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Enhancing the Resolution in Imaging using Folded Metamaterial Split Ring Resonator Structure at Microwave Frequencies

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Abstract. A novel and better resolution topology for reducing the sensing area of conventional Split Ring Resonator (SRR) metamaterial structure is proposed. The conventional planar SRR structure is fabricated on a thin flexible film and is folded to raise its split region slightly up with respect to the plane of the SRR (Folded Split Ring Resonator-FSRR).The structure exhibits strong localization of electric field in the projected region of the sensor, by confining the evanescent waves in that region having dimension much smaller than the operating wavelength. The proposed sensor is placed between transmitting and receiving probes of a Vector Network Analyzer (VNA) to form the sensing probe. Two dielectric samples arranged at different distances of separation are scanned and the corresponding transmission characteristics S_{21} are drawn for analysing the image resolution. The resolution and sensitivity of the above proposed sensor is compared with conventional SRR and is found to be superior in performance. This novel FSRR provides a better resolution and thereby overcomes the diffraction limit in imaging up to $\lambda/30$, whereas for the conventional planar SRR it will be around $\lambda/15$. The design is simple, compact and inexpensive. The potential of proposed sensor can be extended to sub-wavelength imaging of dielectric materials, biological samples and can be used for non-destructive testing.

INTRODUCTION

Evanescent microwave sensors have gained the attention of various researchers due to its unique properties like compactness, high sensitivity and enhanced resolution. Different types of sensors using transmission line based microstrip resonators, meta material resonant structures etc. are seen in literature [1, 2]. Sensors based on metamaterials have recently gained considerable attention due to their ability to detect minute changes in electromagnetic properties in relation to the field perturbation near the sensing probe. Split Ring Resonator (SRR), the negative permeability part of metamaterial is extensively used in various sensor applications [3]. SRR shows inductive and capacitive effects due to near field variations which are highly dependent upon their structure, substrate and dielectric environment [4,5]. Several designs consisting of conventional SRR loaded with coupled lines and waveguides have been proposed and analysed for various sensing applications [6, 7, 8].

In this paper we introduce a novel design having better resolution topology for reducing the sensing area of conventional SRR which offers high resolution. A conventional type planar SRR structure is fabricated on a thin flexible film [9] and is precisely folded to raise its split region slightly up with respect to the plane of the SRR to materialize the Folded Split Ring Resonator (FSRR). This advanced topology is such that the evanescent electric field localized at the projected region of the sensor is utilized for the sensing purpose, thereby reducing the sensing

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area of probe considerably [10]. The proposed high resolution sensing using FSRR is verified by resolving dielectric samples placed at a distances much less than the operating wavelength, which may not be possible using a conventional SRR.

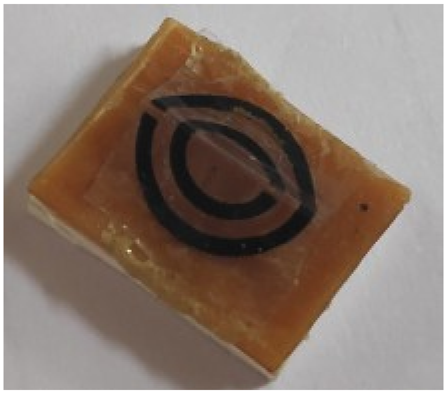

FIGURE 1. Folded Split Ring Resonator (FSRR)

