An Improved Design of Planar Elliptical Dipole Antenna for UWB Applications

Hakki Nazlı, Emrullah Buçak, Bahattin Türetken, and Mehmet Sezgin

Abstract—In this letter, an enhanced planar elliptical dipole antenna design for ultrawideband (UWB) communication and impulse radar systems is presented. The printed-circuit-elliptical (PCE) antenna has been investigated to be an effective radiator for UWB applications. To enhance gain and return loss bandwidth of the antenna, elliptical slots are used on the dipole arms. The gain performance of the antenna has been increased by means of elliptical slots in the frequency range from 2.7 to 11 GHz. The standing wave ratio is less than 2 (SWR < 2) along 94.4% of operation bandwidth from 1.1 to 11 GHz. The radiation pattern in E- and H-plane for certain frequencies, the return loss, and the gain performance are presented with the experimental and simulation results. Moreover, the time domain analysis of the antenna is presented. The antenna introduces low-level ringing and pulse distortion. Consequently, the antenna is very useful for impulse and UWB communication systems.

Index Terms—Elliptical planar antennas, ultrawideband (UWB) antennas, ultrawideband radiation.

I. INTRODUCTION

In the last decade, several ultrawideband (UWB) antenna types have been developed as a result of major advances in communication and narrow pulse applications [1]. By means of UWB antennas, high data rate transmission can be transmitted in short-range local networks and short-duration pulses. The UWB antennas are used in the applications of UWB communication, ground-penetrating radar, through-wall radar, medical imaging, and precision location systems [2]–[6]. There are many kinds of UWB antenna types such as bow-tie, TEM horn, spiral, Vivaldi, and dielectric loaded road antennas [7]–[10]. To design a single, small electrical dimension and broadband antenna is a coveted feature in the point-to-point high-speed data communication systems, particularly. A number of planar UWB antennas have been developed to provide broadband characteristic. Elliptical-shaped monopole and dipole planar antennas are the most known models for the UWB applications in terms of suitable design, low cost, low profile, high-efficiency radiation, and good impedance stability [11]–[14].

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Shen carried out a theoretical analysis of an elliptical microstrip antenna [15]. Schantz studied the various types of planar elliptical dipole antennas from 0.5 to 6 GHz [3], [12]. Murata et al. have shown that the rectangular and triangular slots on the semicircular bow-tie antenna affected antenna performance and optimized them to design maximized bandwidth characteristic using finite-difference time domain (FDTD) method [16]. In [17], the planar elliptical dipole antenna was designed in the range of 750 MHz–6 GHz for wireless communication. Another type of planar elliptical dipole antenna was proposed in differential and single-ended elliptical slot-shaped, as indicated in [18]. In [19], the planar differential elliptical antenna was optimized based on the time domain characteristic of the antenna using genetic algorithm.

In this letter, we present an elliptical slotted planar elliptical dipole antenna (ESPEDA). The proposed antenna operates from 1.1 to 11 GHz using the elliptical slots. In the frequency range, the elliptical slots produce good performance at high frequencies, the antenna gain is increased from 2.7 to 11 GHz, and return loss of 94.4% is less than −10 dB (|S21| ≤ −10 dB) from 1.1 to 11 GHz. Thus, there is no need to use of a feeding network to stabilize return loss. Both gain and return loss performance of the antenna are substantially affected by relative electrical permittivity (εr) of substrate. The location and dimension of slots and the ratio of major to minor axes of the metallic part of the elliptical dipole are specified using CST Microwave studio. The radiation pattern in certain frequencies, the return loss, and the gain performance of the antenna are measured, and they are consistent with simulation results. The time domain characteristic of the antenna is analyzed by using inverse fast Fourier transform (IFFT).

The organization of this letter is as follows. In Section II, the antenna design procedure is described, and the effects of design parameters on the antenna are given. In Section III, the experimental results are presented to verify the antenna performance, and they are compared to the simulation results. The letter is finalized in Section IV with the conclusion.

