Dual Layer UWB Dielectric Probe for Bistatic Breast Cancer Detection System

[#]Laxmikant Minz, Nikolai Simonov, Soon Ik Jeon, Jong Moon Lee
Radio Technology Research Department, ETRI
Daejeon, South Korea
Email: laxmikant.minz@gmail.com

1. Introduction

Breast cancer ranks second as a cause of cancer death in women. An estimated 39,970 breast cancer death were expected in 2011 even though rates for breast cancer have steadily decreased since 1990 owing to improved treatment, decreased incidence and most importantly progress in early detection [1]. Early stage detection is the important key for reducing breast cancer mortality. X-ray mammography is most practically used technique currently for breast cancer screening test, however the X-ray contrast between a tumour and the surrounding tissue is of the order of a few percent – as a result it suffers from a relatively high missed and false-detection rates; and involves uncomfortable compression of the breast [2][3]. X-rays are also ionizing and therefore not generally suited to frequent screening. Microwave imaging is now emerging as a viable alternative to X-ray and has attracted the interest of many researchers throughout the world. Microwave breast imaging is a low-cost, non-ionizing, three-dimensional (3-D) tomography technology that has the potential for improving breast cancer screening and diagnosis [4]-[6].

Antenna design for the microwave tomography has been a challenge for the researcher. The quality of a microwave tomography (MT) imaging is defined by two parameters: sensitivity to small tumours and the spatial resolution, the spatial resolution and sensitivity to small tumours can be improved if to apply examination in ultra wide frequency band including very high frequencies – up to 10 GHz [7]. Also the image reconstruction is more precise if a sensor aperture is smaller and the field distribution is narrower at the aperture to extract scattered field equal to field strength at the desired position in system rather integrated field strength, analogous to sampling in signal processing where an ideal sampler should produce samples equivalent to the instantaneous value of the continuous signal at the desired points, this ensure minimum integration effect or aperture effect. Narrow field distribution at the antenna aperture also plays important role for spatial resolution. Furthermore a compact small size of antenna with low mutual coupling is desirable to reduce the complexities of the physical array structure and to achieve a degree of co-formality with the body. In this paper a two layer dielectric antenna with cylindrical shape and tapering at both ends is proposed which meets requirements of being wideband, having small aperture, concentrated near field distribution, operating at higher frequencies, low mutual coupling and compact in size.

The two layer dielectric rod antenna [8] has been introduced by Chen.et.al. as near field probe antenna for ground penetrating radar application. It’s been adapted to apply in biomedical application for early stage breast cancer detection system developing by Bio EMF team in ETRI. The dielectric material of the two layer dielectric probe has been chosen such that the probe can operate from 2GHz to 6 GHz and can match with the breast material, so that coupling liquid, which is commonly used in MT breast cancer detection system for matching antennas with the human breast, can be eliminated. The bio medical application, advantage, description, simulation and measured result of the designed dual layer dielectric probe are discussed in the paper.

2. Description of the antenna structure

Various types of antennas have been proposed for bistatic breast cancer detection for example planar monopole, slot antenna, Microstrip patch antenna, antipodal Vivaldi antenna, and ridged pyramidal horn but they all doesn’t meet one or few requirements for example monopole and patch antenna has narrow bandwidth, horn antenna aperture size is large and apart from this a coupling liquid is required to avoid high reflection of the emitted signal from the breast tissue in all cases. Dielectric rod antenna is found to have very suitable prospects. Dielectric rod can be used to guide electromagnetic waves and unlike metallic waveguide the lowest mode of a dielectric rod waveguide (HE_{11} mode) does not have a cut-off frequency. Most of energy is guided inside the rod when the rod diameter became greater than the guided wavelength. This adaptive field distribution as a function of frequency makes a dielectric rod a good candidate for UWB antennas. By controlling the material and geometry of the end of the rod, different radiation, gain pattern, beam illumination and bandwidth can be achieved [9]. A dual layer dielectric rod antenna as introduced by Chen.et.al. [8], is shown in Fig. 1(a). The proposed antenna has two concentric cylindrical layer of dielectric, the inner rod is with higher permittivity, εr1 > εr2, to guide the higher frequency component and the lower frequency component is guided through outer rod. The antenna have been modified and optimized to meet the requirement of breast cancer detection, the designed probe is shown in Fig. 1(b). Our design considerably modified the Chen's antenna and using it as a probe.

