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Published in:
2016 Global Symposium on Millimeter Waves, GSMM 2016 and ESA Workshop on Millimetre-Wave Technology and Applications

DOI:
10.1109/GSMM.2016.7500324

Published: 27/06/2016

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Khanal, S., Semkin, V., Asadchy, V., Ala-Laurinaho, J., Alastalo, A., Sneck, A., Mäkelä, T., Tretyakov, S., & Räisänen, A. (2016). Towards printed millimeter-wave components: Material characterization. In *2016 Global Symposium on Millimeter Waves, GSMM 2016 and ESA Workshop on Millimetre-Wave Technology and Applications* Article 7500324 IEEE. https://doi.org/10.1109/GSMM.2016.7500324

Towards printed millimeter-wave components: material characterization

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***Abstract*—This paper presents the results from evaluation of suitable materials and ink properties for printing millimeter wave components. Dielectric parameters (relative permittivity and loss tangent) of various potential substrate materials are extracted from S-parameter measurements and simulations. Test samples are being printed over Polyethylene Terephthalate (PET) substrate and the measurement of their performance will be reported in the final paper.**

Index Terms—printing, material characterization, mm-wave, relative permittivity, loss tangent

I. Introduction

Printing technology is one of the promising methods for manufacturing electronic devices. Different structures can be printed on large areas at one time reducing the manufacturing costs. During the last years, it was shown that printing technology, e.g. inkjet printing, can be used in various applications [1], [2]. In this work, we study other printing techniques such as screen printing and reverse offset printing and their applicability to millimeter wave component fabrication.

In order to design and print electronic structures on polymers, it is necessary to know the parameters of these materials, such as relative permittivity and dielectric loss tangent. Usually, these properties are provided by the manufacturer at low frequencies only which is not sufficient when designing components for millimeter waves. For example, in [3], the authors characterize the SU-8 material at 30 GHz using microstrip and T-resonators structures.

In this paper, measurements of five other materials were performed at 75-110 GHz frequency range. Transmission and reflection coefficients were measured to extract relative permittivity and loss tangent. The aim of this paper is to characterize properties of different materials, possible to use in printing, at millimeter wave frequencies.

II. Material Measurement and Simulation

A. Sample preperation and measurement

Careful sample preparation is vital for dielectric parameter extraction of any test material. In this work, printing material test samples are inserted into steel holders with the dimensions matching the WR-10 (75-110 GHz) standard waveguide. S-parameter measurements are then carried out, with a vector network analyzer, by placing the specimen between waveguide test heads. Both reflection and transmission coefficient magnitude and phase are measured. The material parameters

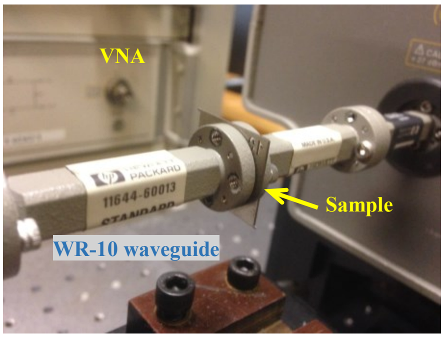

Fig. 1. Material sample placed between the waveguide extension units for S-parameter measurements.

(dielectric constant and loss tangent) are then extracted from (a) comparison to simulation results and (b) analytical formulas relating S-parameters and the sample permittivity. Fig. 1 shows the photograph of the S-parameter measurement setup where the material sample (in the steel holder) is sandwiched between two waveguide test heads of the VNA.

B. 3D simulation in HFSS

High frequency structure simulator (HFSS) software is used to simulate the material measurement scenarios. First, an empty space between the waveguide sections representing the empty holder situation in the real measurement is taken as a reference. Second, a test material sample between the waveguides is simulated representing the printing material sample. Full two port simulation results are obtained for various sets of different dielectric constants and loss tangents, which are then compared with the measurement results to find the best fit for the material dielectric parameters.

C. Analytical extraction

Along with the direct comparison of the S-parameters from measurement and simulation, the material parameters are also calculated using the Modified Nicolson-Ross-Weir (MNRW) method. S-parameters from both simulations and measurements are used to calculate the dielectric constant and loss tangent [4], [5].

III. Results

Fig. 2 presents the comparison plot for transmission coefficient magnitude and losses in the material (PET) sample obtained from measurements and simulations. The closest match to the measurement results are observed for dielectric constant of 3.5 and 0.03 loss tangent in the simulation. Fig. 3

shows the calculated dielectric constant and loss tangent from both simulation and measurement of S-parameters for PET material. Other potential materials, suitable for printing millimeter wave components, were also evaluated in this work. Table I presents the extracted dielectric parameters of various materials, from measurement and simulation at 90 GHz.

