On the Accuracy of Flexible Antennas Simulations

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***Abstract*—The performance of wearable and flexible antennas can be greatly affected by bending and crumpling. While these effects have been studied in the literature, the accuracy of simulation in these conditions should be considered. In this paper, the effects of accurate modeling of the excitation, and the supporting structures are investigated.**

***Keywords*—bending effects, flexible antennas.**

I. Introduction

Flexible electronics have been of interest due to their applications in wearable and the Internet of Things (IoT) [1]-[7]. In this context, many researchers have investigated various types of planar antennas on flexible substrate materials, e.g., textile [1]-[7], flexible 3D printed materials [6], and Liquid Crystal Polymer (LCP) [7]. There are multiple challenges in designing flexible antennas, e.g., material characterization, durable structural designs, feeding structures and matching network designs, and prediction of the effects of bending and crumpling.

To understand the antenna's behavior under various conditions such as bending and crumpling, electromagnetics simulation tools are used, however, it is often difficult to design a simulation setup that exactly mimics the details of measurement setups. In this paper, we intend to show the effects of some of the often missed details that can affect the accuracy of the simulation results.

II. Antenna Model and Analysis

A. Antenna Model

To show the effects of excitation modeling, we chose an antenna described in [7]. This antenna has a very thin layer of LCP (thickness 0.1 mm) as its substrate and is fed through a Co-Planar Waveguide (CPW) line. The overall size of the antenna is 20 mm × 32 mm in its flat shape. The other dimensions are mentioned in Table 2 of [7]. All the measurement results are taken from this reference are referred to as "Measured_Ref".

B. Excitation Model Effects

All the simulations in this paper are performed using ANSYS HFSS 2019 R3 [8]. There are various excitation models available in HFSS. The most common ones used for planar antennas are wave-port and lumped-port. We do not show the lumped-port model in the paper for brevity. The Lumped-port requires an additional structure to connect two ground planes of CPW that can lead to deviation from the measurements without careful consideration. We considered three types of Wave-ports, as shown in Fig. 1. This figure clearly shows the differences between the current distributions on the planar monopole for these three feeding methods. To investigate further one can examine the impedance seen by the port. Fig. 2 shows the real part of port impedance for various cases. While SMA (SubMiniature version A) model maintains the 50 Ω impedance, even after bending the antenna in the H-plane, the other wave-port models show a variation of impedance. Fig. 3 shows how these can affect the accuracy of the reflection coefficient compared to measured values for a flat antenna.

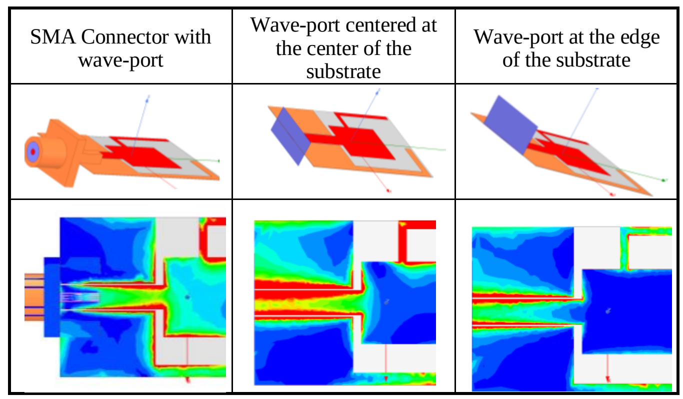

Fig. 1. Comparison of three different excitation models in HFSS and the current distribution generated by them.

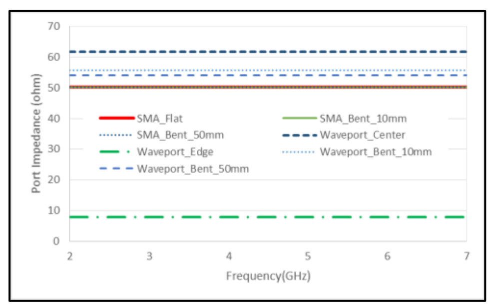

Fig. 2. The real part of the port impedance of different types of excitation for flat and bent antenna models.

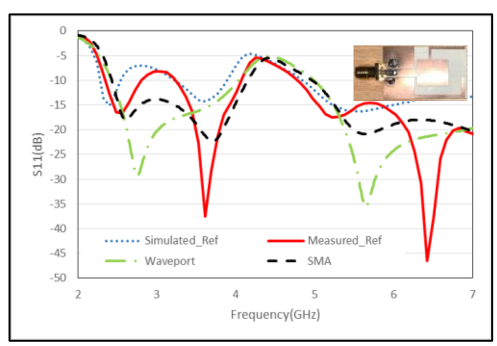

Fig. 3. Reflection coefficient comparison for SMA and waveport fed antennas with the measured values (Measured_Ref) and simulated values (Simulated_Ref) obtained from [7].

This work is supported financially by PADT Inc.

