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# Transmission Line Coupled Split Ring Resonator as Dielectric Thickness Sensor

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**Abstract.** An optimal method for measuring the thickness of dielectric films using Split Ring Resonator (SRR) is presented in this paper. A transmission line coupled SRR connected to a microwave Vector Network Analyser (VNA) is used as the measurement setup. The thickness of the dielectric film is evaluated from the shift in resonant frequency of SRR when dielectric film is placed on it. Dielectric films of thickness 0.1 mm and dielectric constant 2.3 are used for the study. The results obtained from simulations using HFSS software are found to be in good agreement with the experimental results. The possibility of using this method for measuring thickness of thin films, proximity sensing, strain sensing etc. are also discussed.

## INTRODUCTION

Electromagnetic signals in the range of microwave frequencies have received significant attention in sensing and characterization of dielectric materials. Structures and materials that can be used as sensors in engineering applications are elaborately reported in the literature [1, 2]. Sensors that are economical and utilizing minimum volume of samples are desirable for various applications. Signal frequencies ranging from microwave to terahertz range are elaborately used in various types of sensors for material characterization, bio-medical and other engineering applications [3, 4].

Constituent unit cell of metamaterials is a good choice for the realisation of various types of sensors [3, 4]. Metamaterials, also called left handed or backward wave media, are a new class of artificial materials with ordered composites that exhibits unusual electromagnetic properties from microwave to optical frequencies. Unusual behaviours are due to the negative values of permeability $\mu$ and permittivity $\varepsilon$ of the basic building block of the meta-medium. Split Ring Resonators (SRRs) are the most commonly used negative permeability unit of these materials [5, 6]. Different types of SRRs like Edge Coupled SRRs (ECSRR - conventional SRR), Broad-side Coupled SRR (BCSRR), Double SRR (DSRR), etc. are proposed for wide variety of sensing applications [3, 7-9]. All these structures excited in presence of external electromagnetic fields make use of resonant properties of the SRR in relation with the structural and environmental factors [6, 10]. SRRs excited using free space waves and those employing transmission lines for excitation are the two basic methods reported. In free space method, SRR is placed in the near field of a transmitting probe for its excitation [6, 11, 12]. In transmission line method, the SRR is directly coupled to propagating wave by fabricating it very near to the strip line on the same substrate. The transmission line employing split ring resonators is impressively studied by various authors [3, 13, 14].

N. Wiwatcharagoses *et. al.* proposed a sensor to detect the presence of dielectric material by placing it on the SRR coupled to a transmission line and have analysed the resonance frequency shift both experimentally and using simulation software [13]. In this paper, we present a dielectric thickness sensor for the precise determination of the

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thickness of a dielectric films/sheets by using a transmission line coupled SRR. Using HFSS software, the resonant frequency shift which is a function of the thickness, for dielectric films of different thickness placed over SRR are analysed and the results are verified experimentally.

