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ANALYSIS OF ENHANCED COUPLING PERIPHERAL TYPE RING RESONATOR SENSOR FOR LIQUID

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ABSTRACT

This paper presents an enhanced coupling peripheral type ring resonator which is study of coupling efficiency at feed lines of the sensor and between an empty quartz capillary. The proposed 2.4 GHz ring-resonator demonstrates significant change in resonance frequency and the insertion loss due to the different coupling gaps. Apart from that, a comparison among developed simulation models is performed in order to determine the effect of gap coupling dimensions.

Keywords: microwave resonant, sensor, materials characterization, resonators.

INTRODUCTION

Microwave resonators enable precise, non-invasive and fast compositional analysis of any phases of materials for a variety of industrial, analytical and quality control applications (A. Masood, 2008). A microstrip ring resonator consists of a closed loop of microstrip line. The ring resonator alone naturally acts as a band pass filter. Resonance occurs at frequencies for which the circumference of the ring is equal to a whole number 'n' of guided wavelengths on the curved microstrip transmission line. For high sensitivity, the sample under test is usually placed in the vicinity of the gap and the Q-factor of SRR sensor is very low if the sample has a high dielectric loss tangent (Nora, M, 2014).

It is well known that ring resonators have low radiation loss, high Q value and two orthogonal modes (dual mode) (D. Preetha and T. Jayanthy, 2014). The dual-mode characteristic of the resonator is obtained by introducing perturbation along the ring such as notches or short stubs on the ring or by asymmetrical access (M.K.M Salleh *et al.*, 2008). Therefore, the design of ring resonator involves the adjustment of the perturbation along the ring and/or the adjustment of the coupling gaps. However, the lack of computer-aided design models for the gap discontinuity has led to tedious calculations at the early design stage of such a resonator; hence it's hard to make analysis on the structure dimension.

The enhanced coupled line are used to feed the ring. With such topology, the dual resonance can be obtained, whereas the electric characteristics of the resonator can simply be measured by varying the line impedance of the ring. In this paper, an enhanced coupling type resonator is presented where the coupling-gaps and stub-gaps effect were analyze to gain improvement on the sensitivity and an accuracy of the structure.It is well known that the effective permittivity of a microstrip line has strong dependency on the permittivity of a medium above its surface (M.T. Jilani *et al.*, 2014). Whereas, small permittivity variations in the above medium can be easily determined by its effective permittivity through this technique. By adding this coupling method, insertion loss is reduced but gap-capacitance is increased, substantially.

It has been reported that, the previous research workhas proved, Microstrip ring-resonator can be used for liquid characterization by using various type of coupling techniques. However, to detect a small volume of sample with high sensitivity required specific characterization of structure. Thus, the main objective of this study is to analyze the best effect on the coupling-gaps by using enhance-coupled method; so that the characterization of the liquid samples will be more reliable and accurate.

ANALYSIS OF COUPLING RING RESONATOR

There are several type of coupling in microstrip ring-resonator design that has been research the effectiveness and performance due to application approach. Each type of coupling has their pros and cons. Based on different coupling peripheries, the coupling schemes can be classified into several types which are loose coupling, enhanced coupling, annular coupling, direct coupling and side coupling (K. Chang, 1996). However, there are other name for modification design of coupling such as quasi-linear coupling which is also been known as enhanced coupling periphery (M.T. Jilani *et al.*, 2014). Coupling coefficient, g can be define as;

$$g = \frac{Q_o}{Q_e}$$

which can be applied to both series (g = Zo/R) and parallel (g = R/Zo) resonant circuits, when attached to

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a transmission line of characteristic impedance Zo. The coefficient can be classified into three cases:

g< 1: The resonator is undercoupled to the feedline.
g = 1: The resonator is critically coupled to the feedline.
g> 1: The resonator is overcoupled to the feedline.

Commonly used resonators for Microstrip circuits are open-end resonators, stub resonators, dielectric resonators, and ring resonators. The boundary conditions force the circuits to have resonances at certain frequencies. The voltage wave is maximum at the open edges. Therefore, the resonances occur for the ring circuit, resonances occur when

$$2\pi r = n\lambda_g n = 1, 2, 3... \quad (1)$$

One can find the resonant frequencies by using the relation (K. Chang, 1996). Where n is the number of mode of the design model.

$$\lambda_g = \frac{1}{\sqrt{\varepsilon_{eff}}} . \frac{c}{f} \quad (2)$$

The value of guided wavelength, λ_g can be calculate by using equation (2) and this is related to the gap of coupling range. If the gap is reduced the gap capacitance will be increased hence coupling will be tight. This increase in gap-capacitance results in the deviation of a resonator's inherent frequency to lower frequency, which is known as its "pushing effect". Although it lowers the insertion-loss but the effect on resonance frequency is more significant. With symmetric feeding and without any discontinuity in the structure, themaximum field occurs at these gaps. Since the coupling region has maximum field point, hence, it will be more sensitive to overlay permittivity variations (M.T. Jilani *et al*., 2014).

