Characterization of the electromagnetic properties of textile fabrics for the use in wearable antennas

Declercq Frederick

Supervisor(s): Prof. Dr. Ir. Hendrik Rogier

Abstract— **Efficient textile antenna design is based on an accurate knowledge of the electromagnetic properties of textile materials. Therefore, we propose a characterization method that removes the perturbations in the calculated properties, due to imperfect deembedding and inhomogeneities of the textile microstrip line structure.**

Keywords— **wearable antennas, permittivity, loss tangent, textile transmission lines**

I. RESEARCH CONTEXT

THE new generation of garments, equipped with intelligent textile systems, will be able to continuously monitor the environmental and biomedical conditions of the user. A wireless link that transfers the acquired data to a nearby control unit is established by an antenna. A patch antenna like the one proposed in [1], constructed from conventional fabrics and conductive e-textiles allow unobtrusive integration of the antenna in the new generation garments and this without disturbing the movements of the user. Specifications such as radiation efficiency, bandwidth and resonance frequency of these antennas are in essence determined by the electromagnetic properties of the textile substrates, e-textiles and the antenna geometry. Unlike conventional high-frequency laminates, the electromagnetic properties such as permittivity ϵ_r and loss tangent $\tan\delta$ of textile substrates are not readily available. In this research an accurate electromagnetic characterization of textile substrates is performed and the results are validated by comparing simulated and measured antenna performances.

II. CHARACTERIZATION METHOD

The characterization method is based on scattering (S-)parameter measurements of two microstrip lines with different lengths. Next, a deembedding algorithm, based on symmetry and reciprocity of the test structures, extracts the complex propagation constant $\gamma = \alpha + j\beta$ from the measured two-port S-parameters. However, these measurements performed with a vector network analyzer are far from being ideal. Non-identical coax-microstrip transitions due to fabrication inaccuracies are responsible for the errors in the deembedded transmission line parameter. Also dimensional tolerances of the textile transmission lines, traction and torsion applied by the measurement cables, parasitic mode excitation and electromagnetic coupling results in an unphysical behavior of the extracted effective permittivity and loss tangent as a function of frequency. Modelling these perturbations as an unknown noise contribution and applying the matrix-pencil method as averaging method allows us to minimize the errors in the extracted electromagnetic properties [2].

III. EXPERIMENTAL RESULTS

A. *Materials and teststructures*

The proposed method was used to characterize two differently woven aramid fabrics. fabric 1 is a plain weave from yarns with two different thicknesses (uneven surface) while fabric 2 is a twill weave from identical yarns (even surface).

F. Declercq is with the Information and Technology Department, Ghent University (UGent), Ghent, Belgium. E-mail: frederick.declercq@UGent.be

The antenna substrates consist of an assembly of three and four aramid layers, resulting in an overal substrate thickness of 1.8mm and 1.67mm for fabric 1 and 2 respectively. The aramid layers and conductive surfaces were assembled by means of an adhesive sheet. For each of the two substrates, two pairs of microstrip lines with a length difference of about 60mm were fabricated. The first pair, based on solid copper foil for the conductive surfaces, allowed us to estimate the $\tan\delta$ of the aramid substrate. The conductive layers of the second pair were made out of $Flectron$, a copper coated nylon fabric.

B. Experimental results

The extracted $\epsilon_{r,eff}$ and $\tan\delta$ for the twill and plain woven aramid substrates is depicted in Fig.1 and shows us that the weave pattern affects the density of the substrates and thus the corresponding EM-properties. The extracted $\epsilon_{r,eff}$ at 2.45GHz for fabric one and two are 1.42 and 1.67, respectively, resulting in an $\epsilon_r = 1.57$ for fabric one and 1.91 for fabric two. The calculated averaged $\tan\delta$ over the frequency range from 1GHz to 10GHz is 0.007 and 0.015 for fabric one and two respectively.

C. Validation

For validation purposes, two planar antennas on each substrate were designed using Momentum from Agilents Advanced Design System. The copper foil based antenna allowed us to evaluate the extracted $\tan\delta$ by fitting the simulated radiation efficiency to the measured radiation efficiency. A corrected $\tan\delta$ = 0.012 and 0.019 results for fabric one and two, respectively. Comparing the simulated resonance frequencies of the Flectron based antennas as depicted in Fig. 2 allowed us to evaluate the calculated ϵ_r and this while taking into account a geometrical tolerance of $\pm 0.5mm$ of the antenna's length. The corresponding ϵ_r intervals for fabric one and two are [1.54-1.61] and [1.88-1.95] from which we can conclude that the extracted permittivity is accurate given the geometrical tolerance.

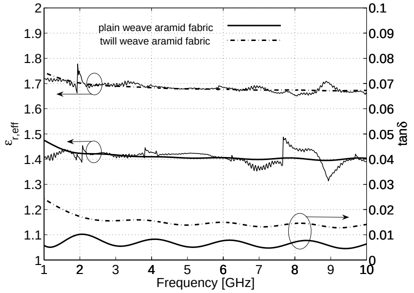

Figure 1. Electromagnetic properties aramide substrates

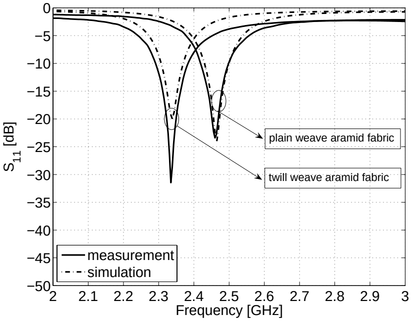

Figure 2. Reflection parameters Flectron based textile antennas

IV. CONCLUSIONS

A new matrix-pencil two-line method was proposed for the dielectric characterization of textile materials. This method minimizes the deviations in the calculated EM properties of the substrate which are caused by transmission line inhomogeneities and geometry uncertainties.

REFERENCES

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