A T Slot Monopole Antenna for UWB Microwave Imaging Applications

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Abstract

This paper presents the design, optimisation and physical implementation of a compact ultra-wideband (UWB) printed circular monopole antenna (PCMA) for microwave imaging applications, specifically for breast cancer detection. The profile of the proposed antenna features T- Slots etching over a driven circular patch. To achieve the desired impedance bandwidth both in free-space and in proximity to human tissues, the geo- metrical profiles of the T - slot monopole antenna are optimised using the surrogate model assisted differential evolution for antenna synthesis (SADEA) optimiser. The bandwidth, gain, radiation pattern and efficiency of the optimised antenna are then evaluated. The simulation and measurement results of the antenna's responses are deduced to be in reasonable agreement for the input impedance, gain, radiation pattern and efficiency, respectively, in the operating band of 3.1 GHz to 10.6 GHz. The proposed antenna also gives an adequate radiation in the broad side direction, which contributes significantly to clutter level reduction, and makes the proposed antenna applicable for effective and efficient microwave imaging applications.

1 Introduction

Microwave imaging applications in non-destructive experiments have had a tremendous and vital impact in both civilian and military applications. Microwave imaging applications in non-destructive experiments also finds ongoing and potential applications for several medical applications such as breast cancer imaging application [1-3]. Breast cancer remains a major cause of death among women in the United Kingdom with one in eight women being diagnosed; thus, causing many thousands of deaths every year [4]. Early detection of breast cancer through screening programmes is highly imperative in finding effective and efficient ways of prevention and possible cure.

Over the past decades, investigations focusing on breast cancer research for early detection employ techniques such as X-ray mammography, magnetic resonance imaging, ultra-sound and computed tomography. X-ray mammography is assumed to be the most effective detection method due to its increasing rate of successful outcomes in comparison to other imaging techniques. However, X-ray imaging has some drawbacks such as breast compression discomfort and critical health and safety regulation due to highly ionising nature of the electron beam used for X-ray scanning. False positive and negative alarm rates are also a major concern in X-ray imaging [5-7].

Microwave imaging offers interesting alternatives to X-ray imaging mainly because of its non-invasive and non-ionising features. Microwave imaging also does not require breast compression and it can reconstruct clear and detailed three dimensional (3 - D) images. In its basic form, microwave imaging employs the differential of the water content between the cancerous tissues and non-cancerous tissue. This is because the normal tissue is transparent to microwaves in contrast to the anomalous tissue. The high water content clustered within the cancerous cell colonies act as a strong scattering point and the resulting differential response is used to determine the presence of tumour [1, 8 - 10].

Microwave imaging for breast cancer detection can be classified into the following three approaches [8]: features:

- Passive method: In this approach, segregation of the malignant tissues from the healthy ones is achieved by using microwave radiometry to sense the increase in the temperature of the tumour [11]. The temperature measurement is then used to map out the image of the inspected region of the breast tissues for further diagnosis and verification.

- Hybrid method: The combination of both microwave and ultrasonic sensors is used to determine the presence of tumour in this method. The tumour conductivity is higher when compared to the normal tissue, so microwave energy is preferentially absorbed by the tumour, thereby heating and expanding it. The pressure wave created by the expanded tumour is then detected and transformed into an image to locate the tumour using an ultrasonic transducer [12].

- Active method: This method is further divided into tomography and radar based active microwave imaging [13]. Tomography involves the use of a single transmitter to radiate pulses into the breast tissue, while some placed around the breast issue to receive any backscattered signals. Radar-based active microwave imaging involves the use of short-pulse signals transmitted from a single UWB antenna into the breast tissue and any backscattered signals are received by the same antenna. For both tomography and radar-based active microwave imaging, the transmitting and receive processes are repeated at various positions for the transmitter and locations around the breast. The generation of fully mapped 2 - dimensional and/or 3 - dimensional images is achieved through the control and reconstruction of the backscattered energy or signals.

High level of image resolution can be achieved by a UWB pulse obtained from receive and transmit antennas. The basic antenna requirements are large fractional bandwidth, low side lobes and low levels of mutual coupling between the array elements. Antenna configurations such as bowtie [14], Vivaldi [15], and horn [16] are all candidates for UWB pulses. However, some of these configurations may be not be suitable for size reduction or compactness and low cost physical implementation as it is required for microwave imaging applications. Monopole antennas are planar, light, compact and suitable for low cost physical implementation [17]. Though Monopole antennas are suitable for microwave imaging applications, a constrained bandwidth performance tends to limit their applications. Surrogate model assisted differential evolution for antenna synthesis (SADEA) is a state-of-the-art algorithm for efficient antenna optimization [18]. SADEA optimiser in Antenna Design Explorer (ADE 1.0) has been demonstrated to be an effective tool for the bandwidth optimisation of microwave antennas [19].

