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Microwave Imaging Using Arrays of Vivaldi Antenna for Breast Cancer Applications

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ABSTRACT

This paper presents the design of a Vivaldi antenna for microwave imaging applications, specifically for breast cancer detection. A number of parameters are studied and optimized for breast imaging application over ultra-wide band frequency (3-9 GHz). The overall size of the antenna is 0.57 λ x 0.406 λ at the lower frequency of 3 GHz. Advanced image reconstruction algorithms based on the reflected signal of the Vivaldi antennas are then utilized for the imaging task. The algorithms provide sharper and superior identification capability, accurate and reliable positioning, strong robustness, and efficient computational speed.

Key words: Breast cancer, Microwave imaging, Ultra wide band and Vivaldi antenna

1. INTRODUCTION

Microwave imaging applications in non-destructive experiments have yielded tremendous and vital impact in both military and civilian applications. This application also finds ongoing and potential relevance for several medical applications such as breast cancer imaging application [1-3]. Breast cancer is a disease that occur due to the presence of malignant cell inside the breast tissue. This scourge constituted a major cause of unwanted death among women all over the world[4]. In the United Kingdom, one in eight women are being diagnosed; thus, causing many thousands of deaths every year[5], it is therefore imperative for its early detection. Early detection and treatment could yield the survival rate of almost 97%, which emphasizes the serious requirement for reliable, effective and efficient method of early breast cancer detection. Medical imaging currently depends on various techniques, including X- ray mammography, magnetic resonance imaging (MRI) and echography. However, these techniques witness some impediments and hence more effective and efficient approaches are desired. The use of microwave subsurface radar (MWR) as a medical imaging technique for breast cancer screening offers several benefits over other imaging methods[6]. Microwave imaging is non-ionizing, non-invasive, and low cost and it does not require breast compression as compare to x-ray mammography. Microwave imaging does not need the infrastructure of the MRI which is very large and costly. Additionally, Microwave imaging techniques have the advantages of high data rates, low complexity, and low spectral power density. In microwave imaging, the antenna is used as a transceiver to transmit and receive microwave signals into the breast tissues. This principle is based on the variation of electrical properties of different tissues such as the relative permittivity and conductivity. The scattered signal reflected from the antenna are used to detects the contrast in the dielectric properties between normal and tumor tissue in a more efficient, effective, safe and accurate manner. This technique uses the differential of the water content between the cancerous tissues and non-cancerous tissue. Normal tissue is transparent to microwaves in contrast to the anomalous tissue. The high water content clustered within the cancerous cell colonies and act as a strong scattering point resulting in differential response for the determination of tumor [3, 7-10].Thus microwave imaging could serve as an early stage screening tool, thereby saving a lot of life.

Vivaldi antenna is a good candidate for microwave imaging due to its wide band, high gain, stable directional radiation pattern, end fire radiation, and resonant at lower frequency. Other features are low cost and low profile[11]. Several types of Vivaldi antenna have been designed for medical imaging such as miniaturized antipodal- Vivaldi antenna, cross-vivaldi antenna, Vivaldi antenna with planer director and cavity backed Vivaldi antenna [12-15]. Vivaldi antenna designs have challenges of size reduction and gain which are due to its feeding transition techniques and parametric geometry of the antenna[16]. Some of these challenges are studied to improve the performance of the antenna. In[17], a Vivaldi antenna is proposed by adding parasitic ellipse inside the flare. Although, the parasitic ellipse improve the field coupling, however the antenna has large dimensions of (140mm x 66mm) and the antenna does not reach lower frequency and hence not suitable for arrays. In [18], a tapered slot antenna of size (75 mm x 75mm) is studied. Antenna parameters were optimized and directive radiation pattern is achieved but resonant are not obtained at high frequency.

In this paper, a new, low profile, low cost, enhanced impedance band width and high performance tapered slot antenna for microwave imaging, especially for breast cancer detection is presented. The antenna size is small compared to the studied antennas and its cover ultra-wide band frequency. Simulated and

Measured results indicated that the proposed antenna can obtain bandwidth from 3 to 9 GHz with high directive radiation pattern. The design modeling was carried out using Computer Simulation Technology - Microwave Studio (CST-MWS) and based on the design antenna, imaging reconstruction was carried out using four algorithms which are simulated with and without tumors within the breast tissues for high resolution and improved performance of clutter rejection. The remainder of the paper is organized as follows: Section 2 presents and discusses the design, physical implementation and image reconstruction algorithm of the proposed UWB antenna. Concluding remarks are provided in Section 3.

