine parameters optimizing the shape of printed monopole antenna which gives the UWB characteristic (3.1-10.6 GHz). For the size reduction, we have fixed a maximum patch space.

Genetic algorithm (GA) is a global optimization technique based on the principles and concepts of natural selection and evolution. In GA, the population is the set of possible (trial) solutions, and each individual from the population is characterized by chromosome-like structures. The possibilities of survival for each individual are evaluated by the cost function, that is, function to optimize. The result of this evaluation, called fitness, plays an important role in selection and reproduction. Finally, evolution is achieved through the application of genetic operators which are: selection, crossover and mutation. It is worth noting that the GA operates on a coded version of the parameters rather than the parameters themselves. There are multiple versions of GAs according to the coding and/or genetic operators. In this work, the antenna design is carried out with an efficient mixed integer GA that is proposed in [Haupt (2007)]. This GA is versatile and more robust since it can work with real and/or binary values in the same chromosome. The fitness we’ve adopted is defined as:

\[
\text{Fitness} = \text{Max}\{S_{11}|3.1\text{GHz} \leq f \leq 10.6\text{GHz}\}.
\]  

(1)

\(S_{11}\) is the return loss at the frequency \(f\). Its expression is given by Eq. (2).

\[
S_{11} = 20 \log\left(\frac{Z_{\text{in}} - Z_c}{Z_{\text{in}} + Z_c}\right).
\]  

(2)

\(Z_c\) and \(Z_{\text{in}}\) represent the characteristic impedance of microstrip line, and the input impedance of the monopole antenna, respectively.

The fitness function involves the application of full-wave electromagnetic method, such as method of moments (MoM), finite elements method (FEM), and FDTD method. Among these methods, we have selected FDTD method because it enables, unlike the others, a broadband analysis with only one simulation. The FDTD method is based on the discretization in both time and space of time-domain Maxwell’s curl equations [Taflove and Hagness (2000)]. To minimize the reflected wave from the outer boundary, the uniaxial perfectly matched layer (UPML) absorbing boundary condition is used [Gedney (1996)]. In the FDTD analysis, step sizes for the \(x\)- and \(z\)-direction (\(\Delta x\) and \(\Delta z\)) are chosen such that the width (\(W_f\)) of a microstrip feed line and the substrate thickness are equal to \(6\Delta x\) and \(3\Delta z\), respectively. The step size in the \(y\)-direction (\(\Delta y\)) equals 0.5 mm. To ensure the algorithm stability, a time incremental (\(\Delta t\)) of 0.4515 ps is used. A resistive voltage source (RVS) with a 50-\(\Omega\) internal resistance of unit amplitude Gaussian pulse is employed for excitation. 10 UPMLs placed at 5 spatial steps from the structure are used. The analysis time of each individual is limited to 3000\(\Delta t\).

As far as the GA, the research space adopted summarized in Table 1. On other hand, the implemented GA has a population size of 10 with a mutation rate of 5%.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(W_f/2)</th>
<th>(L_1)</th>
<th>(H_1)</th>
<th>(W_2)</th>
<th>(L_2)</th>
<th>(H_2)</th>
<th>(W_3)</th>
<th>(L_3)</th>
<th>(H_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. value</td>
<td>(3\Delta x)</td>
<td>(2\Delta y)</td>
<td>0</td>
<td>(6\Delta x)</td>
<td>(2\Delta y)</td>
<td>0</td>
<td>(6\Delta x)</td>
<td>(2\Delta y)</td>
<td>0</td>
</tr>
<tr>
<td>Max. value</td>
<td>(12\Delta x)</td>
<td>(35\Delta y)</td>
<td>(5\Delta y)</td>
<td>(12\Delta x)</td>
<td>(30\Delta y)</td>
<td>(10\Delta y)</td>
<td>12(\Delta x)</td>
<td>25(\Delta y)</td>
<td>15(\Delta y)</td>
</tr>
</tbody>
</table>
3. Results and Discussions

In the GA, a better design is defined to have a lower fitness value. Fig. 2 illustrates the convergence results of the optimization, where the solid line curve shows the fitness of the best individual for each generation, and the dash line gives the average fitness of all individuals. The minimum value obtained after 40 iterations is -10.56 dB. It represents the greatest value of the return loss over the 3.1-10.6 GHz band frequency.

The optimized dimensions of the rectangular patches are as follow:

Table 2. Optimized dimensions of the patches.

<table>
<thead>
<tr>
<th>W_1</th>
<th>L_1</th>
<th>H_1</th>
<th>W_2</th>
<th>L_2</th>
<th>H_2</th>
<th>W_3</th>
<th>L_3</th>
<th>H_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>22Δx</td>
<td>28Δy</td>
<td>3Δy</td>
<td>6Δx</td>
<td>25Δy</td>
<td>2Δy</td>
<td>11Δx</td>
<td>18Δy</td>
<td>12Δy</td>
</tr>
</tbody>
</table>

The geometry of the obtained antenna is presented in Fig. 3. The overall size of this UWB non-overlapped printed monopole antenna is 22.8 mm × 29.5 mm × 0.813 mm. This size is smaller than all antennas cited above.

The return loss is computed in 2-12 GHz band frequency using our own FDTD with UPML absorbing boundary condition, and the results are shown in Fig. 4. It is seen that the 10-dB return loss bandwidth is 7.65 GHz.
GHz (3.05-10.7 GHz). Furthermore, to verify the results of FDTD, the antenna is simulated using Ansoft HFSS. Good agreement is observed which validates the GA/FDTD design procedure.

![Fig. 4. The simulated return loss of the optimized UWB antenna.](image)

The simulated radiation patterns in the E-plane and H-plane for 4, 6, 8 and 10 GHz are depicted in Fig. 5. The results show that the radiation pattern is quite stable as the frequency changes with an almost omnidirectional radiation patterns in the H-plane.

![Fig. 5. Radiation patterns: ─── H-plane, and ─── E-plane.](image)
The antenna peak gain is illustrated in Fig. 6. It is observed that the gain levels of the antenna are 2.38-4.43 dBi. The gain is then flat enough in the frequency band.

4. Conclusion

A new UWB printed monopole antenna structure is achieved through the study presented in this paper. Five non-overlapped rectangular patches presenting nine degrees of liberty are optimized to get to 3.1-10.6 GHz frequency band. The design process is done by use of a computationally efficient GA/FDTD code. The optimized antenna is analyzed using both FDTD and HFSS. The obtained bandwidth is 7.65 GHz ranging from 3.05 GHz to 10.7 GHz. Moreover, the antenna provides a good radiation pattern and a quasi-flat gain over the entire frequency band. Thanks to UWB performance and low-profile of this designed printed monopole antenna, it can be exploited in several UWB systems, especially in hand-held devices.

Acknowledgments

A. Assir likes to thank Dr. Mohamed Chaibi, Santander/Spain, as well as Mr. H. Houasli, Settat/Morocco for their support.

References

Authors Biography


A. Oumnad was born in Morocco in 1957. He received Engineer degree in Electronics from ENSEEIHT Toulouse in 1984, and Doctorat d'état from Ecole Mohammadia d'ingénieurs (EMI), Rabat in 1999. He is working as professor in Electrical Engineering department at EMI, Rabat. His area of research includes Speech coding, Spread Spectrum and Wireless systems.