MATERIALS AND METHODS

Designing and simulation

A dual-port Microstrip ring-resonator with a resonant frequency of 2.4 GHz is designed on CST simulation software. The dimension of the structure is calculate based on following relation (D.M Pozar 2012)

Width of ring-resonator

$$\frac{w}{d} = \frac{8e^A}{e^{2A}-2} \quad (3)$$

$$\text{Since } A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}(0.23 + \frac{0.11}{\varepsilon_r}) \quad (4)$$

Effective dielectric constant

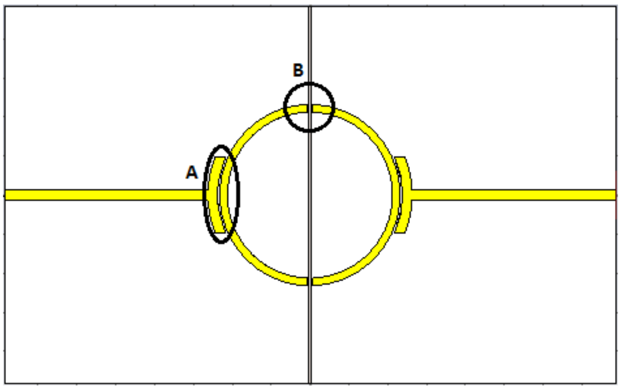
$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} . \frac{1}{\sqrt{1+12\left(\frac{d}{w}\right)}} \quad (5)$$

Length of Feed line

$$\ell = \frac{270\left(\frac{\pi}{180}\right)}{\sqrt{\varepsilon_{eff}}k_0} \text{Since} k_0 = \frac{2\pi f}{c} \quad (6)$$

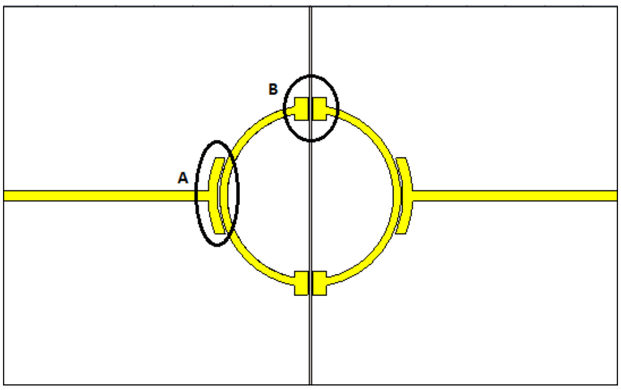
A range of coupling-gap from 0.55 mm to 1.63 mm has been considered in order to study its impact on resonant frequency. Simulation performed without sample over 0-6 GHz range, while corresponding resonant frequency for each coupling gap has been recorded. Rogers RT5880 with thickness 0.787 mm is constructed on a dielectric of a relative permittivity 2.2 and loss tangent 0.0009. The thickness of the copper is 0.0175 mm to ensure the highest possible Q-factor. Quartz capillary tube are used. The inner diameter of the quartz capillary is Qi = 0.3 mm and outer diameter Qo = 0.4 mm. There are two gaps under study that we focusing as shown in Figure-1.

A. Without stub



(a)

B. With stub



(b)

Figure-1. Enhanced coupling peripheral ring resonator. (a) Without stub at the middle. (b) With stub at the middle.

