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Temperature Dependence of Relative Permittivity: A Measurement Technique Using Split Ring Resonators

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***Abstract*—**A compact method for measuring the relative permittivity of a dielectric material at different temperatures using a single circular Split Ring Resonator (SRR) metamaterial unit working as a test probe is presented in this paper. The dielectric constant of a material is dependent upon its temperature and the *LC* resonance of the SRR depends on its dielectric environment. Hence, the temperature of the dielectric material in contact with the resonator influences its resonant frequency. A single SRR placed between transmitting and receiving probes connected to a Vector Network Analyser (VNA) is used as a test probe. The dependence of temperature between 30 ºC and 60 ºC on resonant frequency of SRR is analysed. Relative permittivities 'ε' of test samples for different temperatures are extracted from a calibration graph drawn between the relative permittivity of samples of known dielectric constant and their corresponding resonant frequencies. This method is found to be an easy and efficient technique for analysing the temperature dependent permittivity of different materials.

***Keywords*—**Metamaterials, negative permeability, permittivity measurement techniques, split ring resonators, temperature dependent dielectric constant.

I. INTRODUCTION

AMONG the material characterization studies, the precise determination of dielectric constant at different working environments is important from the application point of view. Out of these different parameters, the variation of dielectric constant with temperature finds its use in different sensor applications in the fields of medical instrumentation, electronic and electrical industry etc. This dependence of dielectric constant on temperature for different materials is already reported [1], [2].

There are several techniques described in the literature to determine the dielectric constant at different temperatures [3], [4]. Among these different techniques, open-ended coaxial probe method, cavity resonance methods, quasi-optical resonator method, split-cylinder resonator method etc. are commonly employed [5], [6]. Many of these methods require specific working conditions to be satisfied for the precise determination of the above-mentioned variation of temperature on relative permittivity. In this paper, we present an efficient and simple method for the measurement of dielectric constant variation with temperature using a SRR metamaterial unit [7], [8].

SRRs are constituent molecules of metamaterials showing negative permeability. SRRs present exotic resonant nature which is highly dependent upon the structural parameters of the resonator and the dielectric environment associated with them [9]-[11]. Since the resonant frequency of the SRR changes with different physical working parameters, they find a number of applications in different microwave employed fields. In literature, the effect of dielectric constant on the resonant frequency of SRR is investigated [12]-[16]. As the properties of the metallic resonator structure and the dielectric substrate upon which it is fabricated are all temperature dependent, SRR is also sensitive to temperature variations. The temperature dependence of SRRs is extensively studied [17] in terms of the thermal expansion of the SRR ring and the temperature dependence of substrate permittivity. In that work, with support of sufficient theory, they have shown that the resonant frequency decreases due to increase in temperature by the contributions due to the change in dielectric constant of the substrate and the thermal expansion of the rings. Singh et al. studied the effect of temperature on terahertz metamaterial fabricated on strontium titanate substrate [18].

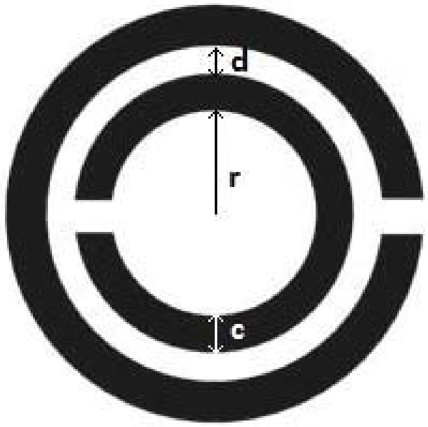

Fig. 1 Schematic representation of the SRR with its structural parameters - inner radius *r*, ring width *c* and spacing *d*

The structure of circular SRR with its parameters is represented in Fig. 1. It composes of two concentric metal rings of width *c* and spacing *d*. The radius of the inner ring is *r*. The two metal rings have small splits on the diametrically opposite sides of the structure. The *LC* resonant nature of the SRR arises from the capacitance and the inductance of the two rings due to charges and currents induced in them by applied electromagnetic field. The resonant frequency of the SRR is given by:

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