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A Coaxial-to-CPW Transition for Microwave Breast Cancer Detection Antennas

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Abstract: *A transition from coaxial-to- coplanar waveguide (CPW) for microwave breast cancer detection antennas is presented and design rules based on analytical calculations and simulated one using CST Microwave Studio 2014 simulator are presented. The measured results show that an operating frequency range extends from 1GHz to 15GHz is obtained. This paper discuss mathematical method of coplanar waveguide (CPW) characteristic impedance calculation and also, developed a graphical charts for coplanar waveguide (CPW) design. Both measured and calculated results are compared and good agreement is obtained.*
Keywords: *Coplanar waveguide, Microwave, Breast cancer.*

I. Introduction

A transition from coaxial-to-coplanar waveguide (CPW) is required to extract accurate measurement result for microwave breast cancer detection antennas.This transition is important for avoiding the air gap that happen when we put the conventional antennas that used in breast cancer detection directly on the skin of the patient. An air gap is found between the connector that fed the antenna and the breast tissue, this air gap cause power losses due to transition from antenna to air and then to breast tissue. This power loss make the cancer detection process more difficult either for end-fire or broad side antenna.There are different types of transition published in the last years, one of the most commonly transition was transform from coplanar waveguide (CPW)-to-microstrip line. Zheng, Papapolymerou and Tentezeris [1] had discussed a transition from CPW-to-microstrip line without vias with afrequency range (10-40 GHz) and this transition used in variety of applications due to its compatibility with RF systems-on-a chip. Zhou and Melde [2] had made a modification and had discussed a transition from coplanar waveguide (CPW)-to-microstrip line with vias to achieve low frequency limit and achieved 36 GHz bandwidth. This transition had been employed on-wafer measurements if microstrip in cases when a low measurement frequency is required. Fang and Wang [3] had discussed a new type of transition from miniaturized coplanar waveguide (CPW) to rectangular waveguide using inductance compensated slot line which almost coveredthe whole X-band (8.2-12.4 GHz) in order to attain the broadband performance and reduce the transition size with 18%. White, Song and Yason [4] had discussed a transition from a coaxial cable-to-coplanar waveguide (CPW) and had achieved insertion loss less than 0.5 dB on printed on-glass antenna operate in the range 0.9 to 2.4 GHz. Mezzanotte and et al [5] had discussed a FD-TD analysis of coplanar waveguide (CPW) to slotline transitions accounting for air-bridge, shielding effects and coaxial connector as well as interaction between discontinuities. Microwave breast cancer detection had been interest for many years. Microwave breast cancer detection had the potential to detect small tumors because microwave imaging depends on the electrical property distributions in the body [9]. The breast was illuminated with an ultra-wide band pulse and the backscattered signals was recorded [10]. The use of ultra-wide band signal was to provide ultra-wideband reflections or microwave signatures and high resolution [9]. The ultra-wide band signal provide high resolution because the resolution was inversely proportional to bandwidth [10]. The goal was to generate an ultra-wide band frequency. Many researches in this field have discussed various types of antenna working in ultra-wide band range.R. Nilavalan and et al [11] had discussed a wideband microstrip patch antenna designed for breast cancer tumor detection to radiate frequencies in the range 4–9.5 GHz into human breast tissue. Maciej Klemm and et al [12] had discussed a radar-based breast cancer detection using ahemispherical antenna array consists of 16 UWB aperture-coupled stacked-patch antennas. Bourqui and et al [13] had discussed a balanced antipodal vivaldi antenna with dielectric director for microwave breast cancer detection system in the frequency range from 2.4 to 18 GHz.Matteo Bassi and et al [14] had discussed an integrated microwave imaging radar with planar antennas for breast cancer detectionoperates on the broad frequency range from 2 to 16 GHz. Mamadou Hady BAHand et al[15] had discussed a vivaldi antenna design for breast cancer imaging within the range of 3.1-10.6 GHz. Malyhe Jalilvandand et al [16] had discussed an ultra-widebandof a hemispherical array of 16 compact bowtie antennas operate in the frequency range of 1.2–7 GHz for breast cancer detection. Most of printed monopole antennas present an ultra-wide band but have a problem in matching to a 50 Ω coaxial line, [17]. This paper presents a novel coaxial-to-coplanar waveguide (CPW) that is suitable for breast cancer detection antennas. Ordinarily, the coaxial inner connector's pin is soldered on top of the middle conductor of a Coplanar while the connector's shield is soldered to the ground plane. In this way, the axes of the coaxial and coplanar are perpendicular, presenting a transformation from transverse electromagnetic (TEM) to quasi-TEM.The proposed transition cover the frequency band from 1 to 15 GHz. The measurements show good agreement with simulated results. Also, CPW characteristic impedance charts have been developed for different geometries of CPW and for different relative dielectric constant.This paper is organized as, coplanar waveguide (CPW) design and analysis is described in section II, the proposed structure design and analysis is presented in section III and section IV gives conclusions.

II. Coplanar Waveguide (CPW) Design And Analysis

Coplanar waveguide (CPW), [6] is used for transmission lines where all the conductors are in the same plane; precisely, on the top surface of the dielectric substrate. Coplanar waveguide (CPW) is composed of a median metallic strip separated by two narrow slits from a finite ground plane as shown in Fig.1.