DESIGN AND MEASUREMENT

SRR structure is fabricated on a thin copper film by photo chemical etching method after gluing it on a polypropylene film. The structural parameters of the SRR design are inner radius r = 2 mm, width of the ring w = 0.75 mm, spacing between the rings d = 0.5 mm and split width s = 0.5 mm. The SRR structure fabricated on the polymer film is carefully folded to raise its split region slightly up with respect to the plane of the SRR (Folded Split Ring Resonator-FSRR). A photograph of the designed FSRR is given as Fig.1. FSRR is carefully arranged between the transmitting and receiving probes of a Vector Network Analyzer (VNA).The resonant frequency of the FSRR is found to 4.9178 GHz and it is selected as the operating frequency for the scanning process. Any perturbation due to the presence of a dielectric material, will vary the resonant frequency which will reflect as a change in received power. The object under study is arranged on a thin polymer sheet (platform) of thickness 0.1 mm fixed on a frame set at a distance of 0.1 mm above the folded portion of SRR. The entire platform is attached to a computer controlled stepper motor set up for its precision movement with respect to FSRR probe.

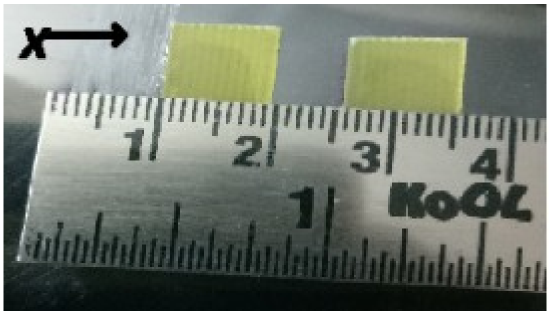

FIGURE 2. Dielectric samples of 1cm width placed on a platform at a spacing of 6mm

Two dielectric strips each of 1 cm width are made from Flame Retardent circuit laminates after removing the copper claddings and placed on the platform as in Fig.2. The samples are moved over the sensing probe with a precision of 1 mm/step in x direction. The experiment is repeated by using a conventional flat SRR for comparison of resolving power. The received power with respect to scanning distance is shown in Fig. 3(a) and 3(b) for FSRR and conventional SRR. It is obvious from the above figures that a separation of 6 mm is resolved by both the probes.

The experiment is repeated by placing the dielectric samples at a distance of 4 mm and the samples are moved over the sensing probe and the corresponding transmitted power with scanning distance for analysing image resolution are shown in Fig. 4(a) and 4(b). Both the FSRR and conventional SRR are able to map the dielectric contrast of the region, but with slight variation. For the conventional SRR the geometrical size within which the strong evanescent electric field confined is comparable with the distance of a dielectric contrast to be analyzed and hence the dielectric change within a distance of 4 mm can be sensed.

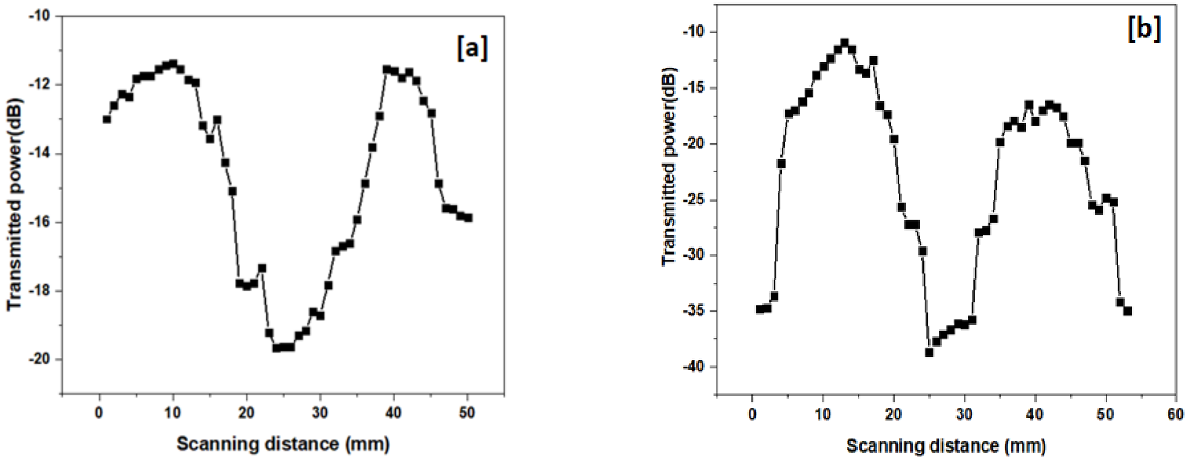

FIGURE 3. Transmitted power with respect to scanning distance of dielectric samples placed at a distance of 6 mm for a) Folded SRR b) Conventional SRR