Along with dimensional and material property modification a simplified balun has been applied for the feeding, thin plates with constant resistivity over the waveguide section is employed to reduce the reverberation and instead of radiation section a taper section only is utilized to have a concentrated near field distribution at the aperture of probe which is important for higher spatial resolution and precise image reconstruction. In figure 1(b), angle α is flare angle of the launcher section; εr1 and εr2 corresponds to the dielectric constant of inner and outer layer, respectively; D1 and D2 represent the diameter of the inner and outer concentric cylindrical rod, respectively; Ll, Lw and Lt indicate length of the launcher section, waveguide section and taper section, respectively. The launcher section of the probe is machined to form a pyramidal shape with flare angle, α, between two opposite surface. Flare angle, α, and the angle of the metallic launcher arms are adjusted and optimized to match the impedance of the balun for achieve better matching over wide band on the basis of [10], the return loss plot is shown in Fig. 2. The balun is simple tapered balun

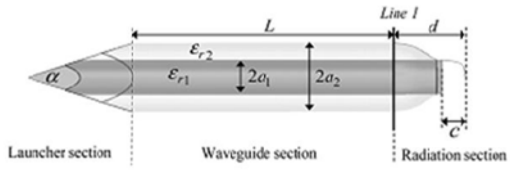

Figure 1(a) – Chen's model

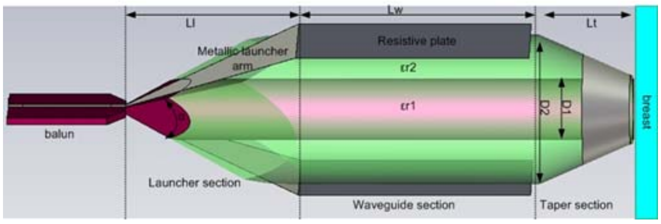

Figure 1(b) – New probe for breast cancer detection system

with dielectric permittivity, same as inner layer permittivity of the dielectric cylindrical rod of probe. The launcher section launches UWB TEM fields which in turn properly transform to HE_{11} mode in the waveguide section. The waveguide section is designed to guide and propagate electromagnetic energy between launcher and taper section. Thumb rule is that most EM energy is confined to a circular dielectric rod if the diameter is greater than the effective wavelength (in material) [8], mathematically:

$$\frac{\lambda_H}{D1\sqrt{\varepsilon r1}} < 1 \qquad 1(a)$$

$$\frac{\lambda_L}{D2\sqrt{\frac{D1\ \varepsilon r1 + (D2 - D1)\varepsilon r2}{D2}}} < 1 \qquad 1(b)$$

Where λ_H and $\lambda_L$refers to highest and lowest wavelength of operational frequency. To minimize leakage along the length of the rod diameters should be kept small and a combination of shielding and absorbing material can also be use to control them. The waveguide section materials permittivities are: εr1= 18, εr2 = 14. As per the above guideline most of the energy above 3.5 GHz is concentrated in the inner rod and the energy above the 1.5 GHz is guided by the outer rod. With the probe material permittivity of 14 and 18 the impedance mismatch between the breast tissue and the probe is low which makes use of coupling liquid not essential. The waveguide section structure is tapered to form taper section of the probe. Tapering is responsible for concentrated field at the aperture of the probe and also makes the aperture dimension smaller agreeing with the system requirement. A small metal layer like cap covers the taper section is introduced to minimize radiation from the ends of the probe and this also helps to keep the field distribution at the aperture narrower.

3. Measurement and simulation result

The characteristics of the new UWB dual layer dielectric probe were measured using vector network analyzer and simulated in commercial software. Figure 2 shows the simulated return loss plot of the designed probe. Probe is well matched over the frequency range of 2-6GHz.

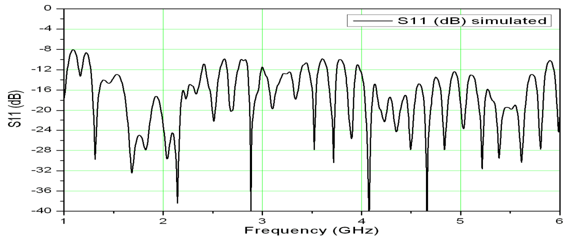

Figure 2 – Simulated return loss plot

The fabricated probe is shown in figure 3(a). Figure 3(b) is showing the measured return loss plot of the manufactured probe. S11 level is less than 8dB over the frequency band of 2-6 GHz. For a probe this level is also satisfactorily. Mismatch in the result would have occurred because of fabrication error. Bandwidth of the designed probe is agreeing with the requirement. Simulation and measurement of the probe is done by keeping probe connected to a cylindrical tank filled with material characteristics similar to human breast.