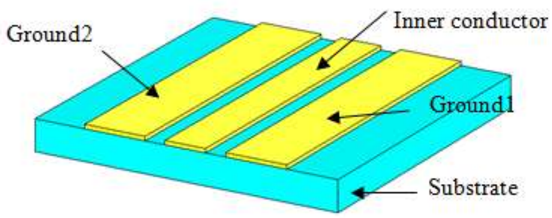


Fig.1. CPW with finite dielectric thickness and finite width ground plane

Coplanar lines advantages arise from the fact that amounting lumped elements is much easier than drilling holes to reach ground plane in other configurations. The performance of coplanar lines is comparable to and sometimes even better than microstrip line in terms of guide wavelength, dispersion, and losses,[6].coplanar waveguides are most promising because of their integration capability with electronic devices and fabrication compatibility with ultra-large scale integration processing (ULSI), [7]. Active elements such as MESFETs can easily be connected to coplanar lines because they are also coplanar in nature. So, coplanar lines are used commonly in monolithic microwave integrated circuits (MMICs), [6]. Borah and Battacharyya [8] use coplanar waveguides to determine the complex permittivity and loss tangent of nano magnetic composite materials over X-band. There is no low-frequency cutoff because of the quasi-TEM mode of propagation. However, the RF electric field between thecenter conducting strip and the ground electrodes tangential to the air dielectric boundary produces a discontinuity in displacement current density at the interface, giving rise to an axial, as well as transverse, component of RF magnetic field, Fig.2.

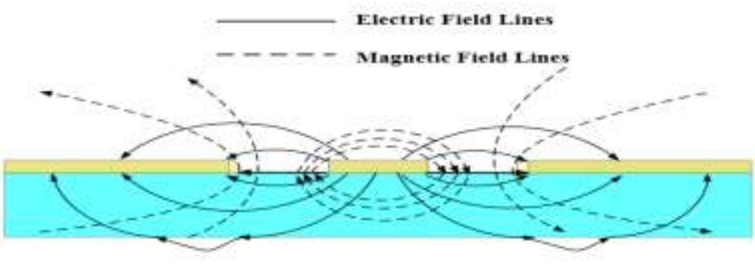


Fig.2. Electric and magnetic field distribution in CPW

There are various types of coplanar waveguides such as CPW with finite dielectric thickness, CPW with finite width ground planes, CPW with a cover shield, conductor backed CPW with a cover shield, conductor-backed CPW, multilayered CPW, asymmetric CPW and asymmetric CPW with finite dielectric thickness.For practical use, CPW with finite dielectric thickness and finite ground plane width is used.

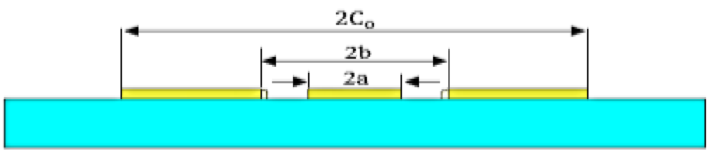


Fig.3. CPW geometry.

The characteristic impedance of the coplanar waveguide (CPW) transmission line is determined by a, band C_o as shown in Fig.3. The relative dielectric constant ϵ_r , the effective dielectric constant ϵ_{reff}, phase velocityυ_{ph}, and characteristic impedanceZ_{ocp}, of a transmission line are given as, [5]

$$\epsilon_{reff} = 1 + \frac{\epsilon_r - 1}{2} \frac{K(k_4)}{K`(k_4)} \frac{K`(k_3)}{K(k_3)} \tag{1}$$

$$\upsilon_{ph} = \frac{c}{\sqrt{\epsilon_{reff}}} \tag{2}$$

$$Z_{ocp} = \frac{30\pi}{\sqrt{\epsilon_{reff}}} \frac{K`(k_3)}{K(k_3)} \tag{3}$$

$$k_3 = \frac{a}{b} \sqrt{\frac{1 - b^2/c_o^2}{1 - a^2/c_o^2}} \tag{4}$$

$$k_3^` = \sqrt{1 - k_3^2} \tag{5}$$

$$k_4 = \frac{\sinh(\pi\, a/2h)}{\sinh(\pi\, b/2h)} \sqrt{\frac{1 - \sinh^2(\pi\, b/2h)/\sinh^2(\pi\, c_o/2h)}{1 - \sinh^2(\pi\, a/2h)/\sinh^2(\pi\, c_o/2h)}} \tag{6}$$

$$k_4^` = \sqrt{1 - k_4^2} \tag{7}$$

$$\text{for} \quad 0.707 \leq k_3 \leq 1$$

$$\frac{K(k_3)}{K`(k_3)} = \frac{1}{\pi} \ln\{2(1 + \sqrt{k_3})/(1 - \sqrt{k_3})\} \tag{8}$$

$$\frac{K(k_4)}{K`(k_4)} = \frac{1}{\pi} \ln\{2(1 + \sqrt{k_4})/(1 - \sqrt{k_4})\} \tag{9}$$

$$\text{for} \quad 0 \leq k \leq 0.707$$

$$\frac{K(k)}{K`(k)} = \frac{\pi}{\ln\{2(1 + \sqrt{k`})/(1 - \sqrt{k`})\}} \tag{10}$$

Where,**C**is the speed of light in free space and **K** is the complete elliptical integral of the first kind, and **K`(k) = K(k`).**A different values of a, b and $C_o$are considered thencalculate Z_{ocp} iscalculated.The process is repeated till the needed value of Z_{ocp} is obtained.Figure 4, shows the flow chart of the CPW impedance calculation tohave the suitable value of Z_{ocp} that we need in our design

