A Dielectric Filled Ultra-Wideband Antenna for Breast Cancer Detection

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I. INTRODUCTION

At present, X-ray mammography is the most prevalent screening process for breast cancer. It is effective in detecting breast cancer in early stages and therefore treatment is more effective. However, mammography has limitations, thus generating interest in alternative detection methods [1]. One method of interest is microwave breast cancer detection which exploits the contrasts in dielectric properties between healthy and malignant tissue. Tissue Sensing Adaptive Radar, (TSAR) imaging has been proposed for microwave breast cancer detection [2]. This paper presents an antenna and its feeding structure for TSAR.

The antenna design requirements are as follows:

- radiate an ultra-wideband signal to transmit short pulses.
- size on the order of a few centimeters to selectively illuminate and permit scanning.
- a half power near-field beamwidth of 2 cm in diameter to avoid smearing of the scatterers that occurs if the field of view of each antenna is too broad.
- a high fidelity necessary for resolution as this ensures the same time signature is transmitted to all points in the volume of interest.
- a good impedance match across the entire band. This ensures that most of the energy is transmitted.

The Slotline Bowtie Hybrid (SBH) [3], [4] is selected as the basic design. The SBH has an integrated ultra-wideband balun to allow it to easily connect via coaxial cable. The SBH is a hybrid of a slotline circuit board antenna and bowtie horn. A slotline antenna radiates when the slot width approaches 0.4 λ. However, it is difficult to maintain behavior over a broad band with simply a slot. The broad bandwidth match is achieved by the slot widening with a Vivaldi profile. The Vivaldi profile connects to a linear section then to a blended elliptical section. All the connections between the sections are continuous on their first derivative. The SBH achieves a flat main beam over the bandwidth by additionally employing triangular bowtie plates on the slot profile. The rolled edge at the bowtie aperture reduces edge diffraction. The introduction of an ambient dielectric in place of free space allows its size to be scaled down.

The SBH is known to provide, in the far-field, a flat main beam, low voltage standing-wave ratio (VSWR), carefully controlled half-power beamwidths (30°) and low sidelobes and backlobes (40-50 dB down) over an ultra-wide bandwidth of 2 to 18 GHz [4]. Its characteristics make it ideal to meet the objectives.

II. METHODS

The antenna and balun are immersed in a dielectric liquid of relative permittivity $\epsilon_r = 10.8$ to achieve a better match to the breast tissue. This dielectric value is chosen because it

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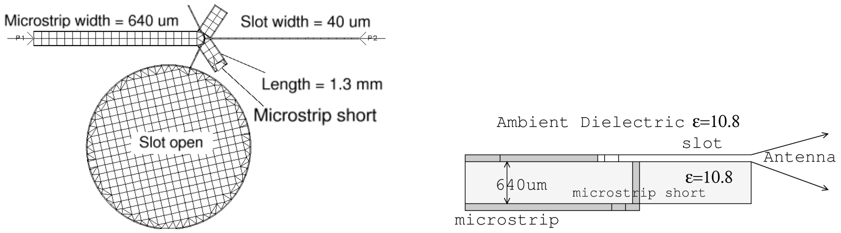
matches that of the printed circuit board and is similar in value to that of healthy breast tissue [1]. This ambient dielectric is incorporated in the design and simulation of both the balun and antenna.

A. Balun

The feeding structure consists of a balun to couple the microstrip to the slotline. Fig. 1 describes the balun. It is a six port junction [5], consisting of a microstrip ‘Y’ over top of a slotline in a ‘Y’ in the other direction. Both the microstrip and slotline width were calculated using empirical formulas to achieve 50 Ω. The branches of the ‘Y’ can be made arbitrarily small provided they are equal. This model used lengths of 1.3 mm. The size of the slot open determines the lowest operable frequency. An acceptable minimum frequency of 500 MHz is achieved with a slot open diameter of 2 cm. The simulations of the balun were performed with a moment method package, Momentum, from Agilent.



a) Top view b) Side view

Fig. 1. The geometry of the balun

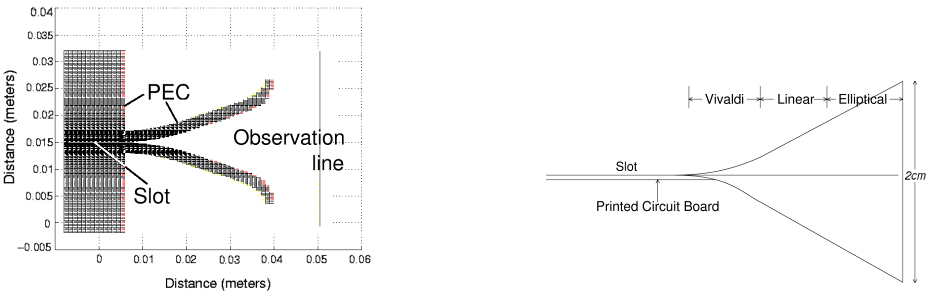
B. Slotline Bowtie Hybrid Antenna

The use of ambient dielectric allows for the geometry of the SBH antenna to be scaled down in size. The cross section of the aperture is 2 cm by 2 cm, and the antenna has an overall length of less than 4 cm. This is a practical size for the TSAR application.

All the major antenna parameters can be controlled by modifying independent elements of its geometry [4]. The E-plane half power beamwidth has nearly the same value as the slotline’s flare angle. Similarly the H-plane pattern depends on the triangular bowtie plate angle. The lowest operable frequency depends on the overall length of the antenna, which is largely composed of the linear and elliptical sections. VSWR is controlled practically entirely by the Vivaldi section.

