Design, Simulation, and Fabrication of an Ultra-Wideband Monopole Antenna for Use in Circular Cylindrical Microwave Imaging Systems

Reza Jafarlou, Changiz Ghobadi, Javad Nourinia
Department of Mechatronics, Ahar Branch, Islamic Azad University, Ahar, Iran

Abstract: In this paper, a novel ultra-wideband Printed Monopole Antenna (PMA) is proposed for use in a circular cylindrical microwave imaging system. The proposed antenna consists of a square radiating patch and a ground plane with a pair of inverted U-shaped slots and two L-shaped parasitic elements, which provides a wide usable fractional bandwidth of more than 130% in ultra-wideband systems (2.9-14.3 GHz). By cutting two modified inverted U-shaped slots with variable dimensions on the ground plane corners and also by inserting two L-shaped parasitic elements on the other side of the substrate, additional resonances are excited, allowing for much wider impedance bandwidth, especially at the higher band. The proposed antenna has an ordinary square radiating patch, thus displaying a good omnidirectional radiation pattern even at higher frequencies. Also, its radiation efficiency is greater than 86% across the entire radiating band. The designed antenna has a small size of 12×18 mm². Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for circular cylindrical microwave imaging systems.

Key words:

INTRODUCTION

A microstrip antenna consists of an insulating substrate with a radiating patch on one side and a ground plane on the other side. The conductive radiating patch can have different shapes, but the common shapes are those that can be readily analyzed (Figure 1). The conductor is often made of copper and gold, for the materials must be in a way that diffraction and radiation fields are greater than at the edges of the antenna; thus, the dielectric constant must be as low as possible (Ammann, 2000; Agrawall, Kumar, & Ray, 1998).

Microstrip resonators can be classified into two types depending on the length and width of antennas. Resonators with a narrow conductor are called microstrip dipole and resonators with a wide conductor are referred to as microstrip patch. Resonance occurs when the dipole or patch dimensions are of the order of a half guided wavelength. Longitudinal current distribution on both antennas is too much. Therefore, their pattern and gain are similar, but they can be different in other properties (e.g. input impedance and polarization). When the signal frequency is in the vicinity of a resonance, a microstrip resonator radiates a relatively broad beam, broadside to the plane of the substrate. A major part of the input signal participates in radiation and thus the resonator acts as an antenna. Since patch dimensions must be of the order of a half guided wavelength, its directivity is very low. For instance, a half-wavelength dipole typically has a gain of about 5 to 6 dB and a beamwidth between 70 and 90 degrees.

High-directivity antennas are required in many microwave applications. Therefore, the antenna must have a narrow beam. In such cases, a single patch is not suitable; rather, a set of radiating elements must be used that have been arranged in a periodic array. This increases directivity. However, the single-patch antennas are suitable in some other applications such as mobile and personal communications where wide beam is required.

One of the main goals in redesigning these antennas is to find a planar shape that yields a higher bandwidth. Various planar antennas with different geometrical structures have been empirically identified (e.g. Wong & Tung, 2001), and automated methods have been developed for achieving an optimal design (e.g. Ojaroudi, Ebrahimian, Ghobadi, & Nourinia, 2010). Therefore, many empirical and experimental changes have been made in antenna design and feeding structures.

To get a clear understanding of the performance of UWB antennas, several types are examined in this article. The focus of the article is on the effect of antenna shape and feeding type on the impedance bandwidth of the antenna. Due to the properties of microwave antennas such as omnidirectional radiation beam, maximal specific absorption rate (SAR), and concentrated radiation beam, they are a good choice for use in radiotherapy (Rossetto & Stauffer, 1999; Bond, Hagness, & Van Veen, 2003).

HFSS software is used to simulate the proposed antennas and filters. Developed by Ansoft, this software has many applications in analysis of microstrip antennas (Kuster & Balzano, 1992).
Results:

Design and Simulation:

The proposed antenna is a planar microstrip antennawith ultra-wideband radiation properties. This antenna has a new structure with a rectangular radiation patch (Figure 2). It is made on a 0.8-mm thick FR4 substrate, and its radiation parameters such as impedance bandwidth and radiation patterns have been tested. The rectangular monopole antenna is fed by a microstrip line on an FR4 substrate with a thickness of 1.6 mm, relative permittivity of 4.4, and a loss tangent of 0.018.
Since the main goal is to design an antenna with UWV radiation, we need to apply techniques that will improve the impedance bandwidth performance of the antenna. One way is to use a pair of inverted U-shaped slots in the ground plane (Figure 3). This increases the impedance bandwidth of the antenna, especially in the upper frequencies in the UWV range. To overcome the issue of lack of radiation in the lower frequencies in the UWB range, we use a pair of L-shaped elements that act as a resonator, coupling the current from the ground structure to the parasitic element (Figure 4). The figure below clearly shows that adding the inverted U-shaped slots and the L-shaped parasitic elements creates two new resonances at 11 and 14.1 GHz frequencies, which in turn improves the impedance bandwidth of the antenna. The other advantage of incorporating parasitic elements in the antenna is improving impedance bandwidth at the lower frequencies of the UWB range.