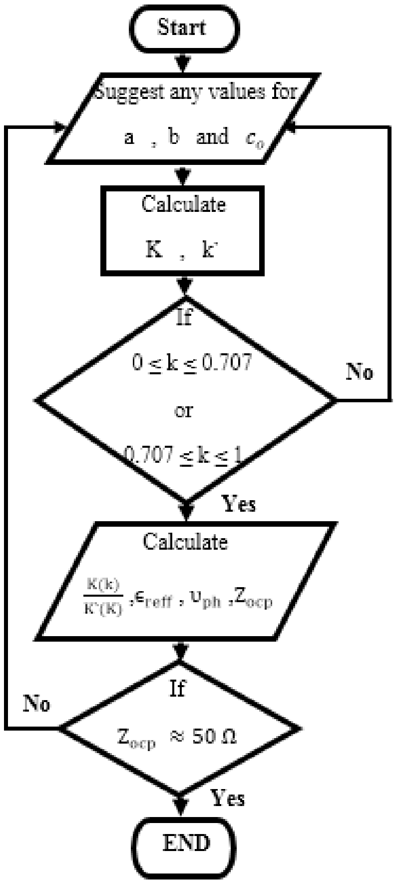
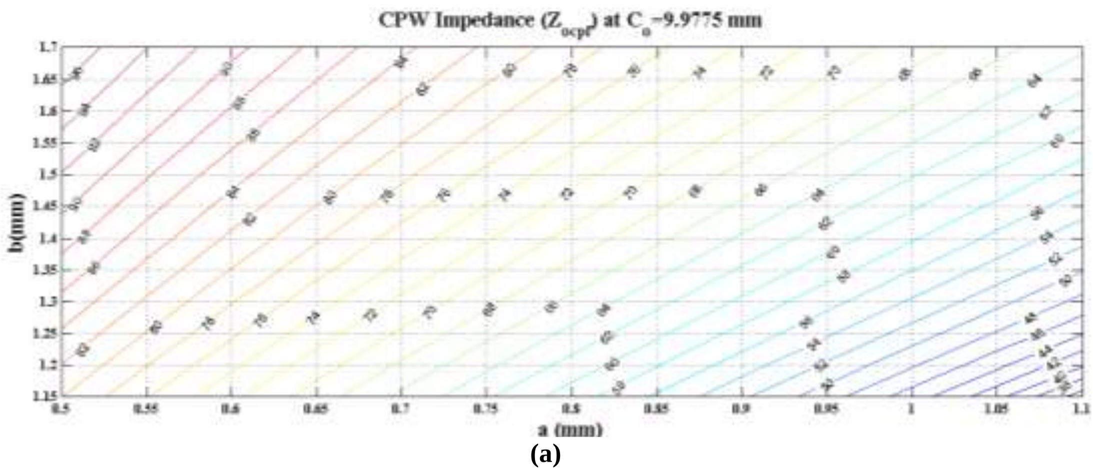
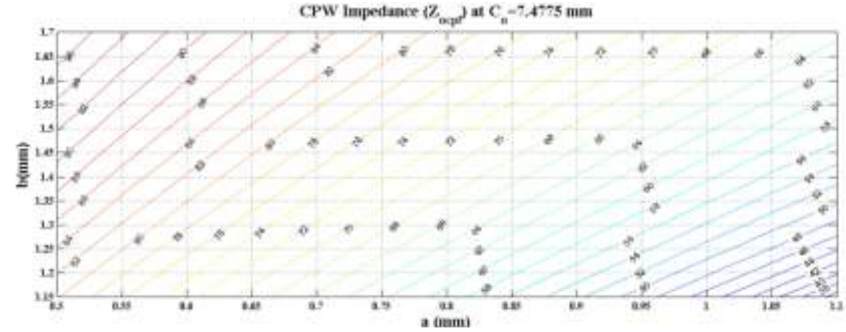


Fig. 4. The flow chart of the CPW impedance calculation

A MATLAB code has been built to calculate the characteristic impedance of CPW in terms of its geometry. The proposed charts give a very fast way in the CPW design process. Figure 5.a shows that the dimensions of a 50Ω CPW of a=1.0115 mm, b=1.2775 mm and C_o=9.9775 mm are obtained. One can notice that any other dimensions could be chosen for the 50 Ω CPW. Also, one can notice that effect of the ground plane size on the impedance value, for example for the 50 Ω CPW with dimension a=1 mm the impedance value is achieved with b=1.22 mm for C_o=9.9775 mm. Also same impedance could be obtained for b=1.27 mm and C_o=7.4775 mm. Also for b=1.23 mm and C_o=4.977531 mm same impedance could be obtained, Figs.5 b and c. So, the developed charts add another degree of freedom to the designer to obtain same impedance but with different geometries according to the antenna or circuit design situation.



