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The Impact of Substrate Materials to the Design of UWB Modern Antennas

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Abstract

The theory of microstrip antennas has motivated us to design a highly improved gain antenna under this category. It is a microstrip monopole antenna characterized by omni-directional radiation as well as a high radiation gain. A review of different methodologies to designing antennas with broad/ultra-wide band performance for various applications is enriched by our original antenna design. This is an original model analyzed over different substrate materials and finally optimized for the bandwidth of (3.3 - 5.8) GHz just below −10 dB of return loss (RL). The antenna is judged for high gain when the ground plane size is reduced to nearly half that of substrate. The impact of the substrate materials is discussed in this article. The master design tool is Ansoft High Frequency Simulator Structure (HFSS), one of Finite Element Method (FEM) based software tools. The antenna would be printed on a 1.524 mm thick Rogers (RO3003C) substrate; overall size of 33.4 × 33.4 squared millimeters. At the optimal resonance frequency of 3.8 GHz, simulation results perfectly agree with the standards of UWB antennas, with a high radiation gain and impedance matching status.

Keywords

UWB Antennas, Enhanced Gain, FEM, Ansoft HFSS

1. Introduction

Printed circuit board (PCB) microstrip antennas belong to the family of Modern antennas; a category that undoubtedly remains very useful in multiple engineering areas such as aircraft, missiles, rockets, spacecraft [1]-[3]; not forgetting commercial areas like mobile satellite communications, global positioning system, Radio Frequency Identification (RFID), Worldwide Interoperability for Microwave Access (WIMAX), Radar Applications, Telemedicine Applications, military systems [4]-[12], etc.

A transmitted signal is UWB if the RL absolute bandwidth exceeds 500 MHz [13] or the fractional bandwidth is more than 20% at −10 dB; noting that UWB utilization was authorized by the Federal Communications

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Commission (FCC) to (3.1 - 10.6) GHz in 2002 [14]. According to [15] [16], printed monopole antennas have many possibilities for UWB performance; thus, the present research focus is put on UWB antennas in theory and practice.

2. UWB Antennas' State of the Art

Some UWB signals were emitted by Hertz in 1887 [17], but the year 2002 awakened both academic and industrial research attention that is continually paid on UWB antennas [18]-[20]. Designers of monopole antennas look forward to reducing ground planes. According to the surveyed UWB antenna designs together with the history of UWB antennas, the reality is that UWB antennas existed for a couple of centuries ago [21] [22].

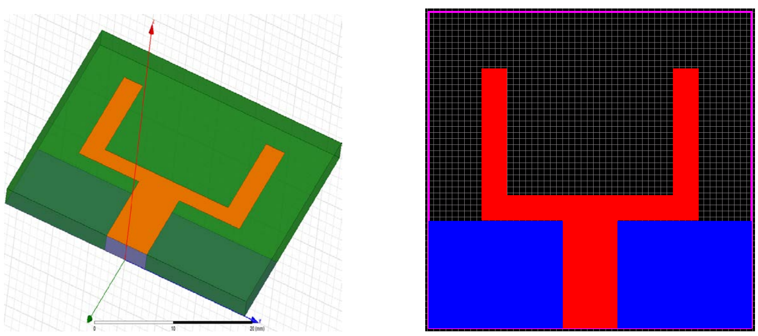
Learning from different authors, our aim now is to furthermore improve on bandwidth and radiation gain performance for PCB's UWB antennas.

3. The Antenna Geometry, Design Methodology and Discussed Results

3.1. Design Structure and Methodology

A three dimensional solver high frequency simulator structure (HFSS) based on FEM [23] is the software tool selected for the present research. The 3D design model is presented in **Figure 1(a)**. The main parts of the model: antenna as a top layer, ground as a bottom layer and the substrate as a keep-out layer were exported from Ansoft HFSS Modeler and manipulated with the conjunction of Auto CAD (Computer Aided Design) and Altium Designer's Printed Circuit Board environment [24] to produce **Figure 1(b)**, which is useful to manufacture the antenna.

For antenna synthesis, the RL is analyzed by time to time to decide on the necessary bandwidth performance. Analyzed over different substrates, the antenna RL results are two dimensionally exported to Microsoft Excel, as. csv format, later compiled together for comparison purpose. Origin Pro 8 for data analysis and graphing is the software tool utilized to prepare the data for **Figure 2**.