2. DESIGN, OPTIMISATION AND PHYSICAL IMPLEMENTATION OF THE PROPOSED ANTENNA

The geometric layout of the top and bottom of the Vivaldi UWB antenna are shown in Figure 1and 2 respectively. The antenna is printed on FR4 substrate with a thickness of 1.6mm, relative permittivity of 4.3 and a loss tangent of 0.025. The overall size of the antenna is 0.57λ x 0.406λ at the lower frequency of 3GHz.The Vivaldi antenna is fed with 50 Ω coaxial cable microstrip lines. Simulated and Measured results indicated that the proposed antenna can obtain bandwidth from 3 to 9 GHz with high directive radiation pattern as indicated in Figure 3. The radiating properties of the proposed antenna are determined by a set of exponential curves, slot lines, tapered rates, the cavity structures, the slot lines, back wall offset, stub arrangement and the feeding position. The main radiating fins are flare with height H_f = 36mm and length L_f = 20mm with a taper rate R of 0.18 (factor determining the opening rate of the flare) of the inner exponential curve and the exponential curve is determined by:

$$x = c_1 e^{Rz} + C_2 \quad (1)$$

Where $C_1 = \frac{x_2 - x_1}{\left(e^{Rz_2} - e^{Rz_1}\right)}$ and $C_2 = \frac{x_1 e^{Rz_2} - x_2 e^{Rz_1}}{\left(e^{Rz_2} - e^{Rz_1}\right)}$

The points $\left(x_1, z_1\right)$ and $\left(x_2, z_2\right)$ represents the end points of the flare. The cavity at the end of the flare is represented as C_d = 10mm. This cavity is adjusted with the equation:

$$C_d = 0.5C_d - 0.5\left(\cos\theta\right) \quad (2)$$

Where $\theta = \sin\left(\frac{S_w}{C_d}\right)$

The cut-off frequency of the proposed taper slot antenna can be calculated with equation 3.

$$fc = \frac{c}{\left[w'\sqrt{\varepsilon_r}\right]} \quad (3)$$

Where F_c the center frequency, c is the speed of light, ε_r is the relative permittivity, and W' is the flare opening rate. S_L represents the slot line between the cavity and flare with a slot line width S_W of 0.5mm. The back wall offset has the value of 5mm. A microstrip slot with a radial stub is introduced to achieve a wider operating bandwidth. The stub angle of the radial stub is at θ =55 degrees with a radius of R = 10mm. The feeding line has a microstrip taper of length F_l = 31.50 mm and taper feed width of F_w =1.50 mm. The microstrip taper is connected to the stub with a microstrip coupler of length L_C = 16.80 mm and width L_W of 1.50mm. The microstrip feeding line is fed with a 50 Ω Sub miniature connector version A (SMA) to feed the antenna. The electrical properties of the SMA connector are 2.08 dielectric constant and 4.62 x 10^4 S/m electrical conductivity.

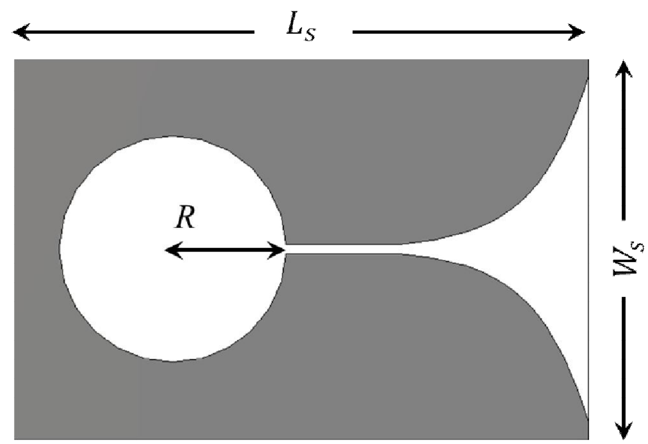


Figure 1: Top layer of the proposed Vivaldi antenna.