Figure 3(a) – Fabricated probe

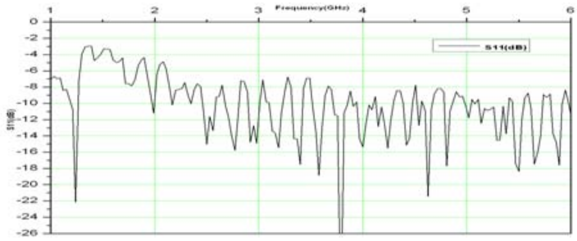

Figure 3(b) – Measured return loss plot

Concentrated field distribution at the aperture of the probe can be analyzed with the field distribution plot at the aperture of the probe shown in figure 4. The distribution is narrow and magnitude spread is ~ 6dB over the 20mm length of the aperture. The mutual coupling of the probe is measured by placing the two probe antenna close to each other and then finding the minimum distance between them. The measurement setup for mutual coupling is shown in figure 5(a) and measured S21 plot for this setup is shown in figure 5(b). This plot demonstrates extremely low mutual coupling between the probes at frequencies greater than 2GHz.

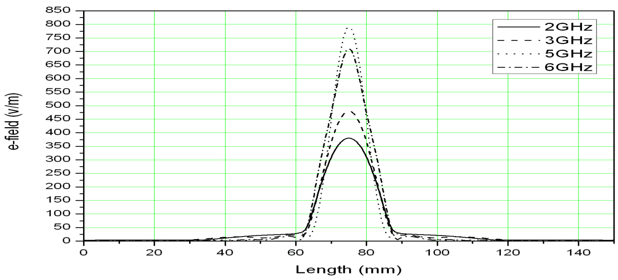

Figure 4 – e field distribution at the aperture of the probe

4. Conclusion

A dual layer UWB dielectric probe has been designed and fabricated for the early breast cancer detection system. The designed probe has wide operational bandwidth (2-6GHz) and low mutual coupling; S21 is below 20dB with separation of only 6cm between two probes. The probe will have higher sensitivity to small tumour and better spatial resolution because it operates at higher frequencies and has concentrated narrow field distribution at the aperture. The fabricated probe showed very high promising results and the probe does not need to be immersed in coupling liquid which can make it easy to maintain in a clinical environment and allow easy sanitation of the equipment after a patient is examined. With the same design configuration, this probe can be applied for even higher frequencies. The only drawback of the probe is its weight. A good amount of work is required in future to further reduce the weight and size of this probe so that system can be very compact and portable.

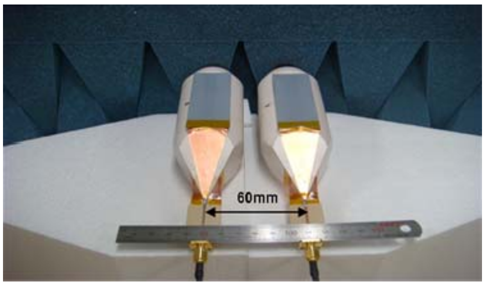

Figure 5(a) – Mutual coupling measurement

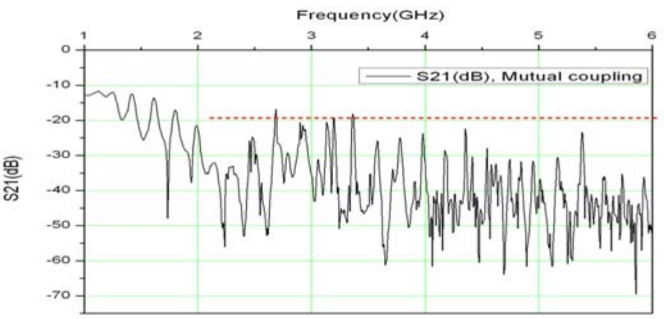

Figure 5(b) – Measured S21 plot with two dielectric probes separated by 60mm

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