

Breast Cancer Detection Using a Conformal Metasurface

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Abstract—This paper presents the utilization of conformal metasurface sheets for breast cancer detection. This technique involves two metasurface arrays with electrically small resonators as a transmitter and receiver. The microwave radiation of the metasurface transmitter is received at the other side of the breast by the metasurface receiver to form an electromagnetic power footprint. The power footprint is influenced differently according to the electrical properties of the breast tissue, thus the presence of cancerous tissue inside the breast can be detected. The achieved results show the feasibility of the proposed technique in detecting the existence of a 15 mm diameter tumor inside an extremely dense breast.

Index Terms—Metasurface, Breast cancer, Conformal, Detection, wearable antenna.

I. INTRODUCTION

The variation in electrical properties between healthy and cancerous breast tissue established the concept of microwave imaging (MWI) for breast cancer detection. In addition, the non-ionizing radiation, cost-effectiveness and non-compression examination of MWI enhanced the effort to develop a 3D breast imaging technique [1]. Toward avoiding mechanical scanning in MWI, an array of flexible receivers and/or transmitter antennas was proposed [2]. However, the number of antennas in the system is subject to the antenna footprint that is a function of the frequency of operation. While smaller antennas are compatible with a high frequency that has a higher resolution, the larger antennas work at a low frequency that is capable of deeper penetration. Such a situation creates an antenna number-penetration-resolution trade-off situation that affects the MWI performance.

In this work, a flexible-conformal metasurface is utilized as a breast cancer detection modality. The proposed technique is based on illuminating the breast by a metasurface antenna and receiving the scattered wave power using electrically small metasurface cells. The receiver is expected to provide an electromagnetic energy pattern instead of an image that maps the breast's internal tissue profile. A different energy patterns can be obtained for healthy and cancerous breasts. By using a metasurface, the antenna number-penetration-resolution trade-off that limits the capability of conventional MWI techniques can be avoided. In addition, the necessity of antenna miniaturization to enhance the resolution can be avoided by the need for only a few scanning steps of the metasurface sheet.

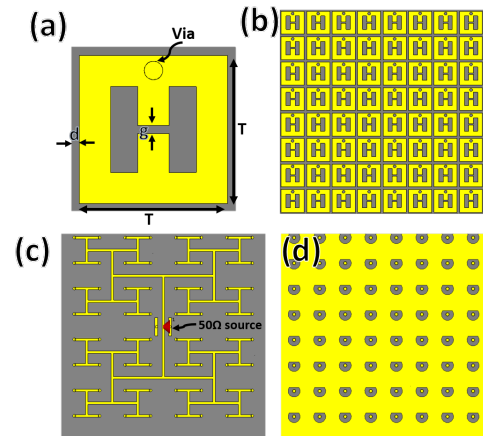


Fig. 1. Schematic showing the proposed metasurface: (a) the design and the geometry of the unit cell, (b) the front view of the metasurface, (c) the back view of the transmitter, and (d) the back view of the receiver.

II. DESIGN METHODOLOGY

The building block of the metasurface receiver and transmitter is a unit cell that is comprised of two split ring resonators positioned face to face to form an electric inductive capacitive (ELC) resonator, as shown in Fig.1(a). The unit cell is shaped from copper on a flexible dielectric Rogers RT 6002 substrate that has a 2.54 mm thickness, 2.94 dielectric constant, and a 0.0012 loss tangent. The back of the substrate is covered by a metallic ground plane to shield the unit cell. A via was designed to act as a path for the current to flow from the ELC to the load.

The dimensions of the unit cell and the spacing at the edges were optimized to reach the highest reflection coefficient/absorption for the transmitter/receivers when the value of the feeding port/resistive load for the transmitter/receivers is 50 Ω . Such an approach can avoid the need for a matching circuit for the transmitter and receivers, hence greater simplicity can be introduced into the system structure. The length and width of the ELC strip is $T=10$ mm, the distance between the cells is $d=0.5$ mm, and the gap of the resonator is $g=0.5$ mm, as seen in Fig. 1(a). With the aim of investigating the behavior of the unit cell, the full-wave electromagnetic simulation software

CST Microwave Studio was utilized [3].