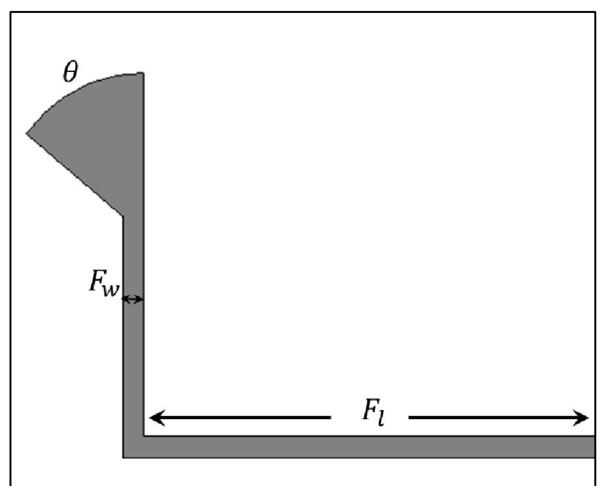


Figure 2: Bottom layer of the proposed Vivaldi antenna.

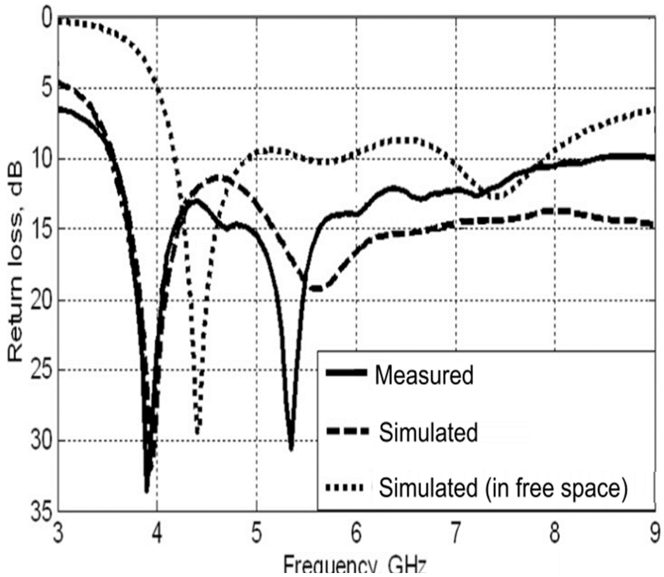


Figure 3: simulated and measured results of the antenna.

2.1 OPTIMISATION METHOD

An initial parametric study of the proposed Vivaldi antenna is carried out using CST MWS to determine the possible search ranges of the design variables. The physical dimensions considered for the parametric study of the antenna include substrate's length (L_s) and width (W_s), the ground plane's length (G_l) and width (G_w), the radius of the stub (R) and the microstrip feed line's length (F_l) and width (F_w) at a fixed copper layer thickness of 0.035 mm. The Vivaldi antenna is optimised using Surrogate Assisted Differential Algorithm (SADEA) in ADE 1.0 using the recommended settings in [19]. The design exploration goal is to minimise the maximum reflection coefficient (S_{11}) in the operating band of 3 GHz to 9 GHz subject to the realized gain (G_R) not being less than 2 dB over the bandwidth as shown in equation (4).

The selected values of the design variables for the proposed antenna after the parametric study and design exploration are shown in Table 1.

Table 1: Selected values of the Vivaldi antenna design variables (all sizes in mm).

Variables	Values
L_s	57
W_s	40.6
F_l	31.5
F_w	1.5
S_W	0.5
θ	55
R	10

Minimize max |S11| over 3 GHz to 9 GHz (4)
Subject to: GR ≥ 2 dB

2.2 IMAGE CONSTRUCTION ALGORITHM

Image reconstruction algorithm can be either data-dependent or non-data dependent image reconstruction algorithm. The data dependent algorithms can reconstruct high-resolution images when the array steering vector corresponding to the signal of interest (SOI) is accurately known, which is difficult in realistic imaging scenarios. In contrast, data-independent beam formers are free from this prior information and have been continuously developed. A number of data-independent algorithms are proposed in recent years, including delay-multiply-and-sum (DMAS) modified weighted- delay-and-sum (MWDAS) and filtered delay-and-sum (FDAS). Compared with the classical DAS algorithm, improved performance of clutter rejection is offered by DMAS and MWDAS. FDAS shows its capability of detecting multiple scatters in dense breasts, where the presence of fibro-glandular tissue is considered. It is recognized that the increased heterogeneity of normal breasts introduced by glandular tissues constitutes a big challenge for tumour detection. There are two reasons for this: first, although there is a large contrast in dielectric and conductivity electrical properties between normal and cancerous breast tissues as shown in Figure 4 and 5 respectively, the difference between glandular and cancerous tissues is much less pronounced. Also the glandular tissue introduces a significant amount of attenuation and dispersion in backscattered signals, making it more difficult to detect any small tumours present.

