Möbius Strip with Back-to-back CPW Transmission Line: Simulation and Microwave Characterization

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Abstract— A Möbius Strip device composed by two CPW — coplanar Waveguide placed back-to-back was constructed simulated and characterized. This device also named B2B-CPWMÖS exhibit a behavior like an infinite transmission line with characteristics capable of retaining a large bandwidth frequencies. This work presents some insight into this behavior by EM simulations using simulators with FIT — Finite Integration Technique and measurements in microwave range from MHz to few GHz. This work also shows how to fabricate simple CPW devices and the perspectives for planarization of this 3D structure. Additional EM behavior such as infinite transmission line and retention of a large bandwidth of signal frequencies of B2B-CPWMÖS is also discussed in this paper. This last capability gives rise to real time retention, RTR behavior and originates the RTR devices. The Möbius B2B-CPW device shows a continuous phase change compared to short-circuited classical transmission line. This paper presents also a qualitative analysis of this kind of structure.

1. INTRODUCTION

1.1. Möbius Strip: Geometrical and Topological Definitions

Some Möbius strip definitions are presented. There are geometrical and topological definitions. The Mobius strip is a one-sided non-orientable surface with Euler characteristic $\chi = 0$. Topologically, the Mobius strip can be defined as the square $[0, 1] \times [0, 1]$ with its top and bottom sides identified by the relation $(x, 0) \sim (1 - x, 1)$ for $0 \leq x \leq 1$, [1] as in the diagrams shown in Fig. 1.

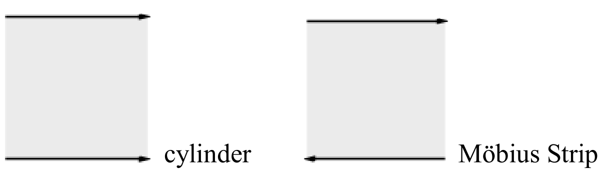

Figure 1: Topological representation of cylinder and Möbius strip.

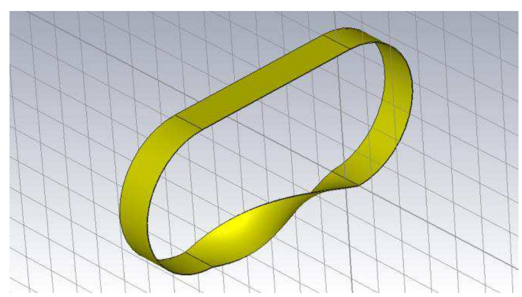

Figure 2: The classical Möbius strip in the simulator environment.

1.2. Signal Feed Considerations

One of the most critical challenges related to the Mobius strip devices is how to excite the structure by means a connection to the generator. This problem was investigated by simulation and measurements with a VNA — Vector Network Analyzer. Several Möbius strip devices were made with different length. A more sophisticated device based on Möbius strip topology is the CPW Back-to-Back Möbius Strip shown in Fig. 3. Due to this special topology, antenna with Möbius strip configuration, if properly bisected, could present approximately the double of electrical length when compared with conventional ring radiators [2]. This could improve, for example, miniaturization of RFID antennas. Several devices were simulated, fabricated and measured showing EM behavior that needs special techniques for simulation, measurement and characterization.

2. BACK-TO-BACK CPW MÖBIUS STRIP: FABRICATION PROCESS

Recent work on this type of devices was done by using special substrates such as Taconic TLY5 [3] with low dielectric constant $\varepsilon = 2.2$ [4]. Antennas and other devices are also fabricated with the above substrate [5]. Initially, in this work, the CPW line is calculated for $50\,\Omega$ impedance on a polyester PET (polyethylene terephthalate) substrate $\varepsilon = 3.4$ with 5 mils (~ 0.125 mm) thickness.

(a) (b)

Figure 3: The constructed B2B-CPWMÖS (a) copper CPW lines on the PET substrate: developed length 295 mm, (b) the complete device with one twist.

Due to the ratio between substrate and copper thicknesses adequate corrections were done. Preliminary layout of CPW lines are printed on the PET substrate. Then, cooper foils with adhesive were cut and bonded to the PET substrate. After full characterization of individual CPW lines, one directional coupler was incorporated to one of the lines. These measurements enable a more precise match between constructed CPW devices.

The dimensions of CPW lines and B2B-CPWMÖS are shown in Fig. 4.

The directional coupler was calculated by simple assumptions and dimensioned for CPW and SMA connectors. One of the CPW lines is kept with a metallic ground underneath the substrate. This additional ground works as a shield between the two CPWs. In the following step both lines are glued back-to-back. Special care must be exercised to avoid excessive adhesive layer and air bubbles between lines. Then the assembly was twisted to establish a Möbius surface and subsequently, make connections to keep electrical continuity for both lines: ground and centerline.

The directional coupler which was inserted in one of the CPW line has PORT 1 for signal feed and the PORT 2 for 50 Ω termination. After SMA connections, the B2B-CPWMÖS is read to be characterized.

3. SIMULATION ENVIRONMENT AND LIMITATION

The topological nature of Möbius strip with a non-orientable surface imposes a limitation on the meshing process in commercial software packages. The meshing procedure is essential to evaluate the response by the numerical methods. Under these constraints there is a special choice of meshing operation when it is attempted to solve the EM equations. The area with the meshes is depicted in Fig. 5.

The simulation of S_{11} parameter is carried out by CST-Studio as shown in Fig. 6.