(a) (b)

Figure 1. Design Model's (a) three dimensional view; (b) top view.

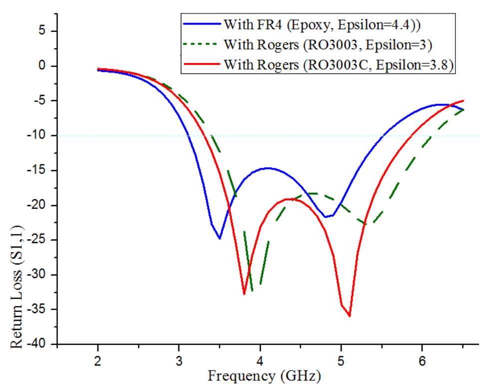


Figure 2. RL with different substrates.

On RO3003C substrate material, the antenna does not only present optimal fractional bandwidth and radiation gain as detailed in **Table 1**, but also, the impedance matching with the input feed line is the most competitive for the pre-set frequency of 3.8 GHz. Therefore, all the results presented from **Figures 3-8** relate to the antenna simulation on Rogers (ROO3C) substrate. Thus, for this specific research, the selection decision fell on Rogers RO3003C whose dielectric constant is 3.8.

3.2. The Simulation Results

3.2.1. The RL and Voltage Standing Wave Ratio

According to [25], the RL is the measure of how much of the available power is not delivered to the load. The

Table 1. Antenna bandwidths and gains with different substrates.

Substrate	Relative permittivity (ε_r)	Fractional bandwidth at 3.8 GHz	Radiation Maximum Gain, [dB]
Rogers (RO3003)	3	63.2%	4.31
Rogers (RO3003C)	3.8	67%	4.23
FR4 (Epoxy)	4.4	63.17%	3.83

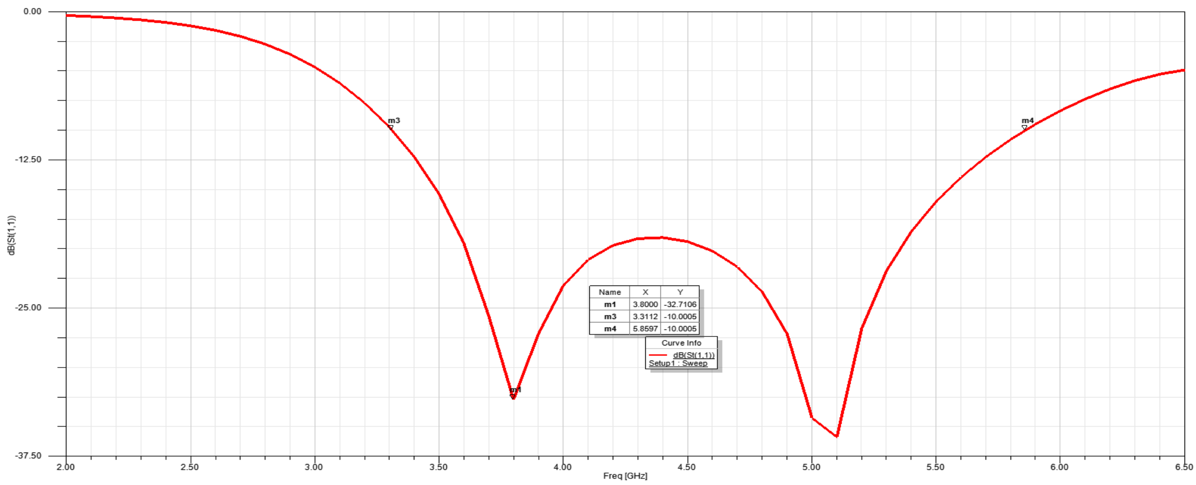


Figure 3. Optimal RL with rogers (RO3003C) substrate.