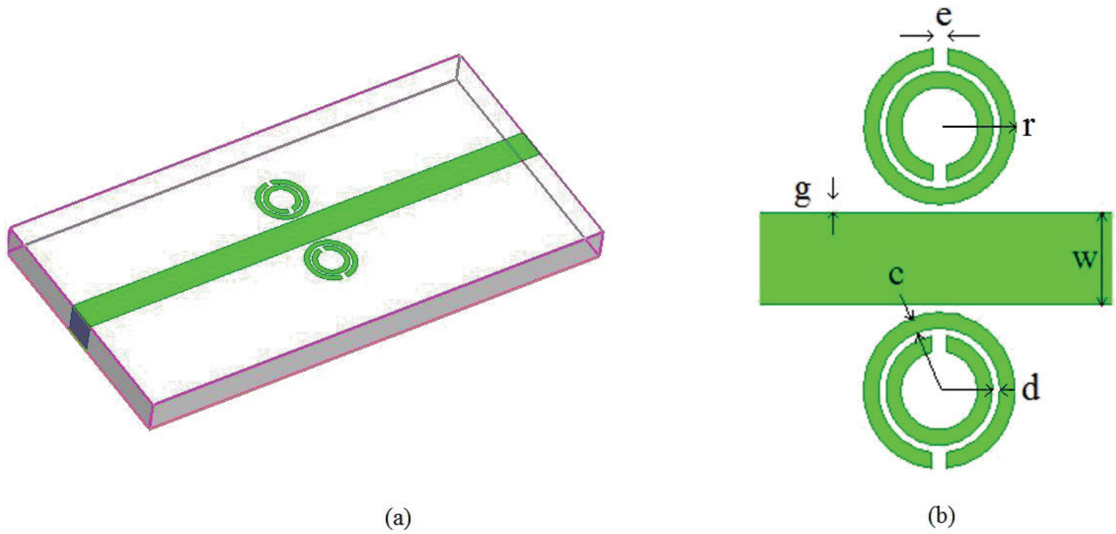


**FIGURE 1.** (a) Structural representation of transmission line coupled SRR on dielectric substrate, (b) Magnified view of SRR section of the structure showing the structural parameters.

## DESIGN AND SIMULATION

The structure of transmission line coupled SRR is represented in Fig. 1 (a) and structural parameters are shown in Fig. 1 (b). The ends of the transmission line (microstrip) are used as the input and output ports. The width of transmission line is represented as *w* and the spacing between SRR and the transmission line as *g*. Two SRRs of same dimensions are placed on either side of the transmission line. SRR unit is made up of two concentric metallic rings of width *c*, outer radius *r*, slit width *e* and the gap between the inner and outer rings *d*. There is a tiny slit of width *e* on each ring which are on diametrically opposite sides. In the presence of an external electromagnetic signal, the rings themselves act as inductor and the gap between them introduces capacitance effect. This results in a simple *LC* resonance oscillation. The sub-wavelength dimension of the SRR allows a quasi-static approximation which leads the structure to resonate in presence of the magnetic component of the applied electromagnetic signal with *f* frequency given by

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

where, L and C are the effective inductance and capacitance of SRR unit respectively.

The proposed structure of SRR is designed to operate near 4.7 GHz using Finite Element Modeling (FEM) analysis by HFSS software. The substrate used for design is FR4 epoxy with dielectric constant $\varepsilon_r = 4.4$ and dimensions – thickness $t = 1.6$ mm, length $l = 40$ mm and breadth $b = 20$ mm. The transmission line has width $w = 2$ mm with characteristic impedance $Z = 50\ \Omega$. The dimensions of SRR structure are as follows – ring width $c = 0.65$ mm, gap between the rings $d = 0.4$ mm, outer radius $r = 0.76$ mm, slit gap of each ring $e = 0.2$ mm and gap between SRR and transmission line $g = 0.1$ mm [15].

Initially, we simulate the resonance behaviour of SRR rings when no dielectric samples are placed over it. Since both SRRs are of same dimensions, they resonate at the same resonant frequency. Figure 2 shows the insertion loss of transmission line coupled SRR ($S_{21}$) having maximum resonant absorption at 4.61 GHz.