Fig. 3: The geometric shape of the rectangular antenna: (a) simple rectangular antenna, (b) simple rectangular antenna with two inverted U-shaped slots, and (c) simple rectangular antenna with two inverted U-shaped slots and a pair of L-shaped resonators.

Fig. 4: The results of the simulated return loss for different antenna structures.

To have a better insight into the behavior of the planar monopole antenna, the current distribution of the antenna is examined. Surface current distributions are simulated using HFSS (Hornsleth et al., 1997) for the new resonant frequencies (11 and 14.1 GHz) and for different antenna structures. Thus, the effect of the inverted U-shaped slots and L-shaped parasitic elements on the impedance bandwidth of the antenna is examined by studying the current distribution of different antenna structures (Figure 4). Considering current distribution in Figure 4a, the presence of the inverted U-shaped structures in the ground plane create new resonant frequency at 11 GHz by changing the path of the electric current. Figure 4b shows that L-shaped resonators direct current from the ground plane to the radiating patch, thus creating a new resonant frequency at 14.1 GHz in the impedance bandwidth of the antenna.
Fig. 5: Surface current distribution on the antenna at 11 GHz (a) and 14.1 GHz (b) frequencies.

**Fabrication:**
Simulation results were analyzed in Protel software for fabrication. Figure 6 shows the fabricated monopole antenna.

![Top View](image1) ![Bottom View](image2)

Fig. 6: The proposed monopole antenna.

The measured and simulated values for the return loss of the antenna are shown in Figure 7. The results showed that, for return loss, the radiation property of the antenna is fully noticeable at these frequencies. The proposed printed monopole antenna is able to radiate at the ultra-wideband range. There is, however, a difference between the simulated and the measured results, which is mainly due to the problems in the measurement stage. One of these problems is uncalibrated measurement devices.

![Graph](image3)

Fig. 7: The return loss of the tested monopole antenna.

The last parameter that has to be examined is the radiation pattern of the antenna. The H-plane patterns are all omnidirectional, which is one of the advantages of the antenna. The main advantage of this pattern in the H-plane is that it reduces the co-polarization level of the omnidirectional pattern. The patterns related to the E-plane are also displayed. In the E-plane, the most important property is the stability of the pattern; that is, the pattern must not shift or rotate with change in frequency. This is also clearly shown in Figure 7.
Fig. 8: The measurement pattern for the proposed antenna: (a) 5 GHz, (b) 8 GHz, (c) 11 GHz, and (d) 14 GHz.
Interstitial Hyperthermia Therapy Using Coaxial-Slot Antenna:

In interstitial hyperthermia, high therapeutic temperatures are applied to the target tumor or cancer without damaging the surrounding tissues (Hamada, Yoshimura, & Ito, 1999). This is done with monopole antennas. Coaxial-slot antenna is the most prevalent type in this form of therapy (Figure 8). In interstitial therapy, specific absorption rate (SAR) is the most important antenna parameter. The slots in the antenna's structure are responsible for generating and controlling SAR. Current distribution at the edges of the slots generates maximum SAR (Ojaroudi et al., 2010).

Microwave imaging systems for removing cancer tissues have a circular cylindrical structure. These systems require small antennas with high bandwidth and omnidirectional radiation patterns. Planar monopole antennas have the appropriate physical features such as simple structure, small size, and low cost. Because of these features, these antennas have received increasing attention for ultra-wideband applications.

Fig. 9: Coaxial-slot antenna: (a) lateral view, and (b) cross-sectional view.

The proposed antenna was tested and the results suggested that the simulated results correspond to measured findings. As shown in VSWR graphs and radiation patterns, the antenna has good radiation, omnidirectional pattern, multi-resonant properties, and smaller size compared to similar antennas.

Conclusion:

In the present research, a new printed monopole antenna was proposed for use in microwave imaging systems. It consisted of a square radiating patch and a ground plane with a pair of inverted U-shaped slots and two L-shaped parasitic elements, providing a wide usable fractional bandwidth of more than 130% in ultra-wideband systems (2.9-14.3 GHz). By cutting two modified inverted U-shaped slots with variable dimensions on the ground plane corners and also by inserting two L-shaped parasitic elements on the other side of the substrate, additional resonances were excited at 11 and 14.1 GHz frequencies, allowing for much wider impedance bandwidth, especially at the higher band. The resulting bandwidth was 2.9-14.3 GHz. The proposed antenna had a good omnidirectional radiation pattern, even at higher frequencies. Also its radiation coefficient was more than 90 percent.

ACKNOWLEDGEMENT

This study is part of a master's thesis in the Electrical Engineering Department of Abhar Branch of IAU. The authors express their gratitude to the esteemed professors of Khoy Branch of IAU, especially Dr. Hassan Hajihoosseinlu and Dr. Mohammad Nasiri for their review of the article.

REFERENCES