II. DESCRIPTION OF THE ANTENNA AND EFFECTS OF DESIGN PARAMETERS

The three dimensions (3D) and the fabrication photograph of the proposed antenna are shown in Fig. 1. The proposed antenna lies in the xy plane, and the z-axis is parallel to its normal direction. Each half of the dipole cutting on yz plane reflects the other one as a mirror image. As depicted in Fig. 1(b), the antenna is printed on a RT/duroid 5880 substrate. In Fig. 1(a), its metallic layer is indicated with a dark gray color; the thickness of substrate and the elliptical slots in the antenna are shown in light gray and white colors, respectively. Fig. 2 shows a front view of the antenna and consists of configuration parameters.
The width \( w \) of substrate indicated in \( y \)-direction is 85.0 mm, and its length \( l \) is fixed at 106.0 mm along the \( x \)-direction. However, the performance of gain and return loss is affected by the width \( w \), length \( l \), and thickness of \( t \), which is shown in Fig. 1(a). During the entire operation bandwidth, the parameters of the inner and the outer ellipses are obtained by using CST Microwave Studio. The diameters of the outer ellipses are \( d_{\text{out}} = 38.0 \) mm and \( d_{\text{out}} = 79.0 \) mm. Here, the subscript of \( x \), \( y \) denotes diameter axes. The ratio of minor to major axis of the metallic part affects the antenna performance. If the ratio decreases, the \( [S_{11}] \) performance of the antenna deteriorates. The diameters \( d_{\text{rin}} \) of the slot ellipses are chosen as 19.5 and 37.5 mm, respectively. The ratio of \( d_{\text{rin}} \) to \( d_{\text{jin}} \) is a very critical value to acquire UWB characteristic and higher gain performance. As the current value of \( d_{\text{rin}} \) increases, the lower bandwidth of the return loss declines, and \( d_{\text{rin}} \) affects generally the gain performance of the antenna.

The distance between the leftmost points of inner ellipse and the outer ellipse for the right arm of the dipole shown in Fig. 2 is defined by \( \Delta x \). It is determined as \( \Delta x = 3.5 \) mm in the end of the simulations. The distance is a very important value to achieve the high-gain performance over the operation band. In addition, if it is so close to the feeding points of the antenna, the return loss performance will get worse. The parameter \( g \), a feeding gap between the dipole arms, is chosen as \( g = 1.5 \) mm. It depends on the fabrication parameter because it is determined with distance between the connector pins. The antenna is fed by 50 \( \Omega \) a single-ended voltage source using an SMA connector. Finally, the overall physical dimensions of the proposed antenna are given in Table I.

### III. EXPERIMENTAL RESULTS

The verification of simulated results for the antenna is pointed out with the experimental results. During the antenna measure-

ments, the HP 8719D network analyzer of Agilent is used to measure the return loss \( (S_{11}) \), the antenna gain in a single direction, SWR, and the radiation pattern of both the E-plane and H-plane at 1.1, 3.1, 6.1, and 10.1 GHz. The time domain characteristic of the antenna is found by taking the IFFT of the experimental data. All measurements are performed in a compact fully anechoic chamber. The network analyzer measurements are made in the frequency bandwidth of 700 MHz to 11 GHz, which contains 1601 discrete data points. Before the measurement, the experimental setup is calibrated (full port calibration) from the cable terminal in the frequency range. All simulated results are produced by CST Microwave Studio. The simulation scenario is also run from 700 MHz to 11 GHz. The convolution perfectly matched layer (PML) is applied in all directions to minimize reflections. The space distance surrounding the antenna geometry is determined by definition of the far-field region in [20].

The experimental and simulation results of SWR and the return loss \( (S_{11}) \) of the antenna for the aforementioned measurement and simulation scenarios are shown in Fig. 3. In some frequency ranges, incompatibility can be seen between the simulated and the measured data, but generally the simulated data agrees with the measured data. As a result, the antenna is well matched across the frequency range, and a balun is not needed to reduce the return loss. Between 3.12 and 3.68 GHz, the SWR is greater than 2, but does not exceed the 2.50 line. Also, for the impulse system, the SWR level of the antenna is a critical parameter to avoid ringing effect. In order to avoid undesired ringing in the impulse system, the antenna input and the RF generator impedance should be matched over the wide frequency band. Therefore, the antenna is very useful for impulse systems due to its low-level SWR over the wide frequency band. The measured and simulated gain results of the considered antenna are shown in Fig. 4, where it is also compared to the antenna model without slots. The gain measurement is done using the IEEE procedure in [21].