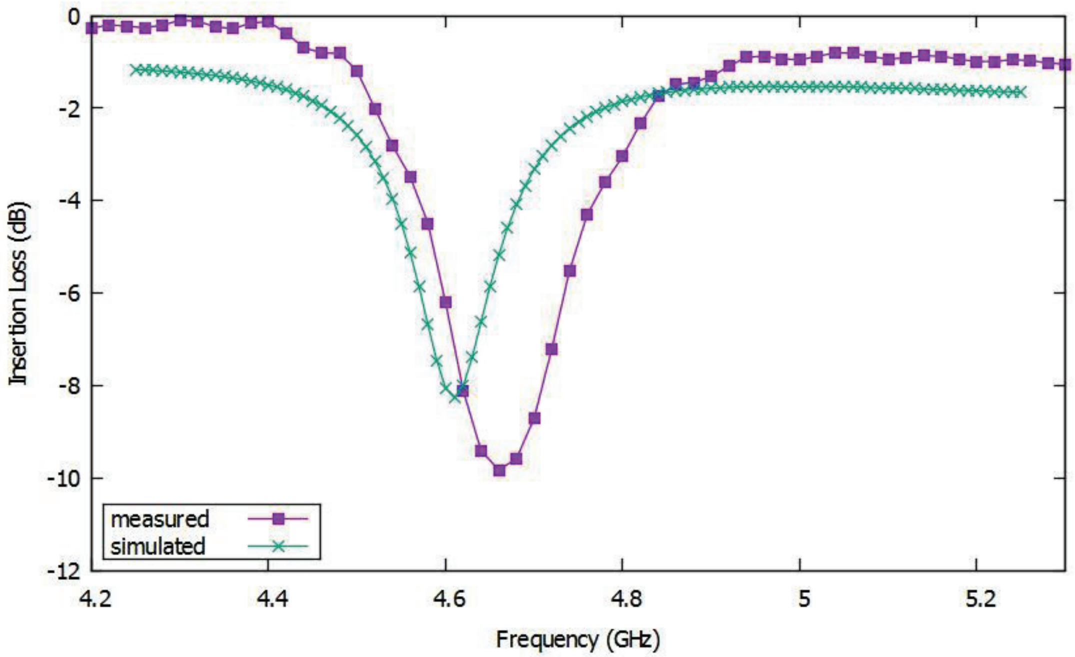


**FIGURE 2.** Insertion loss $S_{21}$ of transmission line coupled SRR obtained by simulation and experiment.

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In the second stage, we simulate the resonant behaviour of SRR in the presence of dielectric sheet sample placed over one of the SRR unit as in Fig. 3. The area of the Material Under Test (MUT) selected should be sufficient to cover the area of one SRR unit. The dielectric constant for MUT is selected as $\varepsilon_r = 2.3$. When the dielectric sample is placed over the SRR, its resonance shifts to lower frequency while the resonance of the unloaded one would be unchanged.

For sensing the thickness of dielectric sample, simulation plots are drawn for sheets of various thickness ranging from 0.1 mm to 1.25 mm. Figure 4 depicts the shift in resonant frequency for MUTs of different thickness placed over SRR. As the thickness of MUT increases, resonant frequency corresponding to the loaded SRR shifts to lower values progressively. After reaching a particular value (4.35 GHz), it remains constant. Resonances around 4.7 GHz are due to the unloaded SRR in presence of various samples.

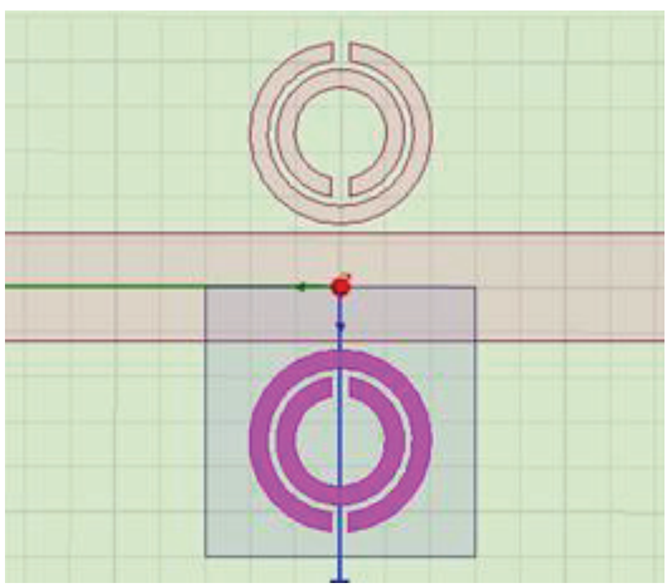

**FIGURE 3.** Top view of the structure of thickness sensor with dielectric sample placed on one of the rings drawn in HFSS