(a)



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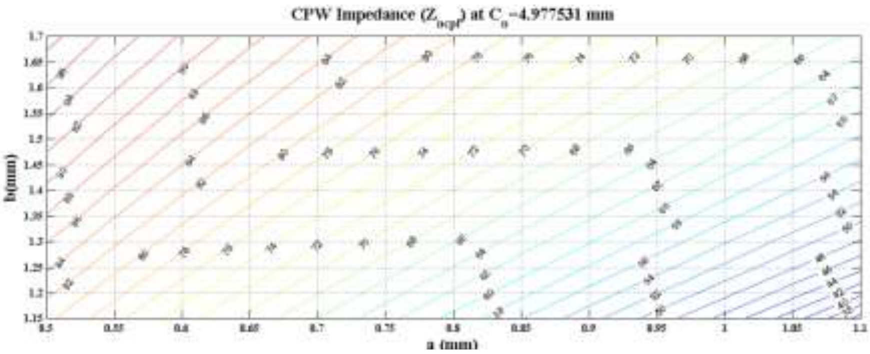


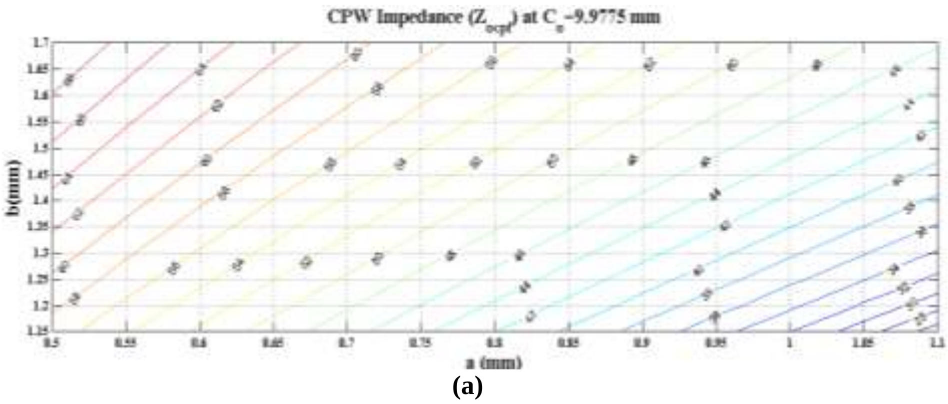
(c)

Fig.5. CPW impedance (Z_{ocpf}) charts (a) C_o=9.9775 mm, (b) C_o=7.4.775 mm, (c) C_o=4.977531 mm and ϵ_r=4.6.

The previous charts can calculate the dimension of the coplanar waveguide at a specific impedance value. The code is repeated at different substrate materials with different relative dielectric constant. Figure 6, Fig.7 and Fig.8 show Z_{ocpf} charts for different values of C_o. Table, 1 show that 50 Ω CPW different dimensions at a = 0.95 mm.

Table 1. 50 Ω CPW dimensions at a = 0.95 mm.

b (mm)	c_o (mm)	ϵ_r
1.171	9.9775	4.6
1.169	7.4775	4.6
1.165	4.977531	4.6
1.645	9.9775	10.2
1.64	7.4775	10.2
1.622	4.977531	10.2
1.295	9.9775	6.2
1.293	7.4775	6.2
1.286	4.977531	6.2
1.019	9.9775	2.2
1.018	7.4775	2.2
1.017	4.977531	2.2



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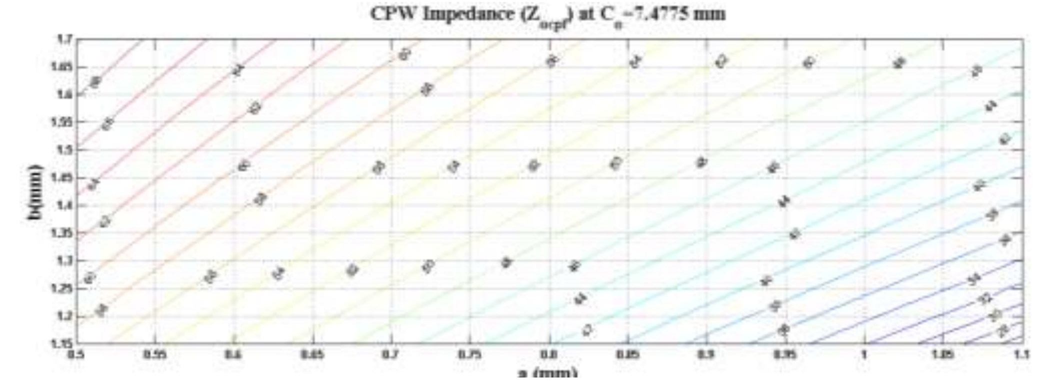