The gain performance of the antenna is measured in the \( +z \)-direction \( (\theta = 0, \phi = 0) \). The measured and simulated antenna gains both with and without slots agree with each other. Thanks to slots, the gain performance increases from 2.7 to 11 GHz. Moreover, as shown in Fig. 4, for \( \pm 5 \) dB gain scale, \(-10 \) dB gain band of the antenna is up to 8 GHz due to the elliptical slots of the antenna. The location and the dimension of

### TABLE I

#### Geometric Parameters for the Antenna

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Optimized Values (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l )</td>
<td>106.0</td>
</tr>
<tr>
<td>( w )</td>
<td>85.0</td>
</tr>
<tr>
<td>( d_{\text{out}} )</td>
<td>38.0</td>
</tr>
<tr>
<td>( d_{\text{out}} )</td>
<td>79.0</td>
</tr>
<tr>
<td>( d_{\text{rin}} )</td>
<td>19.5</td>
</tr>
<tr>
<td>( d_{\text{rin}} )</td>
<td>37.5</td>
</tr>
<tr>
<td>( \Delta x )</td>
<td>3.5</td>
</tr>
<tr>
<td>( g )</td>
<td>1.5</td>
</tr>
<tr>
<td>( t )</td>
<td>0.8</td>
</tr>
</tbody>
</table>
the elliptical slots in the antenna are very important parameters to achieve high gain performance in +z-direction.

The normalized radiation patterns of the antenna are measured and simulated in E-plane and H-plane with the 5° increment at 1.1, 3.1, 6.1, and 10.1 GHz. In given frequencies, the radiation patterns of the antenna are illustrated in Figs. 5 and 6 for the E-plane and the H-plane, respectively. When the radiation patterns of the measured and the simulated results are compared, they agree in both the E-plane and the H-plane at given frequencies. The differences between the simulated and the measured patterns are mainly considered as fabrication tolerances, measurement, and mesh size modeling of the antenna. The time domain analysis of the antenna is performed by using the IFFT of frequency data of the transmitted and received signal.

The basic diagram of the network analyzer used in antenna measurement is illustrated in Fig. 7. Here, \( R_s \) represents the reflected signal in port 1, \( R_g \) is the reference signal or the source signal, and \( B_g \) is the received signal from port 1 to port 2 for \( S_{21} \) measurement. The return loss of the antenna known as \( S_{11} \) (reflection) and the transfer function measurement \( S_{21} \) (transmission) is calculated as \( A_{rx}/R_g \) and \( B_{rx}/R_g \), respectively, depicted as in Fig. 7. Thus, the transmitted signal \( S_t(f) \) from the antenna in port 1 is obtained as follows:

\[
S_t(f) = (1 - S_{11}(f))S_{ref}(f)
\]

where \( S_{ref}(f) \) is the reference or source signal and is equal to \( R_g \). The network analyzer measures the reference and the reflected signals. The time response of the transmitted and the reflected signals from port 1 can be found by taking the IFFT of \( S_t(f) \) and \( A_{rx} \), respectively. The time response of transmitted and reflected signals from the antenna is shown in Fig. 8(a). The reflected signal’s amplitude is nearly 10 times smaller than the transmitted signal. This means that the antenna produces considerably low-level ringing, and it can transmit the narrow pulses for the impulse system.

As shown in Fig. 7, the received signal spectrum in port 2 \( (B_g) \) can be found by multiplying the \( S_{21} \) measurement with the reference signal \( S_{ref} \). For the time domain analysis of the received signal, the transfer function \( S_{21} \) measurement is performed in an anechoic chamber with two identical antennas.
The distance of the antennas is 60 cm. Therefore, the time response of the received signal can be obtained by taking the IFFT of the $B_\tau$ signal. As a result, the received impulse signal from measured data is presented and compared to simulated results in Fig. 8(b). The difference between measured and simulated data in Fig. 8(b) is due to $S_{21}$. As understood from Fig. 4, the simulated $S_{21}$ is higher than measured $S_{21}$, thus the amplitude of the IFFT of $B_\tau$ is directly proportional to $S_{21}$. Finally, the received signal has narrow pulses and has weak dispersion in the time domain. In this case, the transfer function's IFFT has low distortion, and the received signal produces less dispersion.

IV. CONCLUSION

In this letter, an enhanced configuration of the planar elliptical dipole antenna has been designed and released for the UWB communication and the narrow pulsed systems. The antenna operates from 1.1 to 11 GHz. Using the elliptical slots, the gain performance of the antenna is increased on the entire operation bandwidth, and its $-10$ dB band is extended up to 8 GHz. The radiation pattern in the H- and the E-plane, SWR, the return loss, the gain, and the time domain characteristic of the antenna has been investigated by means of both the measurement and the simulation results. The antenna parameters are indicated using the simulation tool of CST. When analyzing the time domain characteristic of the proposed antenna, narrow pulses can be transmitted, and it produces low-level ringing effect for the impulse radar system. Finally, the antenna is suitable to use for UWB applications.

REFERENCES