Submitted On: September 9, 2020
Accepted On: September 9, 2020

https://doi.org/10.47037/2020.ACES.J.351175

A. Bending and Support Material Effects

Fig. 4 shows the simulation results of bending the antenna on a cylindrical surface with a radius of 10mm in the H-plane. We considered the H-plane bending since it has more effects on the feeding structure. Although the SMA model maintains very good matching to 50 Ω (Fig. 1), the simulation results do not match the measurement (Fig. 4 (a)). In the initial attempt, we investigated the effects of conductor thickness or the CPW gap (parameter g in Table 2 of [7]) that could have been affected by the physical bending, however, these had a negligible effect on the results. A closer look at the photograph of the measurement setup in [7] shows that the antenna was bent on a supporting cylindrical structure (Fig. 4 (b)). The reference does not provide information about this material. Two different materials were used for 10 mm and 50 mm bending. In many situations, the effect of the supporting structure is neglected to simplify the simulation. This antenna has a very thin substrate and the support structure has affected the matching. By including a 0.7 mm thick support structure (Fig. 4 (b)) of Plexiglas ($\varepsilon_r = 3.4$) we found that the simulation better represents the measurements (Fig. 4 (c)). In this simulation first, we used a complete cylinder of Plexiglas, but it is also seen that the support structure is not exactly aligned at the SMA location. An estimated ring of vacuum was added to represent this misalignment. A similar investigation for bending with a 50 mm radius showed a support structure such as foam ($\varepsilon_r = 1.6$) with 2.5 mm thickens can represent the support material (Fig. 5).

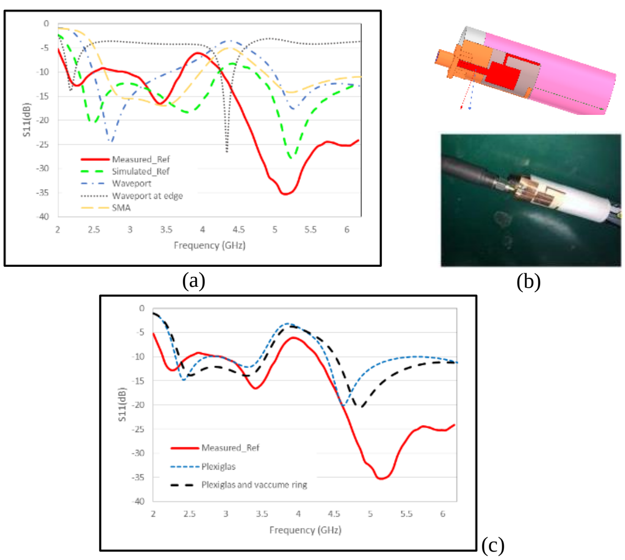

Fig. 4. (a) Reflection coefficient comparison for SMA fed bent antenna on a 10 mm radius without a support structure, (b) support structure, and (c) reflection coefficient with a support structure, measurement data from [7].

B. Surface Curvature Transition Effects

Another detailed effect is the transition from the planar surface to the bent shape. Due to the rigidity of the SMA connector, it is not possible to get a complete bent surface closer to the SMA connection. To include this effect, we connected a bent part to the planar part using a transition area, as shown in Fig. 6. A support structure of Polyester ($\varepsilon_r = 3.2$) with 1.15 mm thickness was used.

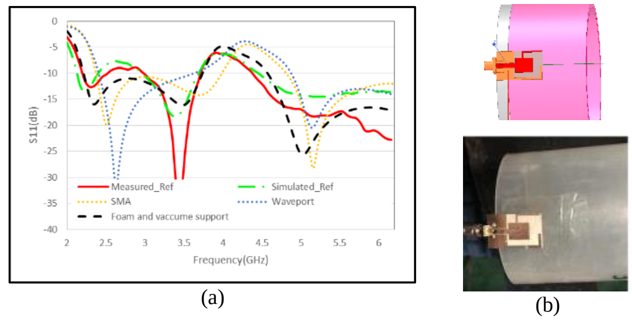

Fig. 5. (a) Reflection coefficient comparison for SMA fed bent antenna on a 50 mm radius, and (b) support structure, measurement data from [7].

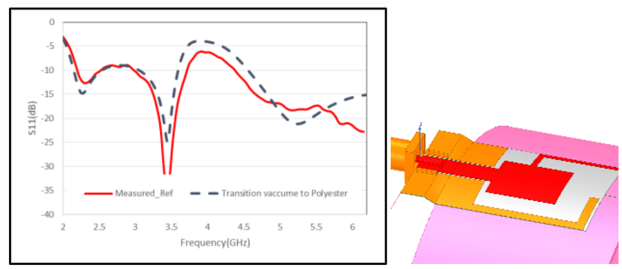

Fig. 6. Reflection coefficient comparison for SMA fed bent antenna on a 50 mm radius with the transition from planar to the cylinder.

III. CONCLUSIONS

The accurate simulation of flexible antennas requires attention to include details of measurement such as support structure, shape deformation, and accurate model of excitation. Due to the length of the paper, detailed examples will be provided in the presentation.

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