Some of the materials, e.g. Preperm 255, exhibit small losses compared to other test material samples. This material can be a good candidate for screen printing, however, for reverse offset printing Preperm was found to be unsuitable since it was disturbing the ink transfer on the substrate from the blanket. Polyethylene Terephthalate (PET) is now being tested for printing preliminary test samples of millimeter-wave structures.

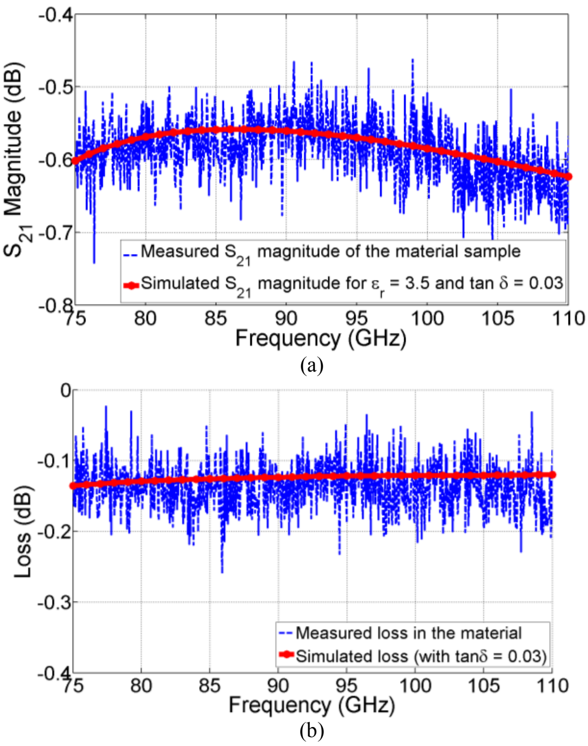

Fig. 2. Comparison of measured and simulated (a) transmission coefficient (S_{21}) and (b) losses, of the PET (Melinex) material for dielectric parameter extraction.

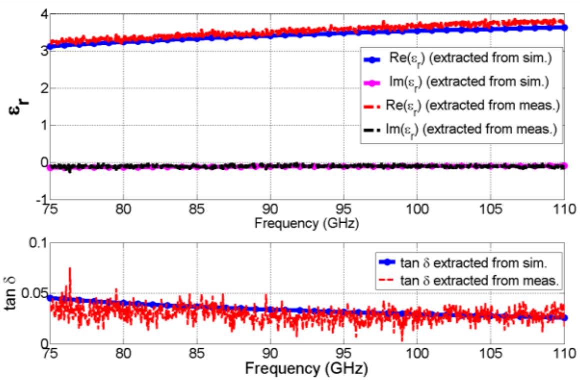

Fig. 3. Calculated dielectric parameters from measured and simulated S-parameters for PET (Melinex) material sample.

TABLE I. DIELECTRIC PARAMETERS FOR DIFFERENT MATERIALS FROM SIMULATIONS AND MEASUREMENTS AT 90 GHZ.

Material	**ε_r (sim.)**	**ε_r (meas.)**	**tanδ (sim.)**	**tanδ (meas.)**
Polyethylene Terephthalate (PET, Melinex)	3.5	3.4	0.035	0.03
Polymethyl Methacrylate (PMMA)	2.3	2.3	0.02	0.02
Polyimide film (PI, Kapton)	4.0	4.1	0.04	0.04
Polyethylene Naphthalate (PEN)	3.1	3.2	0.03	0.045
Preperm 255 (Plastic material)	2.5	2.4	0.005	0.004

IV. INK CHARACTERISATION

In addition to characterization of the substrate material, it is important to study the properties of the ink after fabrication of the test structures. A printed sample structure can placed inside/between the waveguide sections and S-parameter measurements can then be performed to obtain the transmission and reflection properties of the structure. In the final paper, measurement results will be included.

V. CONCLUSIONS

Potential materials suitable for printing millimeter wave components have been studied. Measurement and simulation results for five different materials are reported in terms of dielectric constant and loss tangent. The preliminary test prints are being made with the PET (Melinex) material. S-parameter measurement to obtain the ink properties and overall mm-wave structure performance will be presented in the final paper.

ACKNOWLEDGMENT

This work was supported by the Academy of Finland under the LATERA project. The authors would like to thank Premix Oy for providing Preperm255 material.

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