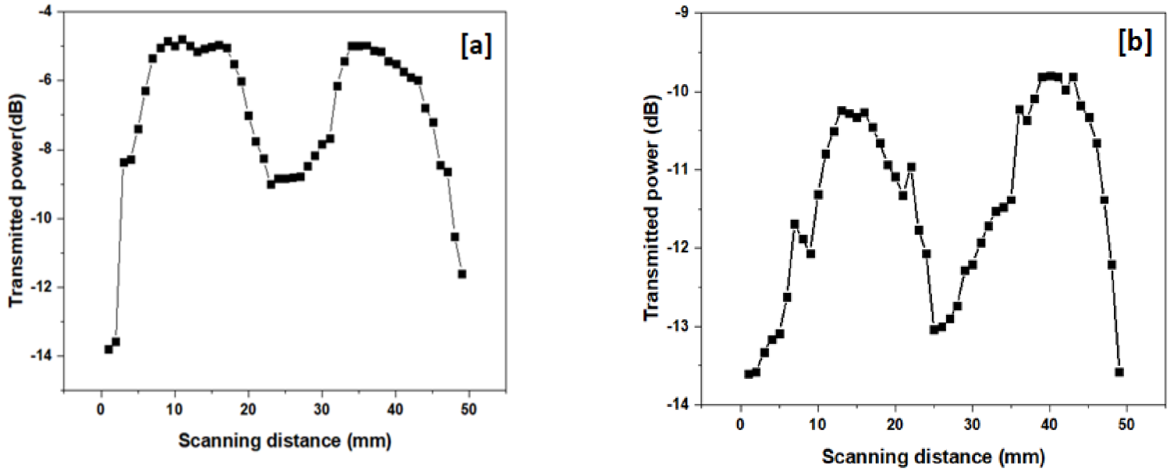

FIGURE 4. Transmitted power with respect to scanning distance for a dielectric spacing of 4 mm for a) Folded SRR b) Conventional SRR.

The experiment is then repeated for dielectric samples placed at a spacing of 2 mm. The received power with respect to scanning distances for both FSRR and SRR are shown in Fig. 5(a) and 5(b). The resolution and sensitivity of the above proposed FSRR sensor is compared with conventional SRR and the novel sensor is able to identify a dielectric contrast within a distance of 2 mm when a microwave of wavelength λ = 6.1 cm is used, whereas for the conventional SRR, the measured data exhibits anomalies and is not able to identify the dielectric change within a distance of 2 mm as it is evident from Fig.5(b). For the conventional SRR, the resolution is limited up to 4 mm.

The experiment is repeated for dielectric samples placed at a spacing of 1 mm and the received power with respect to scanning distances are analysed and are shown in Fig. 6(a) and 6(b) for FSRR and SRR. It is quite clear from the above figures that the resolving of the dielectric contrast within a distance of 1 mm is found to be impossible for conventional SRR, whereas our proposed FSRR scanning probe is able to resolve the above distance.

The proposed novel SRR provides better resolution by reducing the sensing area and thereby overcomes the diffraction limit in imaging up to λ/30, whereas for the conventional planar SRR it will be around λ/15.