An initial study of the antenna is done by choosing practical values for this application. Both the slotline’s flare angle and the bowtie plate angle were 30°. The Vivaldi section had a length of 1.5 cm, the linear section had a length of 1 cm. The elliptical section is based on an ellipse with a major axis of 1 cm and a minor axis of 4 mm. The overall length of the antenna is less than 4 cm.

The antenna is simulated in a three-dimensional finite difference time domain (FDTD) simulator, TOTEM. A graded mesh is used to model the fine Vivaldi section and slot connection. The cell size is 20 μm at the finest and 1 mm at the coarsest. Fig. 2a shows the feeding slotline composed of a pair of two-dimensional sheets, and the antenna composed with PECs. Fig. 2a also indicates the graded mesh. A 50 Ω electric field source in the slot



a) Top view from the FDTD simulations b) Side view

Fig. 2. The geometry of the SBH antenna

excited the structure. A reference structure of the slot only is used for VSWR calculations. The normalized radiated energy is defined as $\int_{-\infty}^{\infty} |E(t)|^2 dt$. This quantity is calculated along the observation line shown in fig. 2a, which is located 1 cm from the aperture and parallel to the ground plane.

The time domain parameter fidelity, F, is important in pulse sending antennas because it's a quantitative measure of how faithfully the output represents the input. For aperture antennas, the output, $r(t)$, is strongly related to the time derivative of the input, $f(t) = dy(t)/dt$. Mathematically it is the maximum of the cross-correlation of the two signals after they are normalized [6] [7].

$$F = \max_{\tau} \int_{-\infty}^{\infty} \hat{r}(t-\tau)\hat{f}(t)dt \tag{1}$$

An antenna is considered to have high fidelity if its fidelity value, F, is greater than 0.9. Fidelity is calculated from the simulation results in the next section.

III. RESULTS

A. Balun

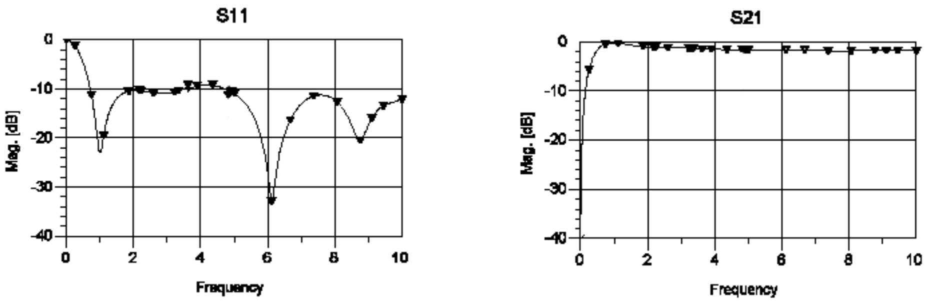


Fig. 3. S Parameters from the balun

Fig. 3 shows that S_{11} and S_{22} remain below -10 dB in the frequency range of 500 MHz to 10 GHz. Insertion loss is less than 2 dB over the same frequency range. Therefore, the balun is adequate for our purposes.

B. Slotline Bowtie Hybrid Antenna

Fig. 4 shows the 3 dB near-field beamwidth is 32° with respect to the end of the slotline. This corresponds to 2 cm, which meets our design requirements.

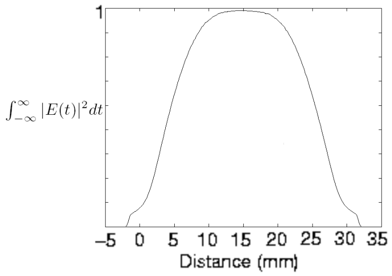


Fig. 4. Normalized radiated energy along a line 1 cm from the aperture

Fidelity is calculated from the simulations along the observation line shown in Fig. 2a. It is also observed that the ripple trailing the pulse has a magnitude 10 dB less than the transmitted pulse. The transmitted signal maintains a fidelity greater than 0.9 throughout the volume illuminated by the antenna, which is sufficient for our design.

IV. Conclusion and Future work

The balun's simulation results showed that an acceptable insertion loss of less than 2 dB can be achieved even when the balun is immersed in an ambient dielectric. The antenna simulations show that it has sufficient characteristics to meet the design objectives. The antenna will be constructed after the balun has been verified.

References

[1] E. C. Fear, S. C. Hagness, P. M. Meaney, M. Okoniewski, and M. A. Stuchly, "Near-field imaging for breast tumor detection," *IEEE Microwave Magazine*, vol. 3, pp. 48–56, Mar. 2002.

[2] E. C. Fear, J. Sill, and M. A. Stuchly, "Experimental feasibility study of confocal microwave imaging for breast tumour detection," *IEEE Transactions on Microwave Theory and Technique.*, Mar. 2003.

[3] L.-C. Chang, "Constant beamwidth ultrawide bandwidth linearly and dual polarized antenna design," Ph.D. dissertation, Ohio State Univeristy, 1996.

[4] A. K. Y. Lai, A. L. Sinopoli, and W. D. Burnside, "A novel antenna for ultra-wide-band applications," *IEEE Trans. Antennas Propagat.*, vol. 40, no. 7, pp. 755–760, July 1992.

[5] B. Schiek and J. Köhler, "An improved microstrip-to-microslot transistion," *IEEE Trans. Microwave Theory Tech.*, vol. 24, no. 23, pp. 231–233, 1976.

[6] O. E. Allen, D. A. Hill, and A. R. Ondrejka, "Time-domain antenna characterizations," *IEEE Trans. Electromagnetic Compatibility.*, vol. 35, no. 3, pp. 339–345, Aug. 1993.

[7] D. Lamensdorf and L. Susman, "Baseband-pulse-antenna techniques," *IEEE Antennas and Propagation Magazine*, vol. 36, no. 1, pp. 20–30, Feb. 1994.