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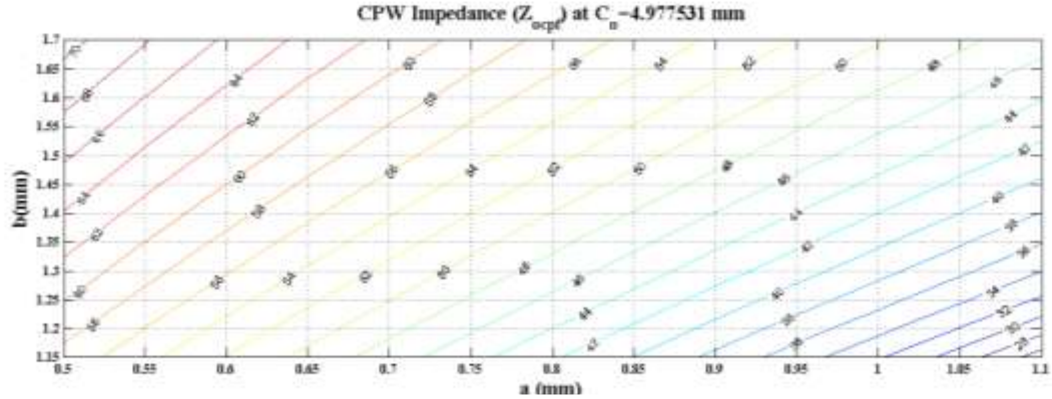
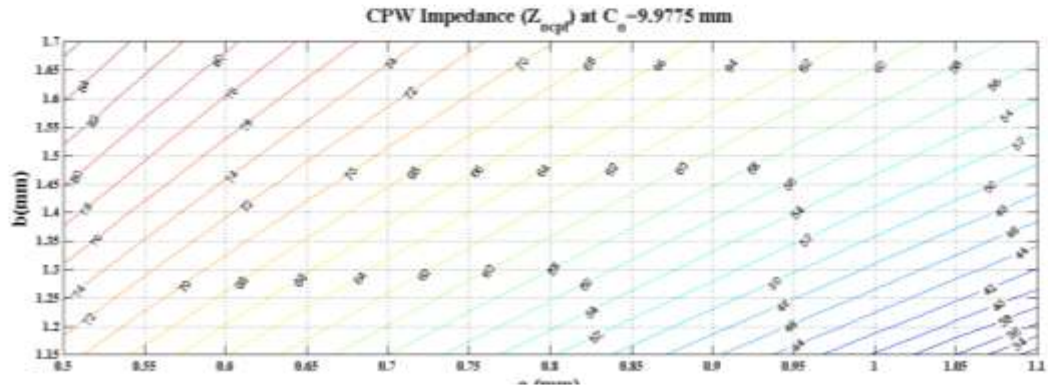


(c)

Fig.6. CPW impedance (Z_{ocpf}) charts (a) C_o=9.9775 mm, (b) C_o=7.4775 mm, (c) C_o=4.977531 mm and ϵ_r=10.2.



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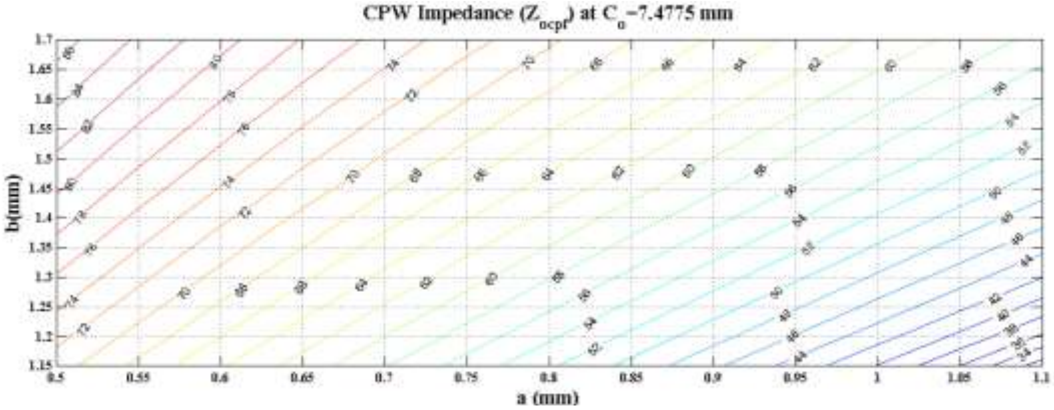

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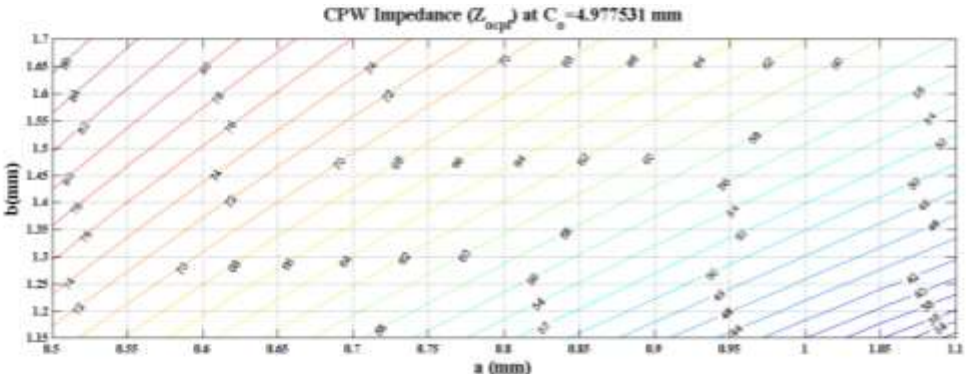
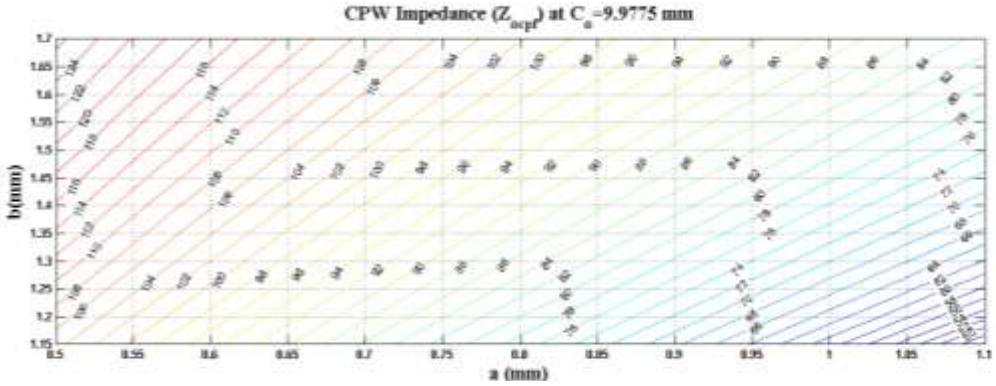


(c)

Fig.7. CPW impedance (Z_{ocpf}) charts (a) C_o=9.9775 mm, (b) C_o=7.4.775 mm, (c) C_o=4.977531 mm and ϵ_r=6.2.