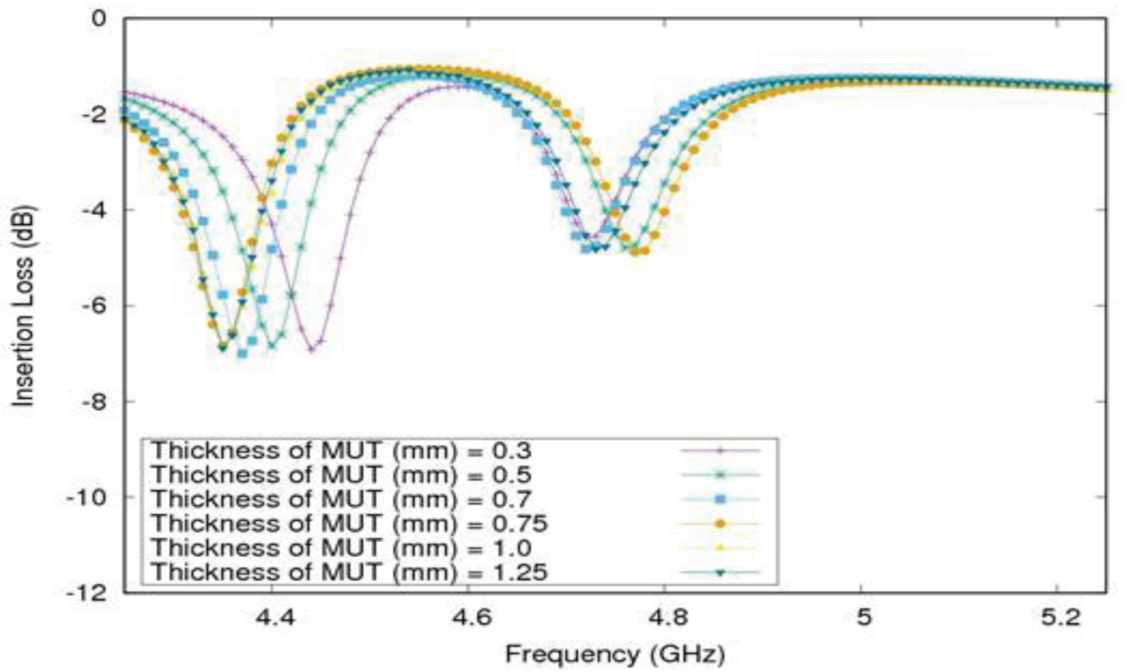


**FIGURE 4.** Simulated insertion loss $S_{21}$ of SRR for MUTs of different thickness

## EXPERIMENTAL VERIFICATION

In order to verify the simulation results, we fabricated a transmission line coupled SRR on a FR4 epoxy substrate of dielectric constant $\varepsilon_r$ = 4.4 having dimensions of 40 mm length, 20 mm breadth and 1.6 mm thickness. All the structural parameters of SRR and transmission line are taken same as that selected for simulation.

Two ends of the transmission line are connected to transmitting and receiving ports of a Vector Network Analyser (VNA). The experimental setup is shown in Fig. 5.

**FIGURE 5.** Photograph of a fabricated SRR coupled transmission line

The measured transmission graph obtained is given in Fig. 2 along with the simulated one. The slight variation observed in the resonant frequency may be due to the small departures in the dimensions of the structural parameters during fabrication process.

Plastic films of thickness 0.1 mm and dielectric constant $\varepsilon_r$ = 2.3 with area 6.5 $mm^2$ are used as the test samples. Different sheets of these samples are placed on one of the SRR unit one over the other and the corresponding resonant curves are obtained and are shown in Fig. 6. As the thickness increases from 0.1 mm to 1.2 mm, resonant frequency shifts from 4.48 GHz to 4.34 GHz. This is almost similar to that obtained by simulation (Fig. 4). For MUTs of thickness more than 0.7 mm there is no significant change observed for the resonant frequency. The resonant frequency of the unloaded SRR remains unchanged as expected at 4.70 GHz.