2.3 IMAGING SYSTEM AND RESULTS

Antenna is main building block for any imaging system that acts as a transceiver for transmitting and receiving microwave signals. The scattering signal is collected with the aid of a vector network analyser (VNA). All these devices are electromechanical circuits and are controlled with a PC. The measurement set up is achieved with these devices to carry out the measurement. The arrangements of the UWB Vivaldi antenna arrays on the breast tissue is shown in Figure. 6. The main aim is to relate the change in the back scattering signal with the presence of tumour. The tumours present within the breast tissue are detected with the antenna arrays. In the experimental set up measurement of Figure 7 and 8 respectively model, the VNA parameters are set with a bandwidth of 10 Hz, the number of points is M = 203, and the spectrum range of 3 to 9 GHz are covered. The use of GPIB port is required to connect the PC to the VNA and the data are received for further processing and analysis. The complex frequency domain S- parameter data are captured with m ranging from m=1, 2…M, and n=1, 2…N, which represents the angular position of the rotation in the experimental set up. It can be seen that the 4 algorithms indicate the position of the tumour as shown in Figure 9 and 10 respectively.

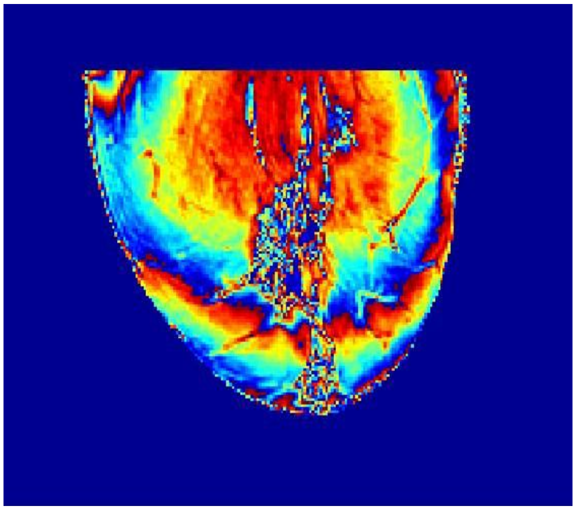


Figure 4: MRI dielectric.

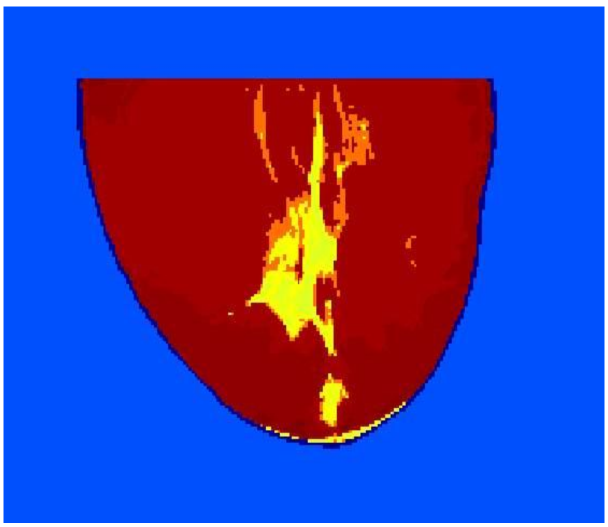


Figure 5: MRI conductivity.