This paper presents the design, optimisation and physical implementation of a UWB printed circular monopole antenna (PCMA) with achieved response characteristics (bandwidth, efficiency, high resolution high immunity, and compactness), which makes it suitable for UWB microwave imaging applications. The design modelling was carried out using Computer Simulation Technology - Microwave Studio (CST-MWS) and the optimisation of the design was carried out using the SADEA optimiser in Antenna Design Explorer (ADE 1.0).

The remainder of the paper is organized as follows: Section 2 presents and discusses the design, optimisation and physical implementation of the proposed PCMA. Concluding remarks are provided in Section 3.

2 Design, Optimisation and Physical Implementation of the Proposed PCMA

The layout of the printed circular monopole antenna (PCMA) is shown in Fig. 1. The PCMA consists of a driven circular patch having four uniform T slots and it is implemented on an FR4 substrate having a thickness 0.8 mm, relative permittivity (ε_r) of 4.3 and a loss tangent ($\tan\delta$) of 0.025. The PCMA features two uniform rectangular planes acting as a partial ground. The feeding of the PCMA is via a 50Ω coaxial cable and a microstrip line.

Minimize max|S11| over 3.1 GHz to 10.6 GHz (1)
Subject to: GR ≥ 2 dB

An initial parametric study of the PCMA is carried out in CST-MWS to determine the possible search ranges of the design variables. The physical dimensions considered for the para- metric study of the PCMA include substrate's length (Ls) and width (Ws), the ground plane's length (Gl) and width (Gw), the radius of the driven circular patch (R) and the microstrip feedline's length (Fl) and width (Fw) at a fixed copper layer thickness of 0.035 mm. The width of throat and depth of head for all the T-slots are equal; the depth of throat and width of head for all the T-slots are equal; thus, all the dimensions of the T slots are uniform and relative to R as shown in Fig. 1. The PCMA is optimised using SADEA in ADE 1.0 using the recommended settings in [18]. The design exploration goal is minimise the maximum reflection coefficient (S11) in the operating band of 3.1 GHz to 10.6 GHz subject to the realized gain (GR) not being less than 2 dB over the bandwidth as shown in (1). The selected values of the design variables for the pro- posed PCMA after the parametric study and design exploration are shown in Table **1**

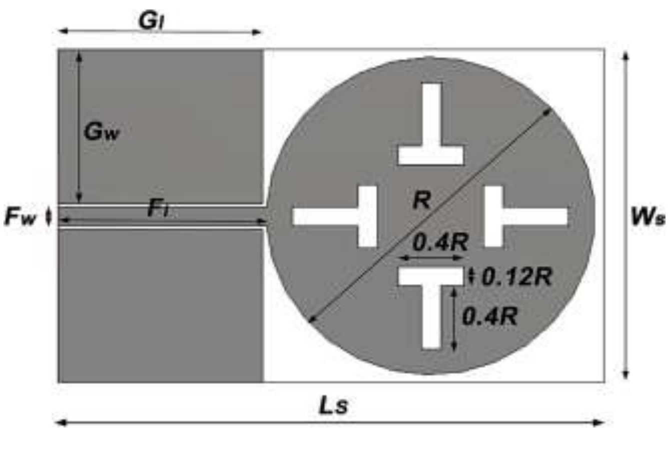


Fig. 1: Layout of the proposed PCMA.

Variables	L_S	W_S	R	G_l	G_W	F_l	F_W
Value	41.50	26.20	12.50	15.57	12.10	15.84	1.47

Table 1: Selected values of design variables (all sizes in mm) for the proposed PCMA.

A low profile, compact and durable design is realised for the proposed PCMA and the physical implementation is shown in Fig. 2. To evaluate the efficiency and performance of the proposed PCMA, the simulated and measured results for the re- turn loss over the operating bandwidth (3.1 GHz to 10.6 GHz) are shown in Fig. 3, and the normalised and un-normalised Eθ and Eφ far field characteristics are shown for two planes (x- z and y-z planes) at two selected frequencies in the operating bandwidth (6 GHz and 9 GHz) in Fig. 4a and Fig. 4b. The proposed PCMA also satisfies the requirement in (1) for the realized gain (GR) at a minimum value of 2.3 dB in the operating bandwidth (3.1 GHz to 10.6 GHz). Specifically, GR > 4.5 dB is achieved in the broadside direction.

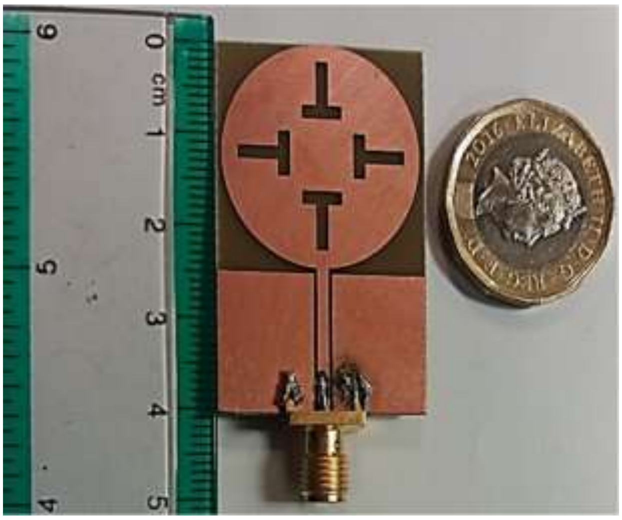


Fig. 2: Physical implementation of the proposed PCMA.