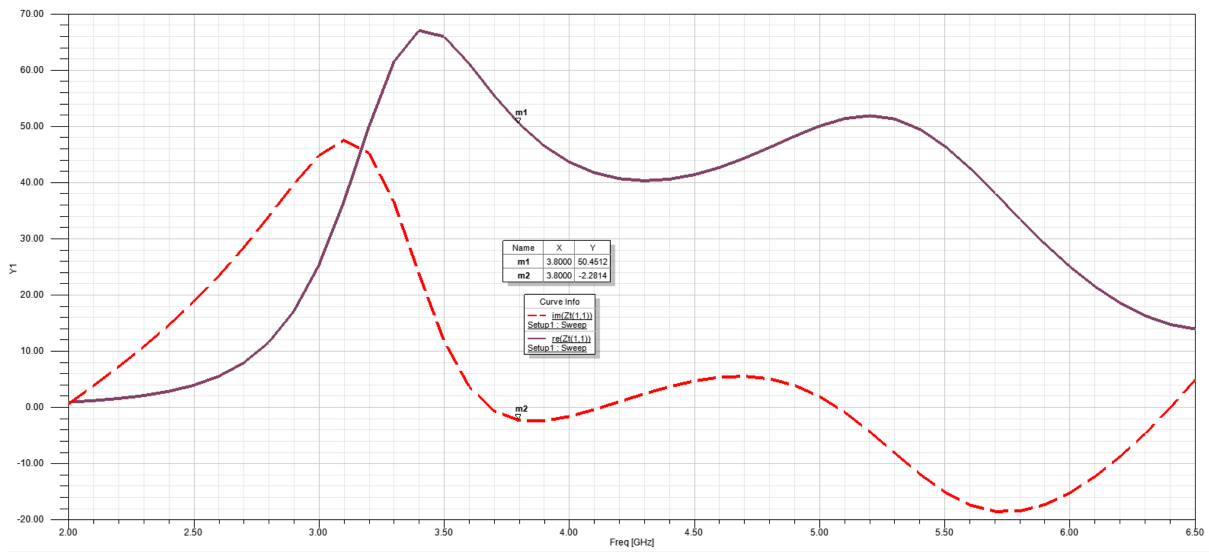


Figure 4. Impedance parameters.

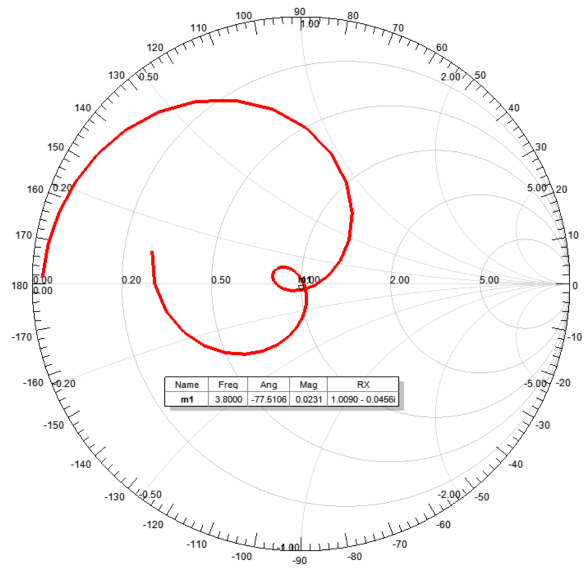
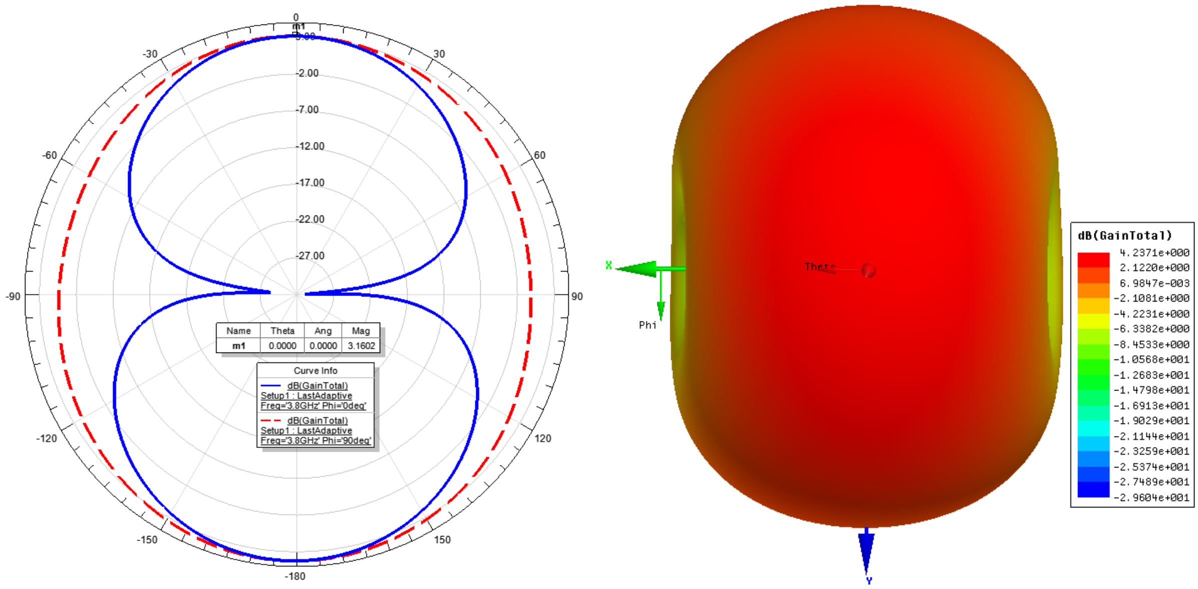