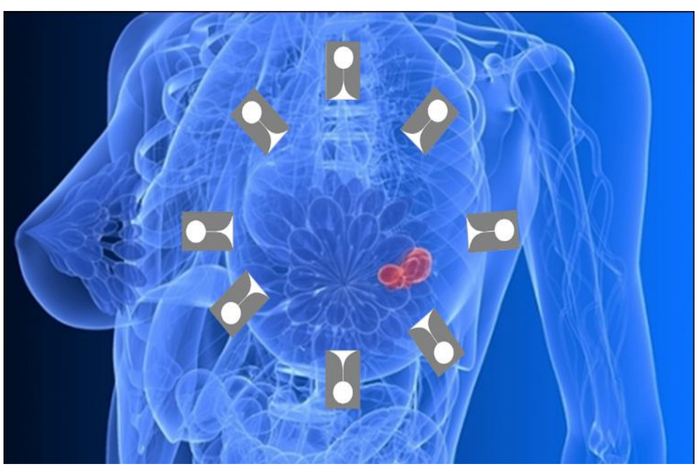


Figure 6: Arrangements of UWB antenna arrays on breast tissues.

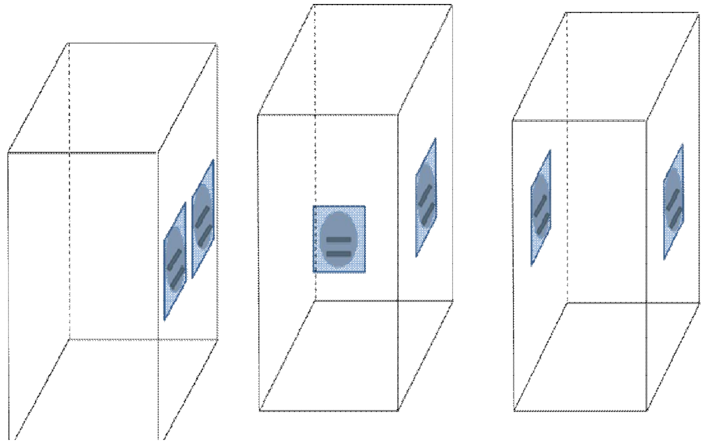


Figure 7: Arrangements of sensors.

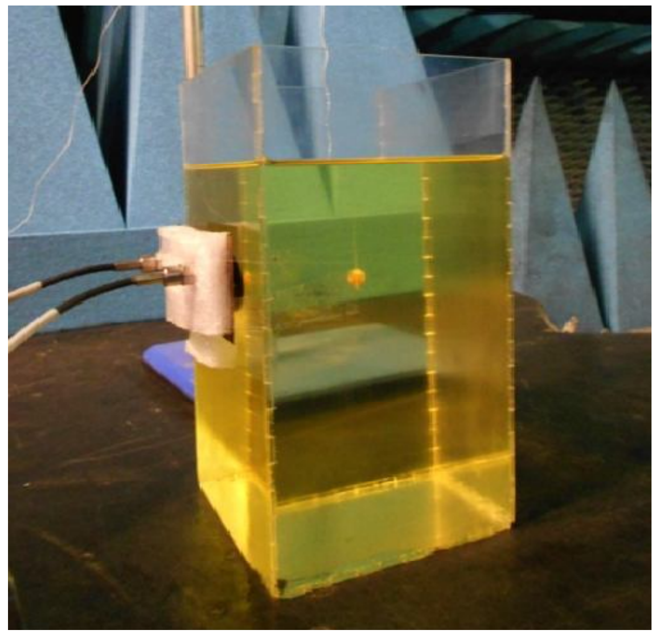
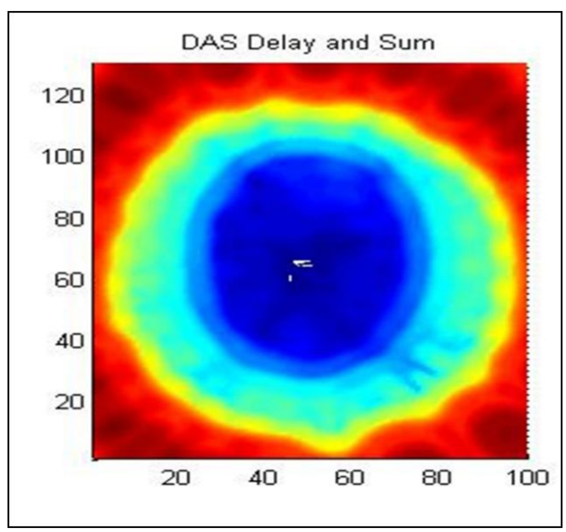
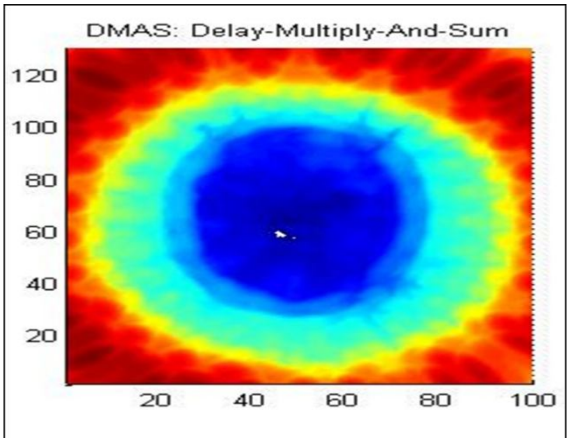