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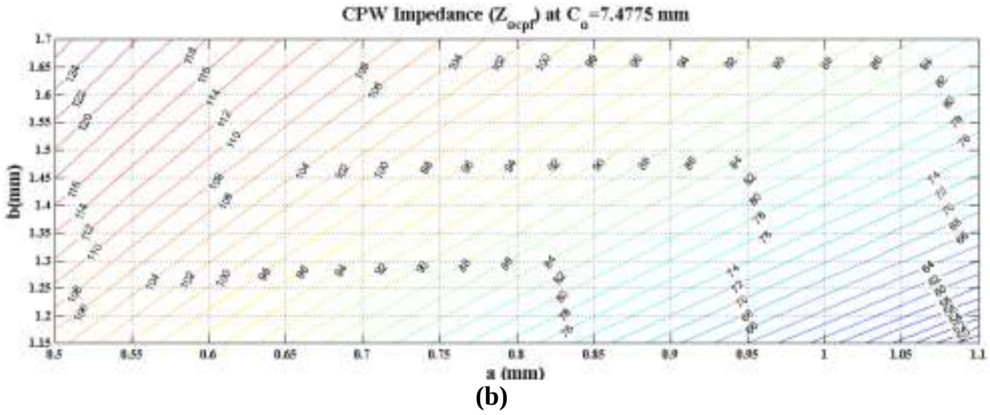

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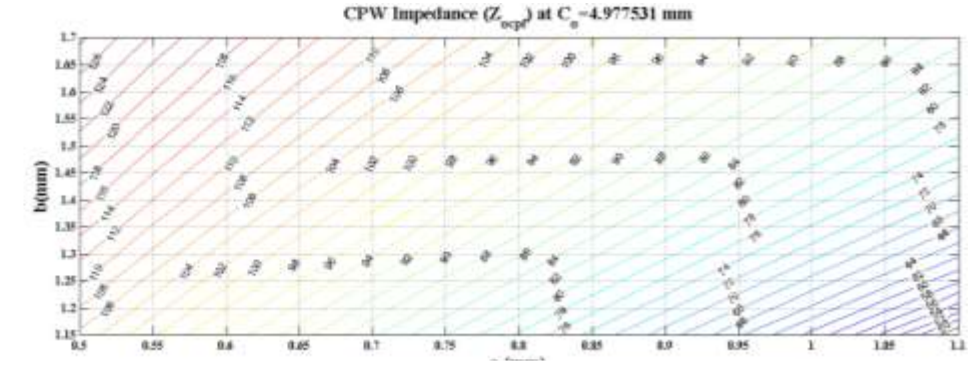
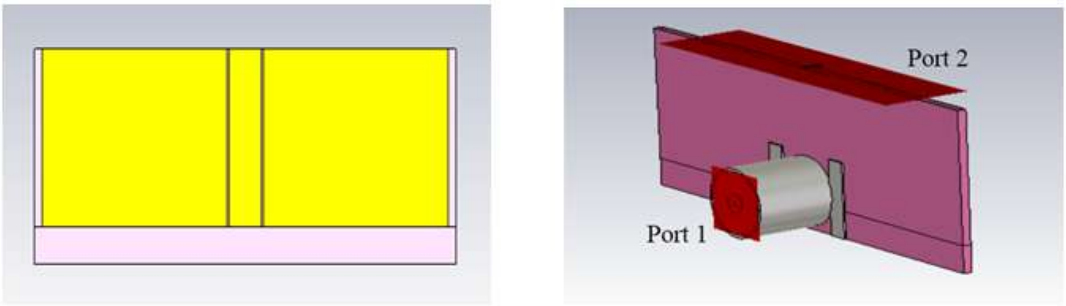


(c)

Fig.8. CPW impedance (Z_{ocpf}) charts (a) C_o=9.9775 mm, (b) C_o=7.4.775 mm, (c) C_o=4.977531 mm and ϵ_r=2.2.

III. CPW Proposed Structure, Design And Analysis

To evaluate this approach, a FR4 substrate with relative permittivity ϵ_r=4.6, dielectric thickness of 1.53 mm and loss tangent of 0.02 is used.A conventional CPW with a=1.0115 mm, b=1.2775 mm and C_0=9.9775 mm is firstly, considered. A coaxial connector with impedance 50Ω is connected in the back of the substrate,the coaxial inner connector is connected with the median strip of CPW and the coaxial ground with the outer strips of the CPW, Fig.10.



(a) (b)

Fig.9. (a) Conventional CPW front side (b) ConventionalCPW backside

The transformation from coaxial line to CPW is simulated using CST Microwave Studio 2014 software, the S-parameters are shown in Fig.11.