Figure 5. Smith chart.



(a) (b)

Figure 6. Radiation power pattern (a) in two dimensional view; (b) in three dimensional view.

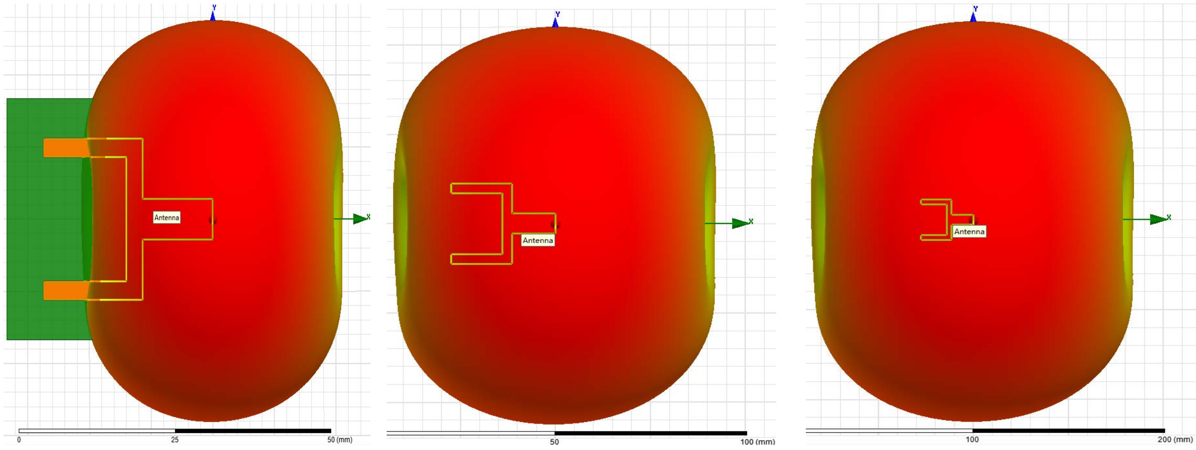
reflection coefficient of a totally matched load is zero and its RL is infinity. The comparative RL when the unchanged antenna structure is analyzed over different substrate materials is shown in **Figure 2**. The optimal RL while the antenna printed over the selected substrate material is shown in **Figure 3**.

The impedance parameters are measured according to **Figure 4**; as per the Smith Chart's measurement in **Figure 5**, the antenna impedance is perfectly matching with the 50 Ω microstrip feed line.

As for the antenna total efficiency (e_T), according to [26], knowing the voltage reflection coefficient at input terminals, Γ, such that

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{1}$$

Z_{in}, the input impedance;



(a) (b) (c)

Figure 7. Radiation fields' overlay (a) 25%; (b) 50% overlay; (c) 100%.

Z_0, the transmission feed line's characteristic impedance, equals to 50 Ω in normal conditions.

Mathematically, the antenna radiation efficiency is approximately unity since the antenna is simulated under perfect electric conduction (PEC) boundary. So, the computed total antenna efficiency is approximated to the mismatch efficiency; calculations were made possible by the measured impedance parameters in **Figure 4**. Both the total efficiency and VSWR are now calculated for a resonance frequency of 3.8 GHz.

$$\Gamma_{(3.8\text{GHz})} = \frac{50.4512 - j2.2814 - 50}{50.4512 - j2.2814 + 50} = 0.00449 - j0.226 = 0.023\angle -78.76^{\circ}$$

$$e_{T(3.8\text{GHz})} = 1 - |\Gamma|^2 = 99.94\%$$

$$\text{VSWR}_{(3.8\text{GHz})} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+0.023}{1-0.023} = 1.023$$

3.2.2. Radiation Results

Figure 6 shows both two and three dimensional radiation patterns while **Figure 7** and **Figure 8** respectively show the radiation fields overlay and the surface currents distribution.