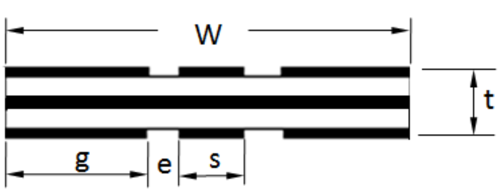

Figure 4: CPW dimensions (out of scale): W = 10 mm, t = 0.445 mm, g = 3 mm, e = 1.0 mm, s = 2 mm, copper foil thickness 0.065 mm, PET thickness = 0.125 mm.

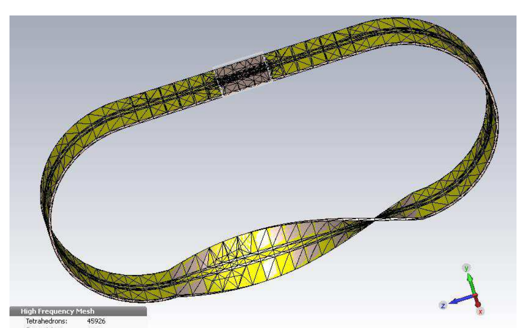

Figure 5: Mesh cells on the structure of a B2B-CPWMÖS.

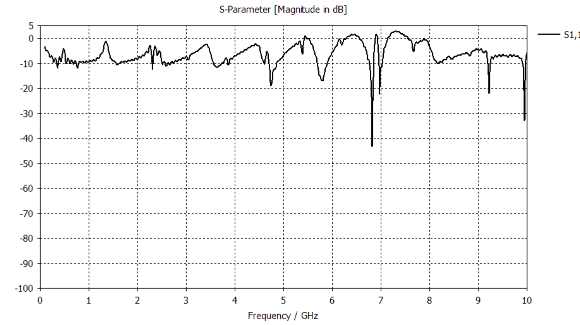

Figure 6: Simulation of B2B-CPWMÖS: S_{11} up to 10 GHz.

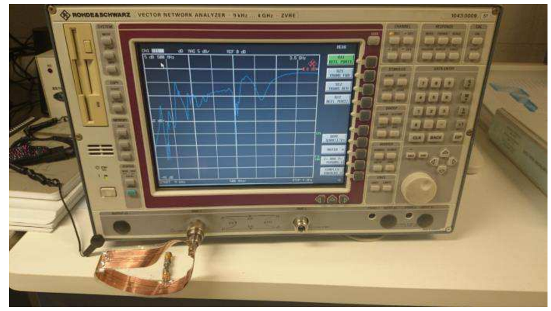

Figure 7: Setup for measurement up to 4 GHz.

4. MEASUREMENTS, RESULTS AND DISCUSSION

The device was characterized by two VNA instruments with frequency range from 0.1 MHz to 4 GHz. The test setup is shown in Fig. 7.

The results as shown in Fig. 8, demonstrate the feasibility of B2B-CPWMÖS devices and the microwave behavior as an infinite transmission line.

Time Domain measurements, (conversion from frequency domain data with IFFT — Inverse Fast Fourier Transform) is obtained, Fig. 9.

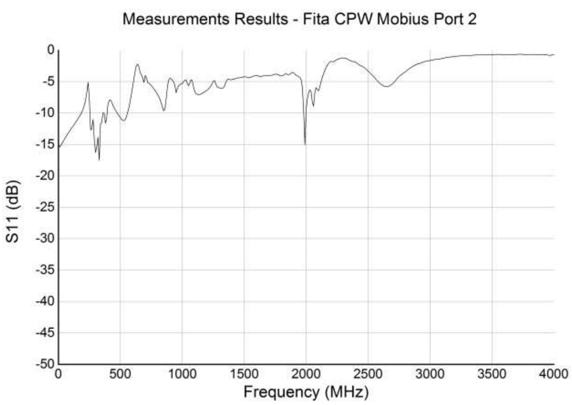

Figure 8: Return loss (S_{11}) measurement for the B2B-CPWMÖS.

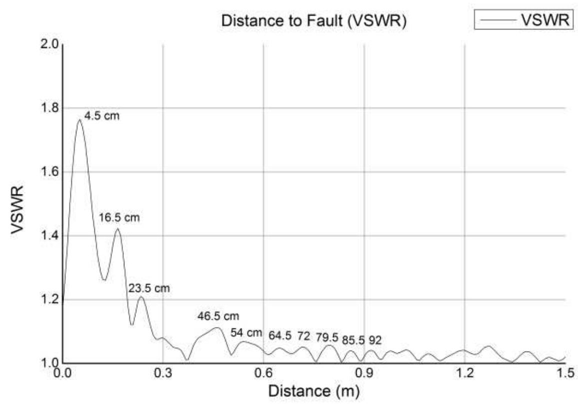

Figure 9: Time domain measurements on B2B-CPWMÖS (see text).

The multiple reflected pulses in the TDR signal (shown as cm values) indicate multiple transit of the signals around the Möbius CPW lines. The first spike at 4.5 cm indicates the reflection at PORT 2 of the directional coupler. The second spike is related the discontinuities created at the point where the two CPWs lines were welded together. The several peaks after 46.5 cm represent [4] the various transit time of the signal around the B2B-CPWMÖS device. The electrical length and guided wavelength λ_g, must be considered for this analysis.

This assumption implies that for a broadband of signal frequencies there is a retention phenomenon that could be demonstrated by real or physical TDR measurements.

There is a need for in-depth Mathematical and Electromagnetics studies to full understanding the Möbius Strip as microwave devices.

A crux of the matter to be investigated is how to planarize such devices to be integrated on planar circuits [6–8] and the combination of this structure with Metamaterials concepts [9].

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