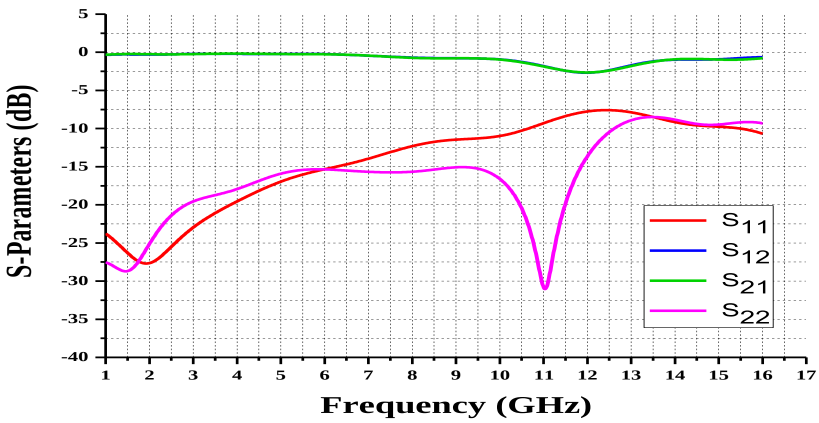


Fig.10. Simulated S-parameters of conventional CPW.

Figure 11 shows that the simulated S-parameters where the operating frequency band extends from 1 GHz to 10 GHz. A slits has been added to the proposed transition for matching purpose [18]. An improvement of about 10 dB has been obtained. The proposed structure parameter and the parameter values are shown in Fig.12 and Table 2.

Table 2. CPW parameter values

A	2.023mm
B	0.266 mm
C	8.7 mm
D	6.2 mm
E	2.7 mm
F	8.7 mm
G	3 mm
I	3.2 mm
J	1.5 mm
K	2.5 mm
L	5 mm
M	5.5 mm

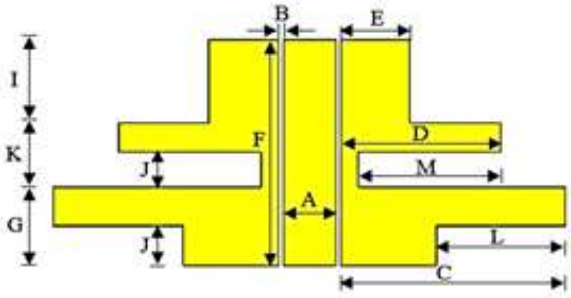
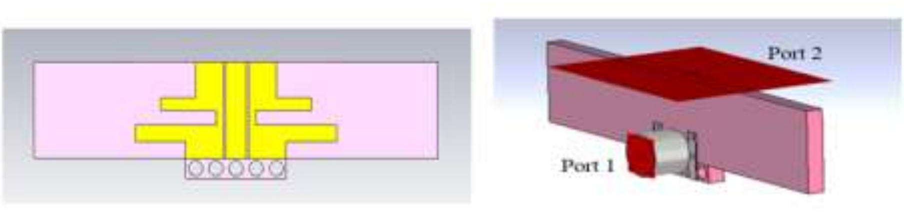


Fig.11. Proposed structure of CPW



(a) (b)

Fig.12. Simulated proposed CPW (a) front side (b) backside.

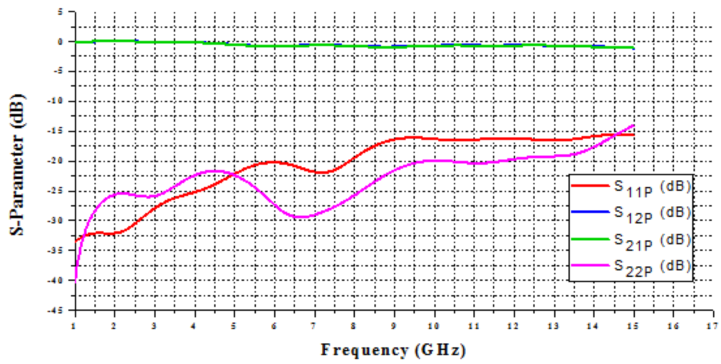


Fig.13. Simulated S-parameter of the proposed transition.

Figure 14 shows that the simulated proposed transition S_{21P} and S_{12P} are almost the same. S_{11P} and S_{22P} are different this due to different feeding schemes one is parallel to the CPW axe and the other is perpendicular to it. Figure 15 show the simulated S-parameters of the conventional CPW and the proposed one. It can be observed, that the return lossS_{11P} of the proposed transition isbetter by 10 dB than the conventional one $S_{11C}$and its band extends from 1 GHz to 15 GHz.

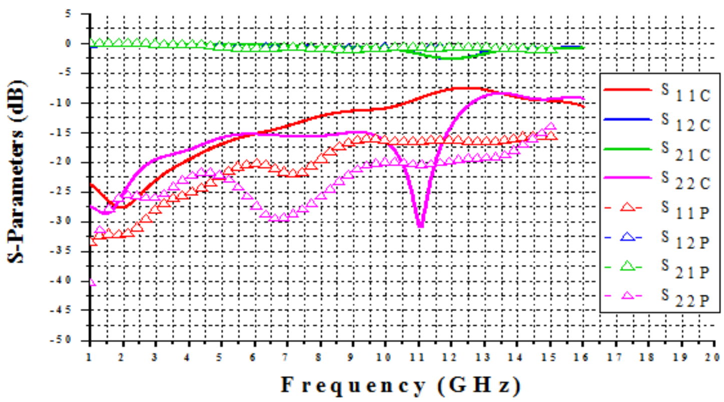
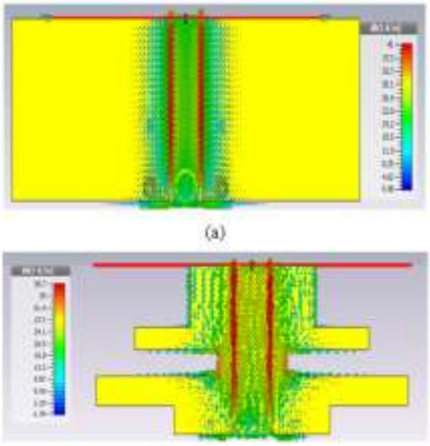


Fig.14. The simulated S-parameters of the conventional and the proposed transition.