The unit cells were arranged in an 8x8 periodic structure to form the metasurface transmitter/receiver, as illustrated in Fig. 1(b). Since the separation distance between the unit cells is small to the degree that it cannot host the feeding network, a second Rogers RT 6002 substrate (0.508 mm thick) was inserted at the top of the ground plane. The presence of the second substrate allows the building of a feeding network for the transmitter to be supplied by a single feeding source, as shown in Fig. 1(c). In the receiver, the introduction of a second substrate was to achieve an accurate antenna reciprocity between the transmitter and the receiver as illustrated in Fig. 1(d). The metasurface transmitter and receiver were bent cylindrically by a radius of about 42 mm (breast radius), as seen in Fig. 2(a). At the receiving side, each unit cell of the metasurface was terminated by a resistive load of 50 Ω . The measured reflection coefficient and the power across the resistive load at the resonance frequency is shown in Fig.2(b).

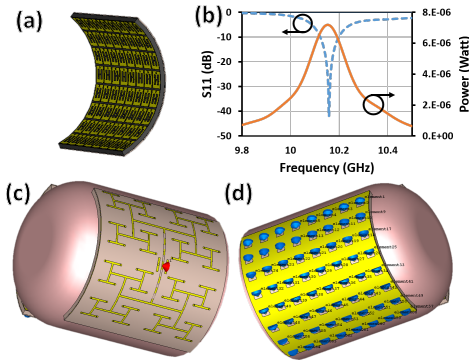


Fig. 2. (a) Schematic of the conformal metasurface transmitter and receiver. (b) The reflection coefficient and the power across one of the terminated loads at the resonance frequency. The numerical setup shows (c) the conformal transmitter and (d) the receiver on the breast model.

III. CANCEROUS TISSUE DETECTION

Toward investigating the capability of the proposed modality, the conformal metasurface transmitter and receiver were placed (in opposite directions) on a realistic breast phantom, as illustrated in Fig. 2(c) and (d). In order to conduct a numerical evaluation, two identical extremely dense breast phantoms were designed using the CST. The breast has a cylindrical shape with a radius of 40 mm and an approximate length of 100 mm (the extent from the chest to the base of the nipple). The breast is covered by a 2mm thick skin, while the internal breast tissue is comprised of fibroglandular and fat tissue with 75% and 25%, of breast volume, respectively. With an objective to differentiate between healthy and malignant breasts, a cancerous tumour was implanted inside one of the breast phantoms, as shown in Fig. 3(a) and (b). Higher electrical properties (conductivity and permittivity) were assigned to the tumor compared to the surrounding fibroglandular tissue [4].

The metasurface transmitter illuminated the breast with microwave radiation at 10.16 GHz. The transmitted wave energy through the breast reached to the metasurface receiver

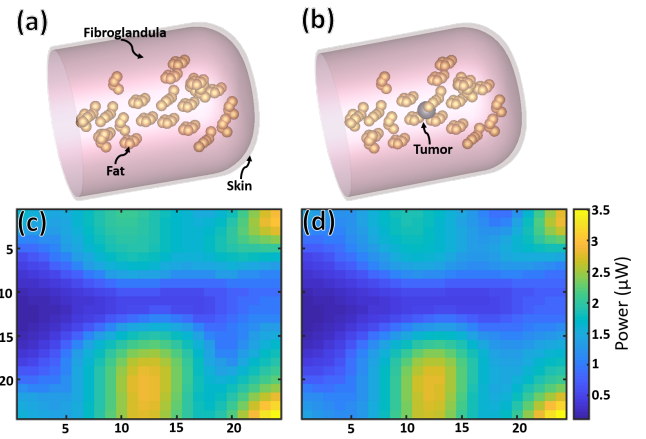


Fig. 3. Extremely dense breast models (a) without a tumor and (b) with a tumor, and the measured power pattern on the metasurface receiver for (c) an extremely dense breast without a tumor and (d) with a tumor.

where the surface current at the ELC flowed through the vias to the resistive loads of each unit cell. After the first radiation session, both transmitter and receiver were scanned over the breast by a very small scanning step that has a fraction of the unit cell's length (in this case, 3mm). Nine scanning steps (3x3) were conducted in order to enhance the resolution. The consumed power at the resistive loads was measured individually and post processed using Matlab to construct the received energy pattern for each breast, as seen in Fig.3(c) and (d). The obtained energy expressions of the healthy breast and the breast with cancerous tissue are different, which is a result of the different internal content of each breast. The presence of the tumor affects the wave propagation through the breast, hence changes the transmitted wave that hits the metasurface receiver.

IV. CONCLUSION

A conformal metasurface array for breast cancer detection has been introduced. The proposed system provides an impression of the electromagnetic energy that offers valuable data for identifying the presence of an anomaly inside the breast. Engaging the metasurface in the transmitter and receiver sides provides a solution to the limitation in the resolution and penetration capability of traditional MWI. The proposed technique shows a high capability to detect a 7.5 mm radius cancerous tissue inside dense breast tissue.

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