Metamaterial Split Ring Resonators made of Polyaniline - polytetrafluoroethylene at Microwave Frequencies

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Abstract – **We present the observance of magnetic resonance for the first time in Split Ring Resonators (SRRs) made of polyaniline - based conducting polymer and verify our experimental result through simulation. The magnetic resonance behavior of Closed Ring Resonator (CRR) and SRR of polyaniline - polytetrafluoroethylene (Pani - PTFE) are presented. The humidity sensitive conducting Pani - PTFE ring behaves like low loss conducting ring with wide-band magnetic resonance whereas the CRR does not show any resonant response as is expected. The results are analyzed using simulation studies for copper rings of similar dimensions. Magnetic resonance observed in Broad-side Coupled Split Ring Resonator (BCSRR) made of Pani - PTFE is also presented, highlighting its role in metamaterial based applications. Realization of metamaterial resonating structures using conducting polymers opens a new realm with immense possibilities in microwave and terahertz technologies.**

I. INTRODUCTION

Conducting polymers has emerged as one of the key areas of research during the last decade in the field of electromagnetic sensors and absorbers. Apart from using conducting polymers for slightly modifying the environmental conditions of the Split Ring Resonator (SRR), no other works are seen reported in the literature[1]. In this work, for the first time, we have fabricated the metamaterial based Broad-side Coupled Split Ring Resonator (BCSRR) structure using polyaniline - polytetrafluoroethylene (Pani - PTFE) conducting polymer and have analyzed its magnetic resonance behavior. This paper also addresses the observance of the widening of resonance curve in relation to the comparatively less conductivity of the proposed polymer with respect to the conventional metallic resonators. During the course of development of BCSRR, we have also analyzed the magnetic resonant behavior of Closed Ring Resonator (CRR) and SRR fabricated using conducting polymer. Experimental results are verified using high frequency simulation software and excellent agreement are observed.

II. MATERIALS AND METHODS

For metallic resonators, the inductive contribution of the resonant frequency exclusively depends on the conduction current flowing through the ring. But since Pani - PTFE is a material having lower conductivity, the displacement current term which is a property of dielectric counterpart of the resonator should also be included in the calculation of the resonant frequency. The effective length of the resonating ring l_1 along with the resonant frequency Ω are given[2] by

$$l_1 = \ln[8R/r] - 7/4 \tag{1}$$

$$\Omega = \omega_o \sqrt{1 + 2\varepsilon k} \tag{2}$$

where ω_o is given by

$$\omega_0^2 = 2c^2/\varepsilon r^2 l_1 \tag{3}$$

where c is the velocity of light, ε permittivity of the material of the ring, R outer radius of the ring, r inner radius of the ring, s is the split spacing and $k = s/2\pi R$.

The preparation process of Pani - PTFE conducting polymer used for fabricating SRRs is described below. Protonated chlorine doped polyaniline (Pani) is formed from aniline and ammonium peroxydisulphate (APS) using a chemical oxidation method. The powdered polyaniline is then made to a sheet form by mixing it in the matrix polytetrafluoroethylene (PTFE) so as to form polyaniline - polytetrafluoroethylene (Pani - PTFE) hybrid sheet[3]. The prepared sheets possessing greater conductivity in humid conditions are then cut into rings of specific dimensions. The schematic representation of the experimental set up along with the photograph of prepared Pani- PTFE sheet together with the drawings of CRR, SRR and BCSRR are shown in Fig. 1. In order to determine the resonant behavior, the polymer resonator is placed between the transmitting and receiving probes connected to a Vector Network Analyzer (VNA).

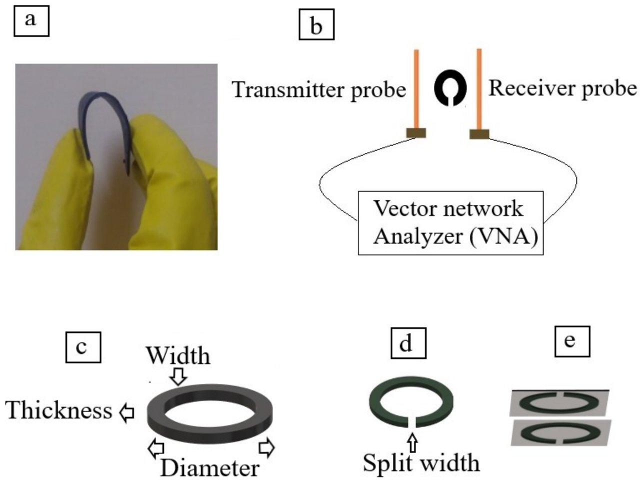

Fig. 1: (a) Photograph of the prepared Pani- PTFE conducting polymer sheet; (b) schematic representation of the resonant frequency measurement setup; (c), (d) and (e) labeled diagram of CRR, SRR and BCSRR.