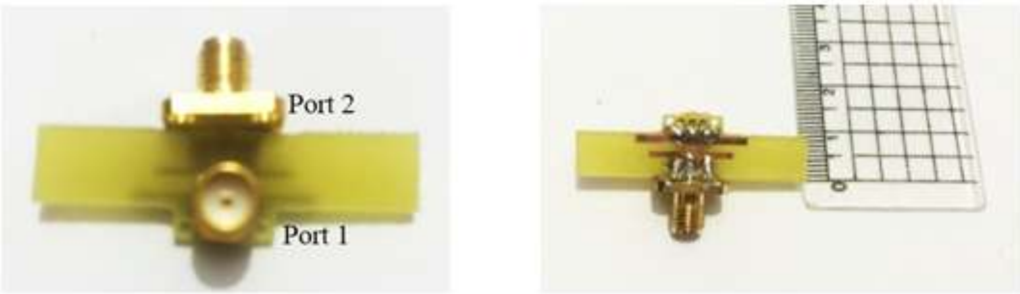
Figures 16 a and b show the current distributions of the conventional and the proposed transition.



(a) (b)

Fig.15. (a) Current distribution on conventional (b) Current distribution on proposed transition.

Figure 17 shows the fabricated proposed Coaxial-to-CPW transition from front side and from backside. Figure 18 shows the measurement process of the Coaxial-to-CPW transition using Vector Network Analyzer (VNA).



(a) (b)

Fig.16. Fabricated Coaxial-to-CPW transition (a) front side (b) backside.

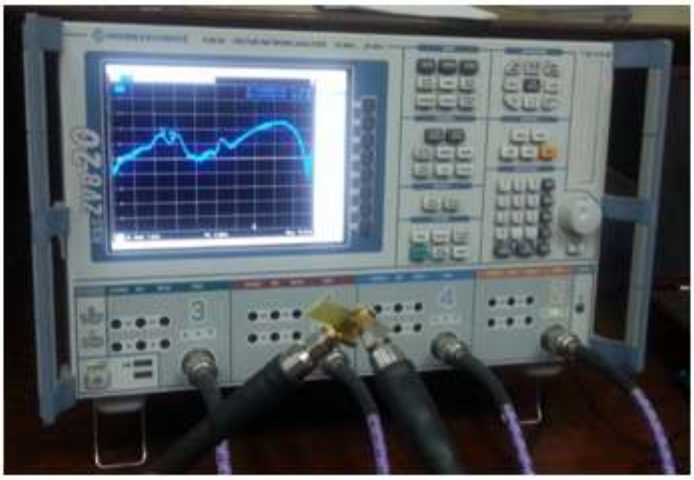


Fig.17. Coaxial-to-CPW transition measurement setup.

Figure 19 shows the measured and simulated return loss and insertion loss of the proposed Coaxial-to-CPW transition. It can be observed, the bandwidth is extended from 1 to 15 GHz which agree well with the simulated results and that's a good result to have a successful transition from Coaxial cable-to-Coplanar waveguide (CPW).

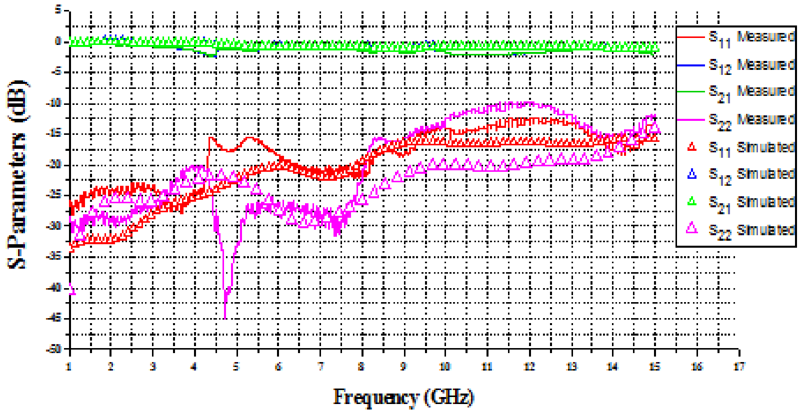


Fig.18. Measured and Simulated Return loss and Insertion loss of Coaxial-to-CPW transition

IV. Conclusion

A transition from coaxial-to-coplanar waveguide (CPW) for microwave breast cancer detection antennas was presented and design rules based on analytical calculations and simulated one using CST Microwave Studio 2014 simulator were presented. A design charts which add a degree of freedom to the CPW was also proposed. The measured results show that an operating frequency range extends from 1 GHz to 15GHz compared with the conventional CPW which extends from 1 GHz to 10 GHz was obtained. Also, an enhancement of about 10 dB was obtained all over the frequency band. The proposed transition presents a good start to any UWB antenna using a CPW as a feeding scheme.

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