A Coaxial Test Fixture for Transmission/Reflection Measurements of Metamaterials

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***Abstract*—Metamaterial structures exhibiting negative permittivity and/or negative permeability have been given considerable attention in recent years, but limited discussion has been given to a standard way of measuring these structures. Often, metamaterial measurements involve cumbersome fabrication and setup procedures making it very difficult in some cases to generate accurate data because of noise in the system or the complexity of the setup. This paper presents the design of a test fixture that overcomes much of the difficulty in metamaterial measurements to provide quick and accurate data. Furthermore, the data generated from this test fixture can be used directly with current extraction routines to determine the effective properties associated with the metamaterial structure.**

I. Introduction

Some common approaches to transmission/reflection measurements of metamaterials involve free space or parallel plate waveguide structures [1] – [3]. Unfortunately, problems exist with such methods that make measurements difficult or tedious. With free space measurements, typically a large number of individual unit cells are used that require meticulous fabrication and setup procedures. There is also the potential for noise or other outside interference compromising the integrity of measured data. With parallel plate waveguide measurements, there are issues with feeding the waveguide, and the waveguide itself may need to be very large as shown in [4]. There has also been recent interest in broadband metamaterials [5] that operate over several octaves requiring a broadband testing apparatus. Furthermore, since the circuits necessary to make broadband metamaterials can be difficult and expensive to fabricate, it would be beneficial to minimize the number of unit cells required for testing. It is, therefore, desirable to have a quick and efficient measurement approach that allows for transmission/reflection measurements in a simple, compact setup that minimizes the required number of metamaterial unit cells.

The coaxial fixture pictured in Fig. 1 alleviates many of the issues presented for the aforementioned test setups. As a closed, easy to feed transmission line, there are no concerns of outside noise that may compromise data integrity, and the well-known and proven TRL calibration method can be used to de-embed up to the edges of the unit cells to eliminate measurement errors. Unlike the coaxial cell presented in [4], the proposed fixture allows for transmission/reflection measurements where the data can be used directly with existing extraction routines similar to that in [1] to extract the effective ϵ and μ of the metamaterial under test. In cases where higher order modes may be a problem, the authors of [6] suggest some methods to suppress higher order modes in coaxial structures that show very promising results.

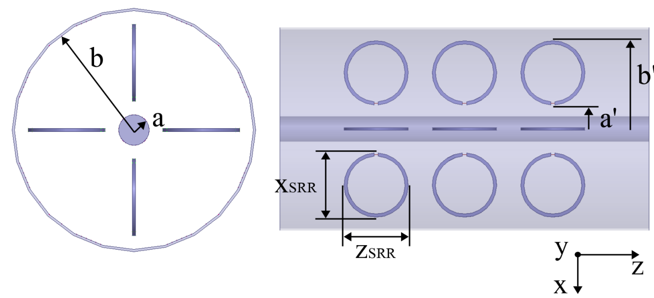

Fig. 1. Coaxial fixture with four rows of three SRRs placed symmetrically around the center conductor with propagation in the +z-direction front view (left) and side view (right)

In the following section, theory is presented for the design of the coaxial fixture. It should be noted that for this paper, only the circular split ring resonator (SRR) structure is considered, but the proposed approach is applicable to other metamaterial structures as well.

II. Analysis and Fixture Design

As a starting point for analysis, consider the case of four rows of three SRRs placed inside of a parallel plate waveguide with width, w, and height, d with perfect magnetic conductor sidewalls. The $\mathbf{E}$ field is oriented along d, the $\mathbf{H}$ field along w, and the direction of propagation is in the z-direction. Each row of SRRs is oriented in the z-direction with uniform spacing between SRRs in each row and separated by a uniform distance. The values of w and d are chosen so the images of the SRRs in the guide effectively create an infinite lattice of SRRs. In order to match these measurements with those taken in a coaxial fixture for the same SRRs, it is desired to match the total incident power for each transmission line structure. Since the input power to each fixture can be controlled, the incident magnetic flux through the SRR can be found by solving for the incident $\mathbf{B}$ fields in terms of the time averaged power to give the following relationship

$$B_y = \frac{\mu_\circ \sqrt{2P}}{\sqrt{\eta_\circ wd}} e^{-jk_\circ z} \tag{1}$$

for parallel plate waveguide, and

$$B_\phi = \frac{\mu_\circ \sqrt{P}}{r\sqrt{\eta_\circ \pi ln\left(\frac{b}{a}\right)}} e^{-jk_\circ z} \tag{2}$$

for the coaxial fixture where P is the time averaged power, $\eta_\circ$ is the free space wave impedance, and $k_\circ$ is the free space wavenumber as no dielectric materials are present in either fixture.