III. Results and discussions

Figure 2 shows the experimental magnetic resonance curves obtained for SRR and CRR of circular geometry made of Pani - PTFE along with the simulation results. The simulated result of the circular copper ring with the same dimension is also shown in the figure for comparison. The wide-band resonance behavior of the Pani - PTFE ring in comparison with its metallic counterpart is due to the lower conductivity of the polymer. A small shift in the resonance frequency between Pani - PTFE and copper ring may be explained in terms of the higher contribution of displacement current due to the non-ignorable dielectric behavior of Pani - PTFE material (Eq. 1, 2 and 3). The absence of magnetic resonance for CRR is also noticed.

Figure 3 shows the resonant frequency curve of Pani - PTFE BCSRR along with the resonance of individual rings used to construct this resonator. Similar to a metallic BCSRR, the resonance frequency of Pani - PTFE resonator is shifted to the lower frequency region due to the coupling effects. The reason for slight enhancement in power above 0 dB for experimental resonance curves of Fig. 2 and 3 needs further investigation.

IV. Conclusion

In this work, we have presented a novel type of metamaterial resonator made of conducting polymer Pani - PTFE. We investigated the resonances in single ring SRR made from conducting polymer. The presence of magnetic resonance in the structure is confirmed using CRR resonance. By coupling two rings suitably, a metamaterial

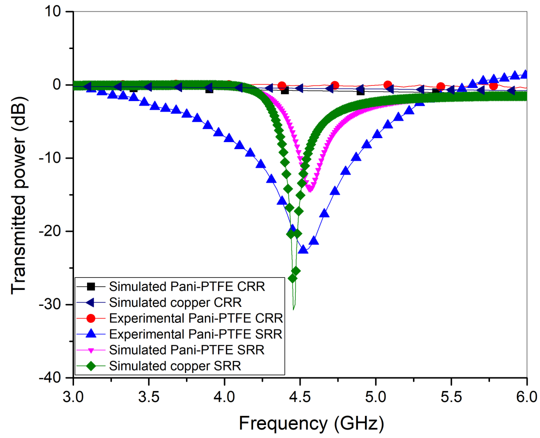

Fig. 2: Simulated and experimental resonant curves of copper and Pani-PTFE CRR and SRR rings of diameter 10 mm, width 1 mm, thickness 3 mm and split width 1 mm.

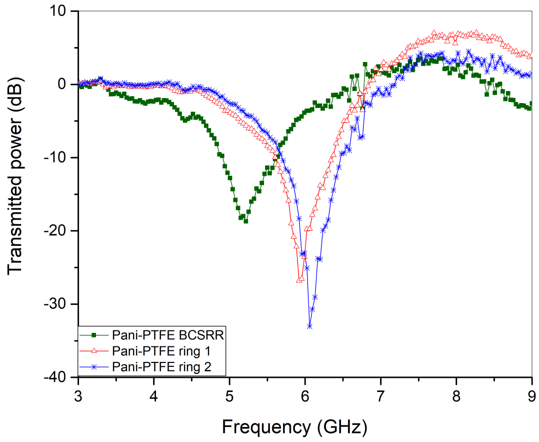

Fig. 3: Magnetic resonances observed in Pani - PTFE BCSRR of dimensions diameter 10 mm, width 1 mm, thickness 1 mm, split width 0.35 mm and separation between the rings 1 mm.

BCSRR structure is materialized and its resonance curves are analyzed in terms of lower conductivity and displacement current effects. Since the proposed material has humidity dependent conductivity properties, this new SRR can have added advantage in humidity sensing applications. The magnetic response of this polymer with tunable conductivity makes it a new candidate for the realization of left-handed materials with attractive features.

References

[1] M. Mayy, G. Zhu, Y.A. Barnakov, M. Noginov, "Development of composite silver-polymer metamaterials, "*Journal of Applied Physics* vol. 105(8), p. 084318, 2009

[2] A. Shvartsburg, V.Y. Pecherkin, L. Vasilyak, S. Vetchinin, V. Fortov,"Resonant microwave fields and negative magnetic response, induced by displacement currents in dielectric rings: theory and the first experiments," *Scientific reports*,vol 7(1),p. 2180, 2017

[3] N. Paul, S.P. Chakyar, K. Umadevi, S.K. Sikha, J. Kizhakooden, J. Andrews, V. Joseph,"Humidity Sensitive Flexible Microwave Absorbing Sheet Using PolyanilinePolytetrafluoroethylene Composite," Arabian Journal for Science and Engineering, vol 44(1), p. 553, 2018