On Controlling the Propagation Characteristics of Microstrip Transmission Lines using Embedded Micron-sized Particles and Static $\overline{H}$-Fields

Jacob M. Parrow, Adnan Iftikhar, Sajid M. Asif and Benjamin D. Braaten
Electrical and Computer Engineering Department
North Dakota State University
Fargo, ND USA
Emails: jacob.m.parrow@gmail.com, adnan.iftikhar@ndsu.edu, sajid.asif@ndsu.edu and benbraaten@ieee.org

Jeffery W. Allen and Monica S. Allen
Air Force Research Laboratory
Munitions Directorate,
Eglin AFB, FL USA
Emails: jeffery.allen.12@us.af.mil, monica.allen.3@us.af.mil

Brett R. Wenner
Air Force Research Laboratory
Sensors Directorate,
Wright-Patterson AFB, OH USA
Email: brett.wenner@us.af.mil

***Abstract*—Methods to control the propagation characteristics of printed microstrip transmission lines (TLs) has many uses in phased-array scanning, tunable apertures and reconfigurable antennas. In this paper, a unique method of changing the propagation along a microstrip TL with multiple magneto-static responsive structures (MRSs) is introduced. Each individual MRS is sub-wavelength in size and does not require a directly connected biasing circuit. In particular, the MRS consists of two parallel conducting planes separated by a dielectric material (forming a capacitor) and a cavity with micro particles that can be orientated/aligned (i.e., moved) using magneto-static fields. The particles can thus be manipulated using biasing fields such that the two conducting planes can then be connected and disconnected, changing the MRS state between capacitive (disconnected) and inductive (connected). The simulation and measurement results in this paper show that the effective permittivity of a 50Ω microstrip TL can be changed using MRSs.**

Keywords—microstrip transmission line; phased-arrays; propagation.

I. Introduction

Microstrip transmission lines (TLs) are used in many aspects of printed antenna design. It has been shown that if the propagation characteristics of TLs can be controlled, unique features such as beam-forming, phase-scanning, multiple operation bands, and specificity of radiated power can be achieved [1]-[2]. However, TL control with PIN diodes, varactors or MEMS [3] may be difficult with traditional techniques as antenna designs become more complicated. This is because some antenna layouts do not allow for the placement of near-by biasing circuitry to control the propagation properties on the TLs. The objective of this paper is to

This work was supported by (FA-8651-15-2-002) by the US Air Force Research Laboratory Munitions Directorate. The authors are grateful for support from AFOSR Lab Task 17RWCOR397 (Dr. H. Weinstock).

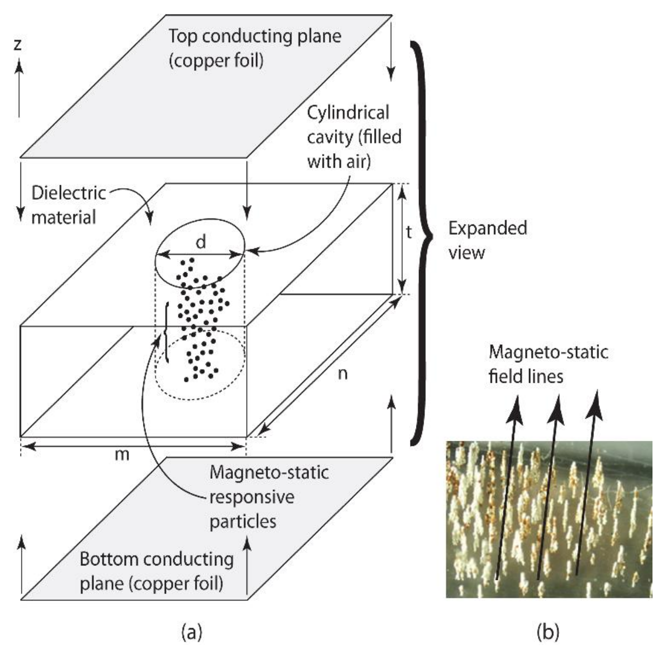

Fig. 1. (a) Expanded view of the MRS and (b) a photograph of the micron-sized particles columnizing in the direction of the magneto-static field lines.

overcome some of these limitations by introducing the use of the magneto-static responsive structure (MRS) [3] shown in Fig. 1(a) as a coupled load on the printed TL shown in Fig. 2 to control TL characteristics. This is done by embedding several of the MRSs in the TL substrate directly below the top conductor. The MRS is sub-wavelength in size and consists of two parallel conducting planes separated by a dielectric material. Within this dielectric material is a cylindrical cavity (along z-axis) consisting of silver-coated micro particles that have a magnetite core. The magnetite core allows these

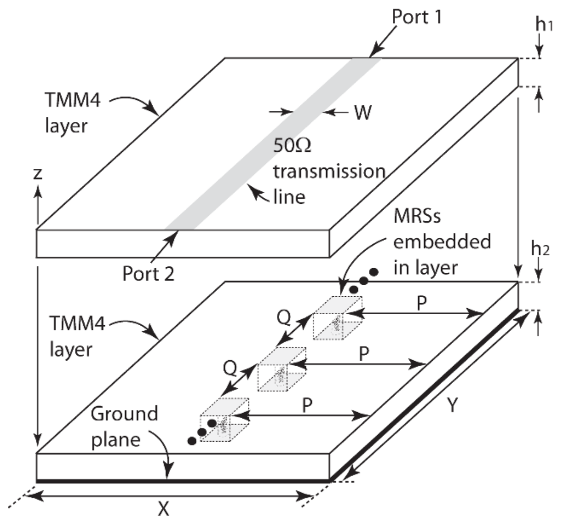

Fig. 2. Expanded view of the 50Ω TL loaded with the MRSs embedded in the substrate.

particles to be manipulated using a magneto-static field. In the absence of a biasing field, the particles settle at the bottom denoted as the OFF state. When an external field is applied, the particles columnize in the direction of the field lines (Fig. 1(b)) electrically connecting the top and bottom plates of the MRS, denoted as the ON state. This switches the MRS from a capacitive (open/OFF) to an inductive state (closed/ON).

