Generalized equivalent circuit model for ultra wideband antenna structure with double steps for energy scavenging

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Abstract. There are various types of UWB antennas can be used to scavenge energy from the air and one of them is the printed disc monopole antenna. One of the new challenges imposed on ultra wideband is the design of a generalized antenna circuit model. It is developed in order to extract the inductance and capacitance values of the UWB antennas. In this research work, the developed circuit model can be used to represent the rectangular printed disc monopole antenna with double steps. The antenna structure is simulated with CST Microwave Studio, while the circuit model is simulated with AWR Microwave Office. In order to ensure the simulation result from the circuit model is accurate, the circuit model is also simulated using Mathlab program. The developed circuit model is found to be able to depict the actual UWB antenna. Energy harvesting from environmental wirelessly is an emerging method, which forms a promising alternative to existing energy scavenging system. The developed UWB can be used to scavenge wideband energy from electromagnetic wave present in the environment.

1. Introduction

Electromagnetic wave sources always present in the environment such as wireless local area network, global positioning system, global system for mobile communications and 4th generation mobile communication. According to federal communication commission definition, UWB refers to a wireless technology that employs a bandwidth larger than 500 MHz or 20% of the center frequency. Ultra Wideband (UWB) antenna is able to scavenge the available energy into the operating bandwidth.

Until now, there are many equivalent circuit models proposed by antenna researchers from the aspect of input impedance or admittance matching. For examples, Wang [2] introduced a degenerated Foster canonical form for electric and magnetic antenna model; Wang and Li [3] circuit refinement method consists of a narrow band model augmented with a macro model; Ansarizadeh [4] circuit topology for rectangular microstrip patch antenna by using non-linear curve-fitting optimization technique to determine exact the parameters of the equivalent circuit model; Ma [5] lumped equivalent circuit model for antenna by using parallel resonant circuit and Zhou [6] conceptual circuit model by connecting input impedance with a parallel and a series LC resonant circuit.

The equivalent circuit of a rectangular narrowband microstrip patch antenna is been related to the physical dimensions of the antenna. Cavity models were being used to model the geometry of a rectangular microstrip patch antenna. Most of the microstrip patch antennas are usually modeled as a
simple parallel resonant RLC circuit. There are a lot of work has been done to calculate the RLC values in the circuit model. For UWB antenna, its radiating element can be seen as several parallel RLC circuit in series due to its matching bandwidth are the result of several adjacent resonances.

2. Research Methodology
The steps taken to accomplish this research work for energy scavenging are as shown in Figure 1.

![Figure 1. Flowchart of research workflow for UWB antenna with double steps](image)

Figure 1 the design of antenna structure and circuit model simultaneously. To design the ultra wideband antenna for energy scavenging, it is essential to determine the material used for the antenna structure. In this case, the material used is FR4 board due to its ease of fabrication. The printed circuit board has the substrate thickness of 1.6mm and dielectric constant of 3.8. While the patch shape for the antenna is chosen to be rectangular in order to ease the designing process. In designing the UWB antenna with the bandwidth of 3.1 to 10.6GHz, several parameters such as patch shape, patch dimension, feed line width, steps, slots and ground plane need to be taken into account. In this research
work, steps and slots are introduced to design the antenna to obtain good return loss result. Moreover, the width of the feed line is also fine tuned using CST microwave studio for a better impedance matching in order to increase the efficiency of energy scavenging.

After several trials with different prototype circuit model, patch cavity model is chosen. It is used as the basic design of the equivalent circuit model for ultra wideband rectangular printed disc monopole antenna. It consists of a series resistor and inductor which represent the surface resistance ($R_s$) and surface inductance ($L_s$) with combination of parallel inductor and capacitor (LC) circuit or also known as resonant circuit to oscillate at its resonant frequency. Figure 2 shows the general ultra wideband equivalent circuit model for rectangular printed disc monopole antenna with double steps. A tuning capacitor ($C_t$) is also introduced into the equivalent circuit model to set the resonance frequency for a better impedance matching with the antenna. In order to determine the accuracy of the equivalent circuit model, a Matlab program code is written for the circuit model as shown in Figure 3. By simplifying the circuit model, the input impedance $Z_{in}$ and the reflection coefficient can be calculated using the impedance at the ports, and then the return loss is plotted. The simulated return loss of the Matlab and AWR microwave office is compared in order to verify the accuracy.

**Figure 2.** Equivalent circuit model for ultra wideband rectangular printed disc monopole antenna with double steps

3. Results and Discussion

The coupling effects between inductors for same patch cavity model is improved by introducing inductor coupling coefficient ($k$) between $L_1a$ and $L_1b$, $L_2a$ and $L_2b$, $L_3a$ and $L_3b$, $L_4a$ and $L_4b$ as shown in Figure 3.

**Figure 3.** Improved Equivalent circuit model for ultra wideband rectangular printed disc monopole antenna with double steps

Figure 4 illustrates the comparison of return loss result between the circuit model with inductor coupling coefficient ($k$) and electromagnetic model with CST. It shows that the equivalent circuit
model with inductor coupling coefficient (k) match very well with the electromagnetic model. The operating frequency and depth of resonant frequency from both simulation results are quite close to each other. There is no shifting in frequency between circuit model and antenna structure simulation result. Hence, it shows that there are coupling effect exist between inductor which need to take account during circuit simulation. By tuning the values of inductor coupling coefficient (k) and other LC component values of the model is sufficient to solve the frequency shifting which happens with basic model as shown in Figure 2. From the Figure 2, the developed UWB antenna has a excellence performance in scavenging energy into bandwidth of 3.1 GHz to 10.6 GHz.

![Comparison of return loss result between circuit model and electromagnetic model](image)

**Figure 4.** Comparison of return loss result between circuit model and electromagnetic model

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