A Printed Dipole Reconfigured with Magneto-Static Responsive Structures that do not Require a Directly Connected Biasing Circuit

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Abstract—An initial study of novel Magneto-static Responsive Structures (MRSs) and their application to the frequency reconfigurability of a printed dipole antenna is presented here. The embodiment of the MRSs consisted of a cylindrical cavity with a diameter of 0.9 mm drilled into a 20.0 mil thick 1.5 mm x 1.5 mm TMM4 substrate. The cavities were partially filled with silver coated magnetic particles and covered on the top and bottom with copper tape. The conducting magnetic particles responded to an externally applied magnetic field and formed columns in the direction of the magnetic field lines. The columns connected the top and bottom conducting planes, acting as a switch. It was demonstrated that the electrical length of an antenna could be changed and the resonant frequencies could be reconfigured from 1.5 GHz to 1.9 GHz by incorporating the MRSs into the dipole antenna and controlling the ON and OFF states of the MRS switch. Overall, it was shown that the simulated results agreed well with the measurements. It was also demonstrated that the proposed MRSs do not need directly connected biasing circuitry, making them particularly useful for complex antenna designs.

I. INTRODUCTION

There is a large need for frequency reconfigurable antennas in wireless devices that operate in multiple frequency bands. Conventional methods to achieve frequency reconfigurability include PIN diodes, field effect transistors (FETs), and radio frequency micro-electromechanical systems (RF MEMS); which require DC biasing circuitry for their operation [1]. Furthermore, some applications cannot accommodate embedded components that require biasing circuitry. Therefore, there is an interest in components that eliminate this requirement.

In this paper, the novel Magneto-static Responsive Structures (MRSs) shown in Fig. 1(a)-(d) are presented and their use to reconfigure a printed dipole antenna is demonstrated for the first time. More specifically, the MRSs consist of cavities in a TMM4 material with silver coated microscopic magnetic particles [2] as shown in Fig. 1(e) and 1(f). When a static magnetic field is introduced to the MRSs, the particles stack and align with the field to connect the two conducting planes (Fig. 1(b)). Then, when the magnetic field is removed the particles settle (Fig. 1(a)), disconnecting the two planes. This then results in a behavior similar to an RF switch changing from an inductive to capacitive state for reconfigurability.

Fig. 1. Magneto-static Responsive Structures (MRSs) evaluation, (a) Side view of a single MRS in the ’OFF’ state; (b) Side view of a single MRS in the ’ON’ state; (c) Dimensions of the MRS and the ’OFF’ state demonstration; (d) MRS shown in the ’ON’ state (particles aligned); (e) Microscopic view of the magnetic particles; and (f) Manufactured MRS cavity partially filled with magnetic particles.

II. MAGNETO-STATIC RESPONSIVE STRUCTURE DEVELOPMENT

The dimensions of the TMM4 material with the cavity are shown in Fig. 1(c). The cylindrical cavity had a diameter of 0.9 mm and was partially filled with the silver coated particles (average diameter = 40.0 microns) shown in Fig. 1(f). Then, the top and bottom of the cavity was capped with conducting copper tape to complete the structure. This resulted in a partially filled cylindrical cavity between the two conducting planes, which was the final embodiment of the structure. As a first step, the MRSs were modeled in the simulation software HFSS. The results of the full wave electromagnetic simulations showed that the MRSs had good...
III. RESULTS

A printed dipole antenna with an integrated balun was designed in HFSS following the procedure reported in [3]-[4]. As shown in Fig. 3, the printed dipole has two radiating arms each with a small gap. The two arms of the dipole were printed on the top of the TMM4 substrate (thickness 1.524 mm) with εr = 4.5 and tan δ = 0.002. Similarly a via hole balun was printed on the bottom side using the concept of a microstrip to strip line transition [3] from 50Ω to 70Ω. The bottom conducting plate of the MRSs was then connected to the large conducting strip of the dipole arms using solder, as shown in Fig. 3, whereas the top conducting plane was attached to the small conducting strip of the dipole arms with copper tape. The S-parameters of the reconfigurable dipole were computed in HFSS and are shown in Fig. 5 for both the ON and OFF states of the MRSs.

Next, a prototype of the layout in Fig. 3 was manufactured and is shown in Fig. 4. A permanent magnet was used to apply a static magnetic field to the MRSs. When the magnet was brought within 1.0 cm of the MRSs, the particles aligned, connecting the top and bottom conducting planes (ON state), and the smaller portions of the dipole arms. The ON state increased the electrical length of the printed dipole and resulted in a measured resonance at 1.5 GHz, as shown in Fig. 5. When the magnet was removed, the particles collapsed and disconnected the two conducting planes (OFF state), and the smaller portions of the dipole arms. The OFF state resulted in a smaller electrical length and a measured resonance at 1.9 GHz, also shown in Fig. 5. Overall, good agreement between simulations and measurements was observed as shown in Fig. 5. This novel technique eliminated the need of biasing circuitry to be directly connected to the antenna to achieve frequency reconfigurability which makes it very attractive compared to currently used methods.

The results of this work can be summarized as follows. The antenna has good matching at 1.5 GHz and 1.9 GHz which, corresponds to the ON and OFF states of the MRSs, respectively. Furthermore, the bandwidth of the reconfigurable antenna in the ‘ON’ state was 8%, whereas in the ‘OFF’ state, the bandwidth was 9.4%.

IV. CONCLUSIONS

In this work, a printed dipole antenna was reconfigured using novel Magneto-static Responsive Structures (MRSs). These structures consisted of a TMM4 substrate with a cylindrical cavity drilled from it. The cavity was then filled with micron-sized silver-coated magnetic particles and capped on both ends with copper tape. When a static magnetic field was applied to the MRSs, the particles formed columns and aligned with the field lines; thus connecting the two conducting plates. This phenomenon was used to connect/disconnect the two conducting plates (made from copper tape) and was shown to work effectively to control the frequency reconfigurability of the printed dipole. Overall, results from the simulations and measurements of the dipole were shown to have good agreement at both frequencies, thus demonstrating the potential of MRSs as an alternative for reconfiguring an antenna without the need of a directly connected biasing circuit.

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