II. Simulation and Measurement Results

The use of MRSs to control the propagation characteristics of the TL in Fig. 2 was modeled using commercial simulation software packages Advanced Design System (ADS) [4] and High Frequency Structure Simulator (HFSS) [5]. Specifically, a 5.0 cm long 50Ω microstrip TL on a 1.016 mm thick TMM4 (ϵ_r = 4.5) substrate was loaded with N = 1, 4, 6, 8, 10 and 12 MRSs, as shown in Fig. 2 and Fig. 3(a). Each MRS had overall dimensions of m = 3 mm, n = 3 mm, t = 0.508mm and d = 0.9 mm. Furthermore, the dimensions of the TL were h_1 = 0.508 mm, h_2 =0.508 mm, P = 23.5 mm, Q = 1.0 mm and W = 1.9 mm in Fig. 2 and Fig. 3(a). Next, the *change* in effective permittivity $\Delta\epsilon_{reff}$ was simulated in both ADS and HFSS for validation and the various MRS values of N. The value of $\Delta\epsilon_{reff}$ was determined by calculating the phase-constant β for various MRS values in both the ON and OFF states. Then, the difference in effective permittivity for a given N was computed using $\Delta\epsilon_{reff} = \epsilon_{eff,ON} - \epsilon_{eff,OFF}$ where $\epsilon_{reff} = \beta/k_0$, $k_0 = \omega/c_0$ and $c_0 = 3x10^8$ [2]. The HFSS simulation results are shown in Fig. 4. The simulation results in ADS were in good agreement. It should be stated that the columnized 10 – 40 micro particles (CONDUCT-O-FIL SM40P20) [6] for the MRS ON state were modeled using vias to optimize computational time. It has been shown in [3] that this is an accurate model. The OFF state was represented by removing the vias. Next, for validation the prototype TL shown in Fig. 3(b) with N = 3 was fabricated and tested. Again, vias were used to represent the particles and the number of particles was estimated using the

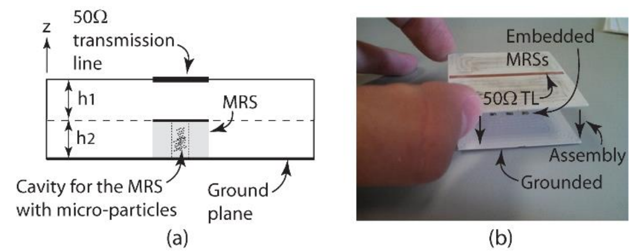

Fig. 3. (a) A cross-sectional drawing of the 50Ω TL loaded with the MRSs embedded in the substrate and (b) a photograph of the manufactured prototype with N = 3.

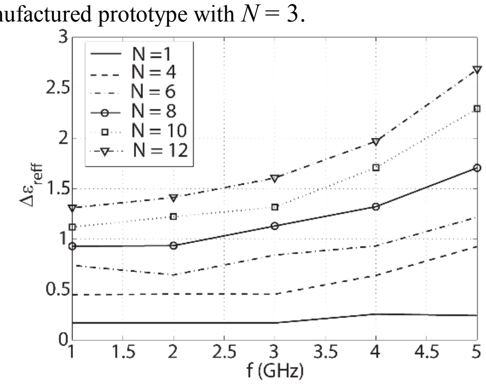

Fig. 4. HFSS simulation results as the MRSs loading the TL are switched between the ON and OFF states for all N values.

techniques reported in [3]. The change in effective permittivity was measured at 2.5 GHz to be 0.25. The values simulated in ADS and HFSS were 0.3 and 0.35, respectively. Note that other values of N = 1 and 5 were measured showing similar agreement and change in $\Delta\epsilon_{reff}$.

III. Conclusions

The use of a magneto-static responsive structure (MRS) to control the propagation characteristics of a 50Ω TL was presented in this paper. The MRS was embedded in the substrate of the TL and loaded it in a distributive manner through coupling. It was shown that the effective permittivity and hence the propagation characteristics of the TL could be changed by controlling the MRS with a magneto-static field. Hence, not requiring a directly connected biasing circuit and illustrating the potential of using MRSs in compact antenna designs.

References

[1] Constantine A. Balanis, *Antenna Theory: Analsyis and Design*, John Wiley and Sons Inc., Hoboken NJ, 3rd ed., USA, 2005.

[2] David M. Pozar, *Microwave Engineering,* John Wiley and Sons Inc., Hoboken NJ, 3rd ed., USA, 2005.

[3] A. Iftikhar, J. Parrow, S. Asif, J. Allen, M. Allen, B. Wenner and B. D. Braaten, "Improving the Efficiency of a Reconfigurable Microstrip Patch using Magneto-Static Field Responsive Structures," *IET Electronics Letters,* vol. 52, no. 14, pp. 1194-1196, Jul. 2016.

[4] Keysight Tech., (Jan. 5, 2016) Advanced Design System (ADS), [Online], Available: www.keysight.com.

[5] ANSYS Inc., (Jan. 5, 2016) High Frequency Structure Simulator (HFSS), [Online], Available: www.ansys.com.

[6] Potters Industries LLC, July 2016. [Online]. Available: www.pottersbeads.com.