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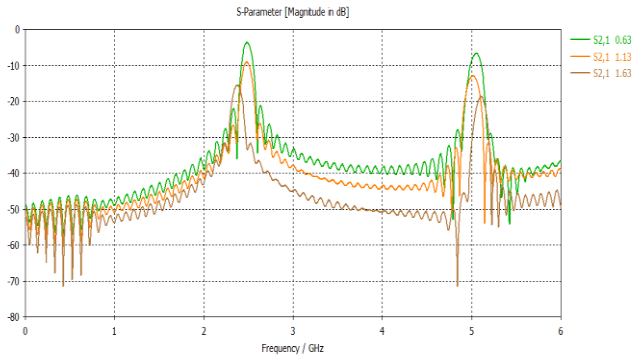
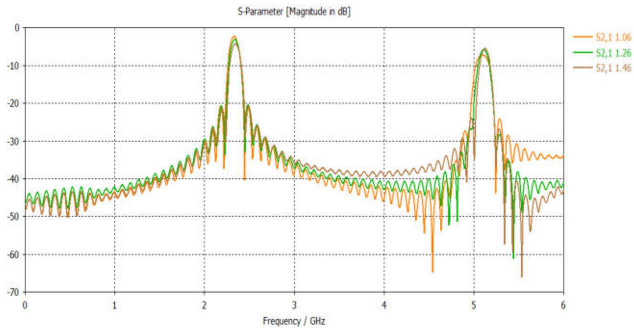
RESULTS AND DISCUSSIONS

Simulation result for the impact of coupling gaps on resonant frequency is presented in Figures 2 and 4. Coupling gaps range from 0.55 mm to 1.63 mm, are used to increase the performance of Microstrip ring-resonator. From simulation results, it can be observed that, small gap at point A causes more shift to high frequency and the insertion loss more better as it approach to zero value as shown in Figure-2. This is because of the small gap will increased gap-capacitance which perturbs the ring's field and causes, "pushing effect" (M.T. Jilani, 2014). As we can see at point B, the insertion loss was enhanced when the size of the gap became smaller. However, the small gap causes more shift from resonator's inherent frequency.

A. Without stub



(a)



(b)

Figure-2. (a) Gaps effect on A (b) gaps effect on B.

The shifting of resonant frequencies was related to the permittivity of the samples. Those relationshipswere linearly changed at -3 dB bandwidth and similar to perturbation equations. Based on the linearity of the relationship, the properties of design model were extracted as presented in Table-1.

Table-1. Enhanced coupling peripheral without stub simulation results (a) Gaps effect on A (b) Gaps effect on B.

(a)

Gaps (mm)	S2,1 (dB)	Q-factor	Freq (GHz)
0.63	-3.7021	62.25	2.49
1.13	-9.1036	55.11	2.48
1.63	-15.516	52.67	2.37

(b)

Gaps (mm)	S2,1 (dB)	Q-factor	Freq (GHz)
1.06	-2.2977	51.78	2.33
1.26	-3.1620	52.00	2.34
1.46	-4.2963	52.22	2.35

From Table-1, it can be seen that the feed line coupling gap has affected the resonant shifting due to the tight coupling of feed line as we reduce the range of gap between the ring resonators and its feed line. Insertion loss was getting better which is approached to zero at smaller gap coupling and quality factor increased linearly. However, as we look into gap effect on B, the insertion loss goes same effect on gap A but the quality factor inversely proportional to the change of gaps. This is due to the electric field distribution on sensing area which is significantly changed as the gap is reduced.

Generally, as the microstrip transmission line only has one ground conductor, the cross sectional electric field distribution propagates through both the substrate and the materials above the substrate. Thus, the microstrip is said to propagate a quasi-TEM mode, in comparison to a pure transverse electromagnetic line. Moreover, the characteristic impedance of the planar transmission lines must be instantaneously matched to the frequency based on wave impedance that relates the transverse electric and magnetic fields of the waveguide. Thus, the maximum amount of E-fields can be produced in order to gain high sensitivity of the resonator sensor. Theresult shows a maximum electric field magnitude distribution at the cross-sectional center of the sensor. The higher E-fields was produces, the higher accuracy of the sensor can be designed as can be observed from Figure-3.