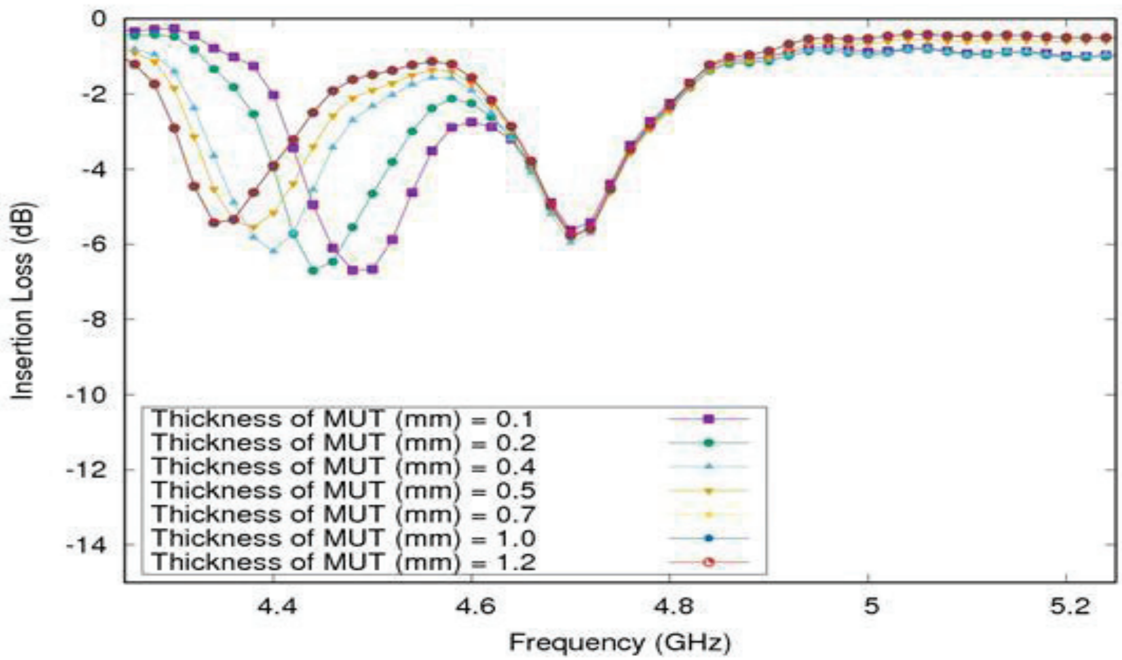


**FIGURE 6.** Measured insertion loss $S_{21}$ of SRR with samples of different thickness placed on one of the rings.

Plot between the thickness of the sample and corresponding resonant frequency obtained from the experimental data is plotted in Fig. 7 along with the simulated results. It is obvious from the graph that both simulated and experimental curves show almost same results. So the thickness of any unknown dielectric sample whose thickness is in between 0.1 and 0.8 mm can be precisely extracted from the experimental curve of the above figure by observing its resonant frequency when it is placed on our experimental setup.

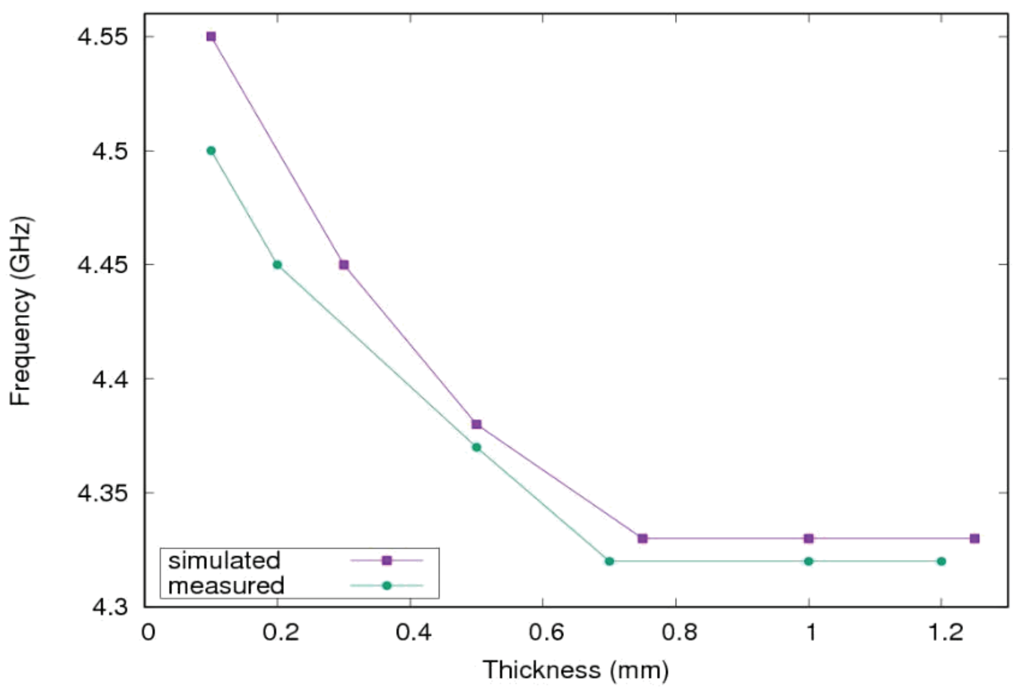


**FIGURE 7**. Curves between frequency and thickness obtained by simulation and experiment for SRR with samples of different thickness.

## CONCLUSION

In this paper, we have introduced a transmission line coupled Split Ring Resonator (SRR) as a dielectric thickness sensor. The simulations are carried out in HFSS software and the results are experimentally verified using a network analyser system. The thickness of thin sheets/films can be precisely determined by this method. Apart from using it as a thickness sensor, same experimental sensor can be used for proximity sensor which may leads to application in fields of strain sensing and pressure sensing.

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