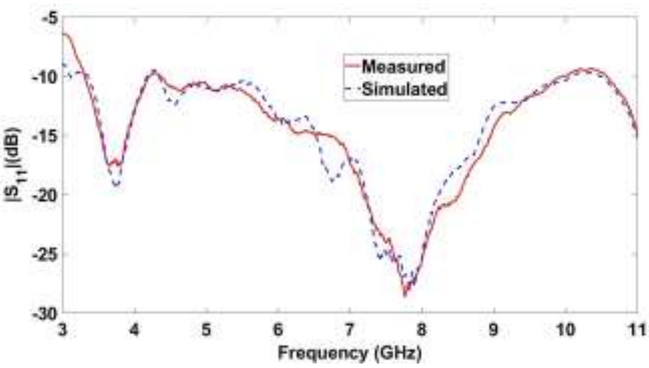
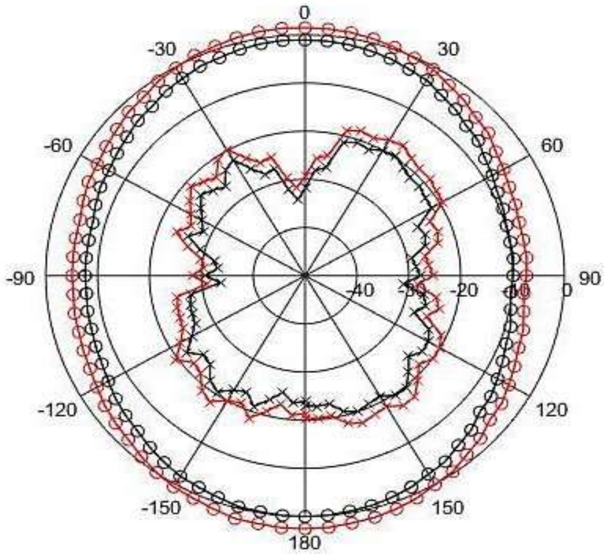
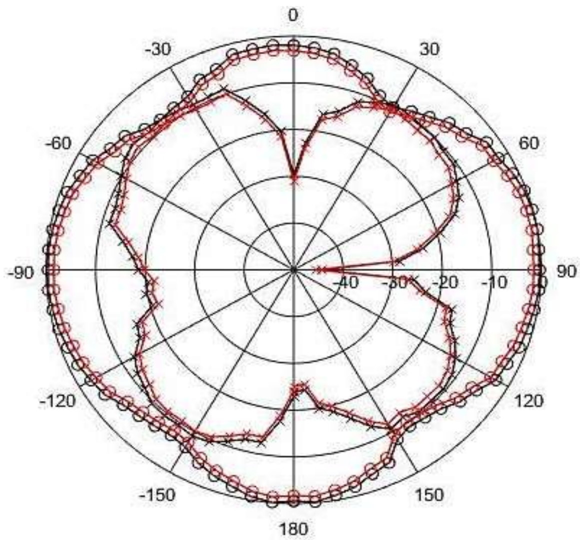


Fig. 3: S_{11} frequency response of the proposed PCMA.

Using the standard -10 dB reference for the evaluation of the return loss, Fig. 3 shows that the proposed PCMA achieves a good impedance bandwidth in the operating bandwidth, and the measured and simulated results are in reasonable agreement. Fig. 3 also shows that the PCMA is multi-resonant with sharp resonances at frequencies which include, but are not limited to 3.66 GHz, 3.8 GHz, 4.6GHz, 7.76 GHz and 8.5 GHz for the measured results. These resonances are expected due to their inducement by the uniform T-slots etched on the driven circular patch. Fig. 4a and Fig. 4a show that the proposed PCMA has sufficient radiation (over 4.5 dB) in the broadside.



(a) 6 GHz



(b) 9 GHz

Fig. 4: Normalised and un-normalised E_θ and $E_{\varphi\,field}$ characteristics (x-z and y-z planes) of the proposed PCMA; Black curve: Normalized, Red: Un-normalized.

3. Conclusions

In this paper, a compact PCMA suitable for microwave imaging applications has been presented specifically for breast cancer detection. The performance of the proposed antenna is studied and optimised using the surrogate model assisted differential evolution for antenna synthesis (SADEA). Simulated and measured results show a reasonable agreement for good impedance bandwidth and a radiation of over 4 dB (broadside direction) in the operating bandwidth of 3.1 GHz to 10.6 GHz. Hence, the proposed PCMA is suitable for image reconstruction and reduction of clutter level in breast cancer detection applications.

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