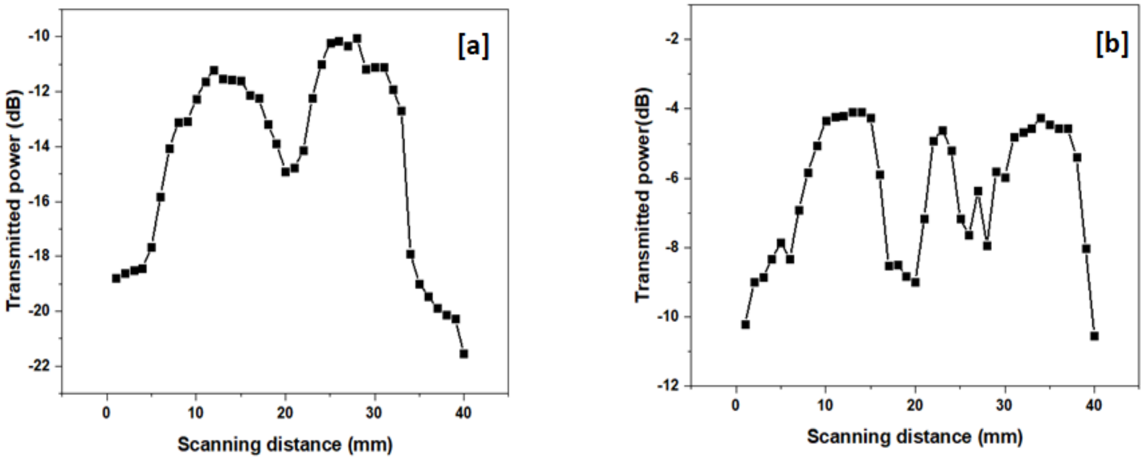

FIGURE 5. Transmitted power with respect to scanning distance for a dielectric spacing of 2mm for a) Folded SRR b) Conventional SRR

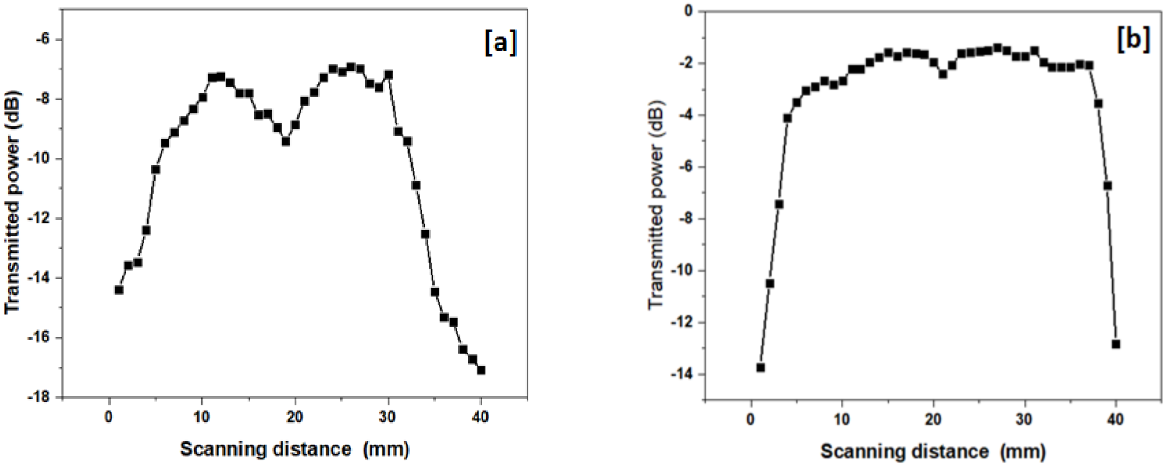

FIGURE 6. Transmitted power with respect to scanning distance for a dielectric spacing of 1 mm for a) Folded SRR b) Conventional SRR

CONCLUSION

We have presented a SRR with novel topology in the form of Folded SRR (FSRR) having better resolving power and imaging capabilities. The strong electric field localized at the small folded split region, makes it possible to image the dielectric environment within a distance much smaller than the scanning wavelength. The technique can be extended to sub-wavelength imaging of dielectric and biological samples, and can be employed for non-destructive testing.

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