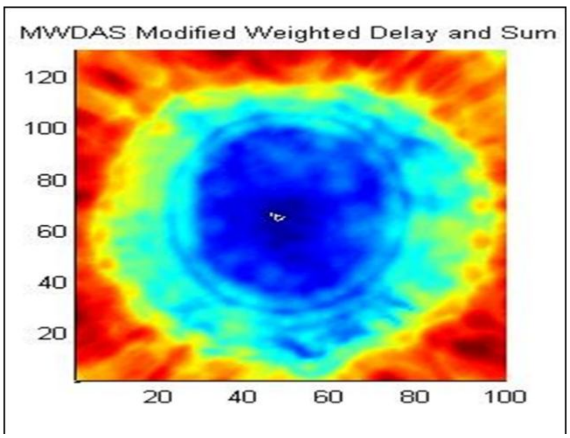
Figure: 8 Model for measurements.



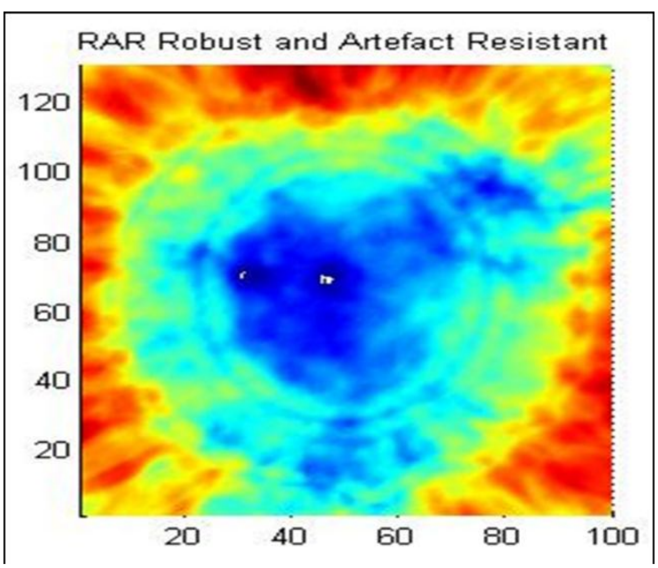
(a)



(b)

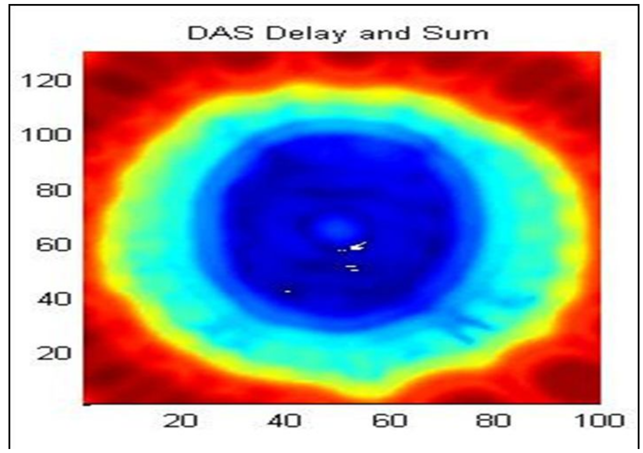


(c)