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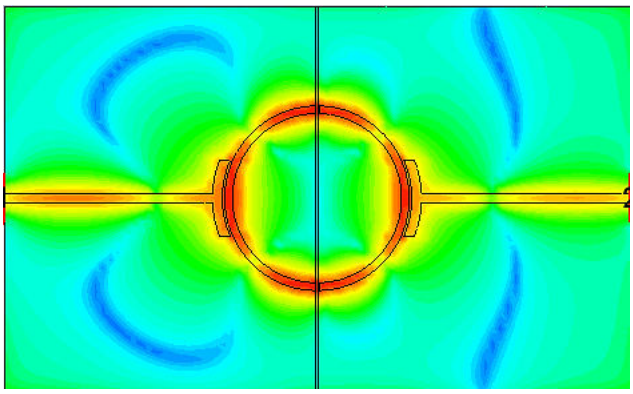
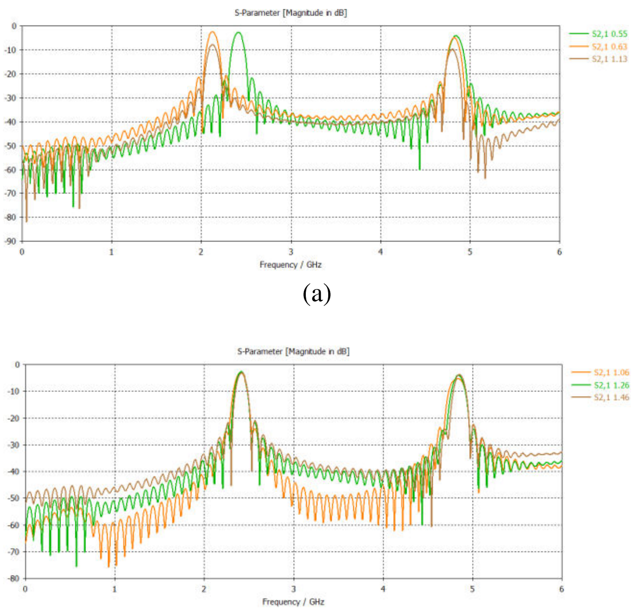


Figure-3. The E-field distribution at port 1 without stub sensor.

Another design that have additional stub on the resonator were analyze the effectiveness of coupling gaps at feeding line (point A) and between an empty quartz capillary (point B) as shown in Figure-4. It is observed that, tight-coupling between the ring and feed shows significant resonance-shift for each corresponding gap, without loaded sample.

A. With stub



(a)

(b)

Figure-4. (a) gaps effect on A (b) gaps effect on B.

Table-2 shows that the larger coupling gap cause resonant frequency shift to lower frequency area and the insertion loss are worse rather than smaller gap of coupling. This is due to the weak capacitance effect between feed and ring itself. The Q-factor can be enhanced with reduce the coupling-gap to produce maximum field where these fields are perturbed by an overlaid liquid sample during testing process. This maximum perturbation leads to shifting in the resonance frequency. Whereas, due to larger gap a minimum field perturbation occurred. Hence, a small shift in resonance frequency is observed.

Table-2. Enhanced coupling peripheral with stub simulation results (a) Gaps effect on A (b) Gaps effect on B.

(a)

Gaps (mm)	**S2,1 (dB)**	**Q-factor**	**Freq** (GHz)
0.55	-2.6181	53.62	2.4131
0.63	-2.3865	48.11	2.1650
1.13	-7.8872	47.30	2.1287

(b)

Gaps (mm)	**S2,1 (dB)**	**Q-factor**	**Freq** (GHz)
1.06	-2.9188	48.15	2.4073
1.26	-2.6181	53.67	2.4153
1.46	-3.0992	53.77	2.4198

For stub designed analysis, the electric field magnitude of the sensor has much better due to the cross sectional area of the sensing area which is larger dimension rather than without stub design. The characteristic impedance of the planar transmission lines were matched enough to the frequency which can cause the maximum E-field magnitude produce at the sensing medium and at the same time increased the accuracy and sensitivity of the resonator in characterizing materials especially liquid samples. The electric field magnitude for stub design can be observed at Figure-5. The shifting of frequencies difference between loaded and unloaded samples can be extracted to gained permittivity and permeability values due to the s-parameter elements for further research purposed.

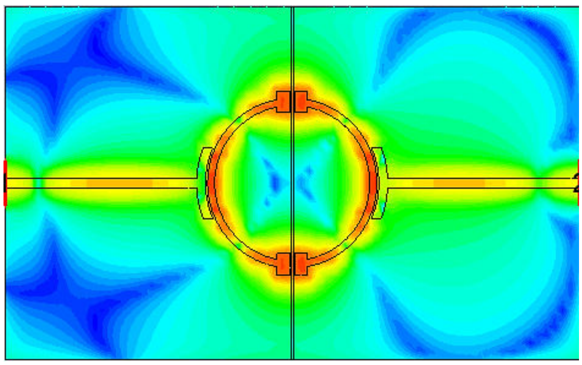


Figure-5. The E-field distribution at port 1 with stub sensor.

CONCLUSIONS

An enhanced coupling peripheral type misrostrip ring-resonator for liquid characterization has been presented. The best gap size is determined by using simulation. It is observed that close coupling will increased the sensitivity and accuracy of the structure where the electric field distribution became more optimal at the solvent area. Hence, the quality factor and insertion loss were improved significantly.

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