3.3. Discussions

With the resonance frequency of either 3.8 GHz or 5.1 GHz, observable from the RL in **Figure 3**, carefully viewing UWB antenna standards [14]-[16], the microstrip monopole antenna presented in this research paper is undoubtedly a high gain Antenna for UWB receivers and transceivers. It is expected to be an excellent candidate array element for base stations' UWB array antenna; thus, highly boosting the obtained maximum radiation gain of 4.23 dB furthermore, in comparison with [20].

Application side, this UWB antenna is expected to find applications with Airport search radar, microwave relays, satellite down communications, Studio-To-Transmitter Link (STL) Microwave relays as well as satellite up communications, as illustrated in **Figure 9**, a summary made according to [27].

Excellent results were obtained by analyzing the antenna on Rogers 3003C, more competitive than on either Rogers 3003 or FR-4 (Epoxy); it has been made clear in **Table 1**. Optimally, the simulation reached to (3.3 - 5.8) GHz, absolute bandwidth, highly exceeding 500 MHz [13]. The calculated fractional bandwidth is 67%, certainly greater than 20% [14]. Radiation results indicate the omni-directional radiation; these are very appreciable parameters for UWB Antennas in general.

4. Conclusions

The pre-set goals to review and present the state of the art in UWB antenna has been successfully strengthened

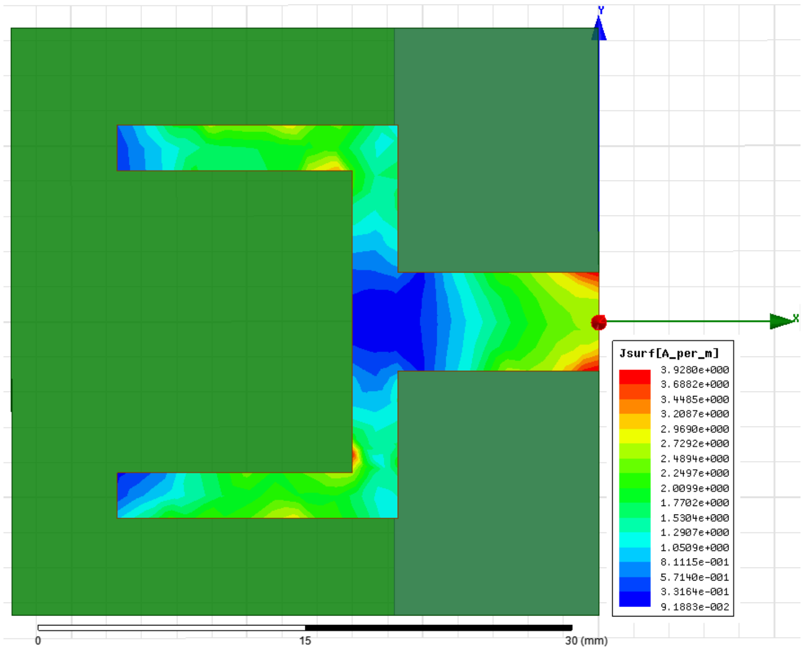


Figure 8. Magnitude surface current density.

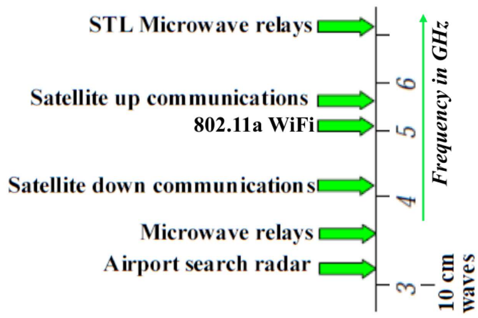


Figure 9. The antenna's applications in the microwave spectrum.

by simulation results, presented here in this research article.

For the well conducted simulation, repeatedly yielding the same results, manufacturing results must certainly match with the simulation results.

We are in the process of manufacturing this antenna; it will then be tested and its measured results will be compared to simulation results. Our antenna prototype will undergo several modifications in order to finally hit the target furthermore.

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