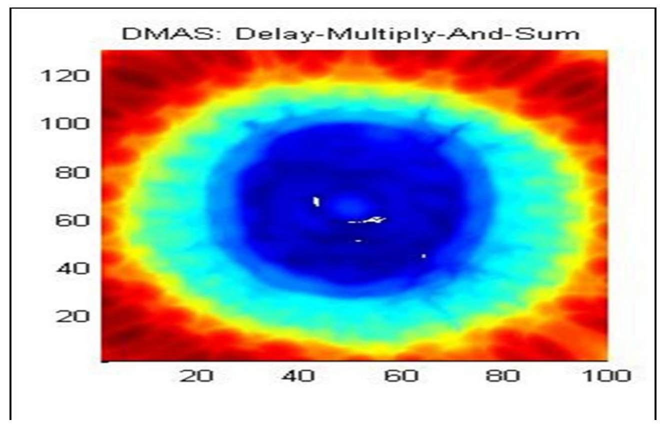


(d)

Figure 9: Illustrations of DAS, DMAS, MWDAS and RAR with cancer.



(a)



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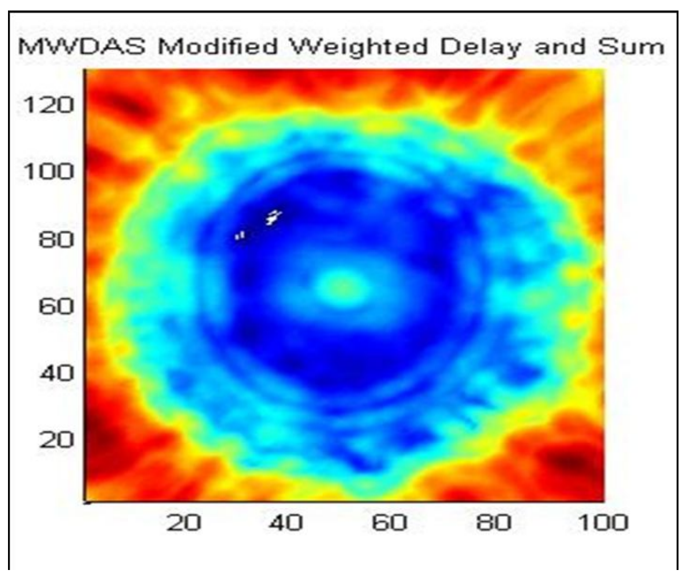

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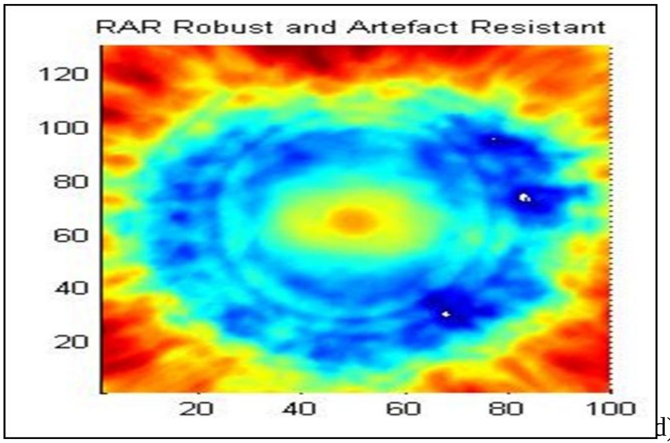

d)

Figure 10: Illustrations of DAS, DMAS, MWDAS and RAR without cancer.

3. CONCLUSION

The design of a taper slot Vivaldi antenna for microwave imaging applications was carried out. An experimental imaging investigation was made using the array of the design Vivaldi antenna, a breast phantom and simulated tumour targets, and a VNA. The measurements demonstrate the capability of the arrays in detecting tumours. The measurements and the imaging techniques presented in this paper can be used as the basis for investigating a 3D inversion algorithm approach, and further experimental investigation of the super resolution concepts.

REFERENCES

1 E. C. Fear, X. Li, S. C. Hagness, and M. A. Stuchly, **Confocal microwave imaging for breast cancer detection: localization of tumors in three dimensions**, *IEEE Transactions on Biomedical Engineering*, vol. 49, pp. 812-822, 2002. https://doi.org/10.1109/TBME.2002.800759

2 A. Mirza, C. H. See, I. Danjuma, R. Asif, R. abd-alhmeed, J. Noras, *et al.*, **An Active Microwave Sensor for Near Field Imaging,** *IEEE Sensors Journal*, vol. PP, pp. 1-1, 2017.