From here, the $\mathbf{B}$ fields can be integrated over the area of the unit cell containing the SRR to give the total incident magnetic flux through the unit cell. It should be noted that as long as the area of the unit cell containing the SRR is the same for both fixtures, the geometry of the SRR itself is irrelevant given that it is consistent for both fixtures. The incident magnetic flux through each SRR unit cell in the parallel plate waveguide is

$$\int_s B_y \cdot ds = \Phi_{pp} = \frac{-\mu_\circ x_{SRR}\sqrt{2P}}{jk_\circ\sqrt{\eta_\circ wd}}\left[e^{-jk_\circ z_{SRR}} - 1\right] \tag{3}$$

and the incident magnetic flux through each SRR unit cell in the coaxial fixture is

$$\int_s B_\phi \cdot ds = \Phi_{coax} = \frac{-\mu_\circ \sqrt{P} ln\left(\frac{b'}{a'}\right)}{jk_\circ\sqrt{\eta_\circ \pi ln\left(\frac{b}{a}\right)}}\left[e^{-jk_\circ z_{SRR}} - 1\right] \tag{4}$$

where a, b, a' and b' are indicated in Fig. 1.

Therefore, to match the total incident flux in each case with equal incident power at the ports, Eqn. (3) must equal Eqn. (4) resulting in

$$\frac{x_{SRR}}{\sqrt{wd}} = \frac{ln\left(\frac{b'}{a'}\right)}{\sqrt{2\pi ln\left(\frac{b}{a}\right)}} \tag{5}$$

where Eqn. (5) is used to determine a and b for the coaxial fixture. By using Eqn. (5) to determine the size of the coaxial fixture, it is ensured that the total incident power and flux through the SRRs is the same for both fixtures leading to the same values of extracted material parameters.

III. Results

To demonstrate the performance of the coaxial fixture presented here, *HFSS* simulation results are presented. The SRR employed here has an outer radius of 4 mm, an inner radius of 3.6 mm, a thickness of 0.31 mm, and a gap of length 0.5 mm. The spacing between each SRR in the direction of propagation is 3 mm. A 400 fF capacitor is also placed in the gap of each ring to make the rings resonate near 2 GHz. The simulated parallel plate waveguide has a height $d = 11$ mm and a width $w = 44$ mm with 11 mm spacing between each row of SRRs in the direction transverse to propagation. The coaxial fixture has an inner conductor radius of $a = 1.6$ mm, and the radius from the center of the fixture to the outer conductor is $b = 12.4$ mm. There is 1.4 mm spacing between the SRRs and the conductors of the fixture making $a' = 3$ mm and $b' = 11$ mm.

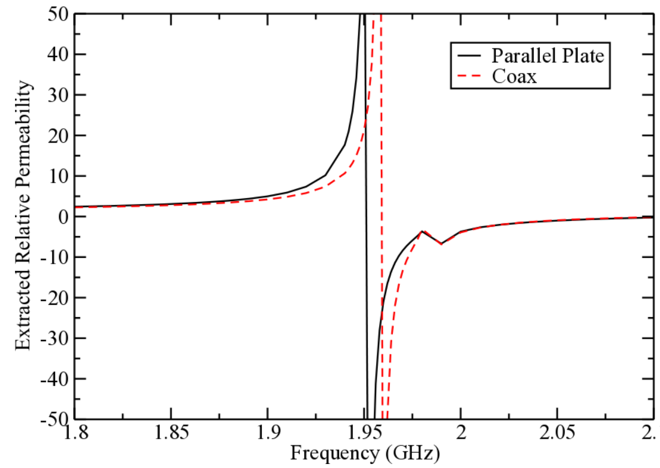

Fig. 2. Coaxial fixture with four rows of three SRRs placed symmetrically around the center conductor with propagation in the +z-direction front view (left) and top view (right)

Figure 2 illustrates comparison data for the rings in the parallel plate waveguide versus the rings in the proposed coaxial fixture. The data in the figure is the extracted relative permeability, μ_r, for the SRRs in each test fixture using the algorithm outlined in [1]. It is interesting to note the slight frequency shift between the two data sets which is thought to be the result of slightly different mutual coupling in the parallel plate waveguide versus that in the coaxial fixture. It is believed that when the coaxial fixture dimensions are chosen such that the mutual coupling matches that in the simulated parallel plate waveguide, no shifts in the resonant frequency will be observed.

Acknowledgement

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