3 S. Adnan, R. A. Abd-Alhameed, H. I. Hraga, I. T. E. Elfergani, and M. B. Child, **Compact microstrip antenna design for microwave imaging,** in *2010 Loughborough Antennas & Propagation Conference*, 2010, pp. 389-392.

4 D. M. Parkin, F. Bray, J. Ferlay, and P. Pisani, **Estimating the world cancer burden: Globocan 2000**, *International journal of cancer*, vol. 94, pp. 153-156, 2001. https://doi.org/10.1002/ijc.1440

5 D. J. Slamon, B. Leyland-Jones, S. Shak, H. Fuchs, V. Paton, A. Bajamonde, *et al.*, **Use of chemotherapy plus a monoclonal antibody against HER2 for metastatic breast cancer that overexpresses** HER2, *New England Journal of Medicine*, vol. 344, pp. 783-792, 2001. https://doi.org/10.1056/NEJM200103153441101

6 N. K. Nikolova, **Microwave imaging for breast cancer,** *IEEE microwave magazine*, vol. 12, pp. 78-94, 2011. https://doi.org/10.1109/MMM.2011.942702

7 D. B. Kopans, **Early" breast cancer detection using techniques other than mammography**, *American journal of roentgenology*, vol. 143, pp. 465-468, 1984. https://doi.org/10.2214/ajr.143.3.465

8 P. M. Meaney, M. W. Fanning, L. Dun, S. P. Poplack, and K. D. Paulsen, **A clinical prototype for active microwave imaging of the breast,** *IEEE Transactions on Microwave Theory and Techniques*, vol. 48, pp. 1841-1853, 2000. https://doi.org/10.1109/22.883861

9 E. C. Fear, S. C. Hagness, P. M. Meaney, M. Okoniewski, and M. A. Stuchly, **Enhancing breast tumor detection with near-field imaging,** *IEEE Microwave Magazine*, vol. 3, pp. 48-56, 2002. https://doi.org/10.1109/6668.990683

10 R. A. Abd-Alhameed, P. S. Excell, J. A. Vaul, and M. A. Mangoud, **Hybrid treatment for electromagnetic field computation in multiple regions**, *Electronics Letters*, vol. 34, pp. 1925-1926, 1998. https://doi.org/10.1049/el:19981348

11 P. J. Gibson, **The Vivaldi Aerial, in *1979 9th European Microwave Conference*,** 1979, pp. 101-105.

12 L. Chen, C. Wang, H. Li, and S. Lan, **A miniaturized antipodal vivaldi antenna for microwave imaging**, in *Antennas and Propagation (ISAP), 2017 International Symposium on*, 2017, pp. 1-2.

13 J. Zhang, E. C. Fear, and R. H. Johnston, **Cross□Vivaldi antenna for breast tumor detection, *Microwave and Optical Technolog*** *y Letters*, vol. 51, pp. 275-280, 2009. https://doi.org/10.1002/mop.24037

14 J. Bourqui, M. Okoniewski, and E. C. Fear, **Balanced antipodal Vivaldi antenna for breast cancer detection**, 2007.

15 M. Abbak, M. Çayören, and I. Akduman, **Microwave breast phantom measurements with a cavity-backed Vivaldi antenna**, *IET Microwaves, Antennas & Propagation*, vol. 8, pp. 1127-1133, 2014.

16 C. Sarkar, **Some parametric studies on Vivaldi antenna,** *International Journal of u-and e-Service, Science and Technology*, vol. 7, pp. 323-328, 2014.

17 I. T. Nassar and T. M. Weller, **A novel method for improving antipodal Vivaldi antenna performance,** *IEEE Transactions on Antennas and Propagation*, vol. 63, pp. 3321-3324, 2015. https://doi.org/10.1109/TAP.2015.2429749

18 B. Wu, Y. Ji, and G. Fang, "Design and measurement of compact tapered slot antenna for UWB microwave imaging radar," in *Electronic Measurement & Instruments, 2009. ICEMI'09. 9th International Conference on*, 2009, pp. 2-226-2-229.

19 B. Liu, H. Aliakbarian, Z. Ma, G. A. Vandenbosch, G. Gielen, and P. Excell, A**n efficient method for antenna design optimization based on evolutionary computation and machine learning techniques**, *IEEE transactions on antennas and propagation*, vol. 62, pp. 7-18, 2014. https://doi.org/10.1109/TAP.2013.2283605