ON THE MEASUREMENT OF DIELECTRIC PARAMETERS FOR PAPER SUBSTRATES FOR RFID APPLICATION

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Abstract: This work concerns the determination of the electromagnetic parameters of the paper at UHF and RFID bands. A measurement cell in the form of an electromagnetic closed cavity has been designed and realized. The cavity contains a plexiglass test fixture for the paper samples. Dielectric parameters of the paper sample are deembedded thanks to the measurement of resonant frequencies of the cavity

Key words: Paper, Substrate, Dielectric properties, Cavity, Measurement.

1. INTRODUCTION

RadioFrequency IDentification (RFID) is a very attractive enabling technology under consideration in numerous applications covering a large variety of domains including security, access control, logistic… Due to their relative low cost and the large distance of communication, passive (i.e. batteryless) UHF tags are very promising. The crucial issues of cost, efficiency, reliability, security, and standards are under consideration by several groups worldwide [1,2]. One the most desired and promising application of RFID technology is the replacement of the well-known bar code identification. To satisfy this objective, the cost of the UHF tags must be greatly reduced in order to be comparable to the cost of bar code. To do that, the cost of the technology process and the tag substrate must be as low as possible. One of the most attractive solutions is the use of the paper as a substrate for tag realization. On the other hand, printing techniques allow today the realization of the antenna and the attachment of the RFID chip.

To be able to design the needed tag UHF antenna, the electromagnetic parameters of the substrate must be known. Thus, we developed a suitable cell for the determination of the electromagnetic properties of the paper. The measurements of the resonant frequencies as well as the quality factor for the empty cavity and the partially filled cavity with a sample of paper allow the extraction of the permittivity and the loss factor of the paper. On the other hand, the variability of these parameters as function of temperature and humidity is considered. At least 9 families of papers have been selected and studied.

2. MEASUREMENT CELL DESIGN

We designed a specific cell for the measurement of paper. This is basically an electromagnetic closed cavity in which we include a test fixture for the paper under test. The cavity is made of metal and the test fixture is made of Plexiglas. Small loop antennas have been added to the cavity in order to feed it and to measure its electromagnetic response.

The sizes of the cavity are chosen in order to reach RFID frequencies in the UHF Bands : 860 to 960MHz. To reduce the size of the cavity, ridge waveguide properties have been used. The test fixture made of plexiglass material contains many slots (less than 700µm tick each).

The measurement setup contains a network analyzer that determines resonant frequencies and transmission coefficients as function of the frequency in UHF and microwave bands.

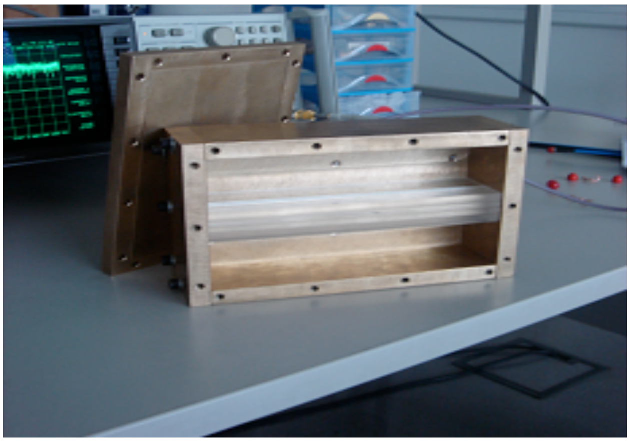

Fig. 1. Measurement cell based on ridged wavequid

We also used a second cell cavity based on rectangular waveguide. The principle of the measurement is similar to the previous cell. However, specific data processing software is available with this second cavity. This software is very useful since it greatly simplifies the data extraction. The figures below give some details on the two cells.

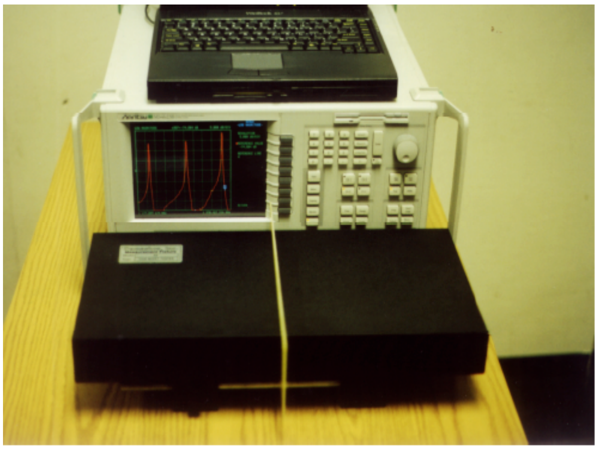

Fig. 2. Cell measurement based on rectangular waveguide. The Network Analyzer shows the resonant frequencies.

3. DEEMBEDDING METHOD

The principle of measurement is based on the use of perturbation technique. This is a very know and efficient method for solving many problems in applied electromagnetism [3].

The measurement method is based on the determination of the resonant frequencies and transmission coefficient. First, we measure the resonant frequencies and the transmission coefficient for the empty cavity. Then we enclose a sample of the paper into the cavity and we measure the variations of the resonant frequencies and the associated transmission coefficient. Then we apply the perturbation technique in order to extract the parameters of the paper [4] (relevant equations are given below).

$$\varepsilon' \approx 1 + k' + \frac{V_0}{V_e}\frac{f_0 - f_e}{f_0}$$

$$.\varepsilon''(\omega) \approx k''.\frac{V_0}{2V_{e0}}\left(\frac{1}{\sqrt{(S_{21}(\omega))_e}} - \frac{1}{\sqrt{(S_{21}(\omega))_0}}\right)$$

$$\tan\delta = \frac{\varepsilon''(\omega)}{\varepsilon'(\omega)}$$

In the previous expressions V_o is the volume of the empty cavity and V_e is the volume is the sample under test. The accuracy of the method is dependant on the ratio between the volumes V_o and V_e. On the other hand it is evident that the volume V_e is a function of the thickness of the paper sample. I this work we used standard sheet of paper with some hundreds of µm as thickness. In the test fixture we designed slots of 650µm thick and then 3 or 4 sheets of papers have been used to fill the slots.

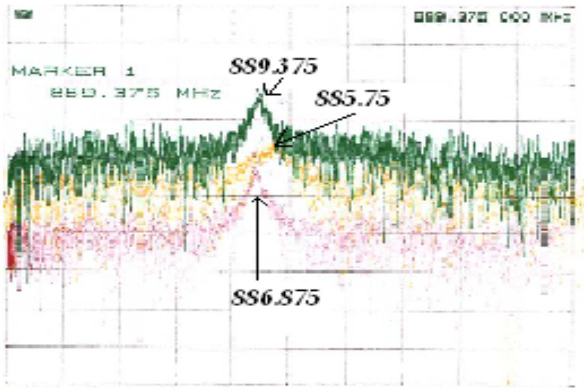

Fig. 3. Example of cavity response for three samples.

4. RESULTS

We selected 9 families of papers. Several samples have been prepared in order to fit the test fixture. The latter is organized in three parallel slots of same size 160mm*27mm. 3 or 4 sheets of paper are necessary in order to fill the slot

The different families have been chosen in order to characterize a large variety of papers corresponding to different thickness, density, orientation, composition and surface state.

#	Density (g/m²)	Thickness (µm)	Permi-ttivity	Losses
1	83,7	160.8	2.3883	0.0452
2	67,2	129.2	3.4551	0.0100
3	92,6	175.4	2.4527	0.0412
4	95,9	119.8	2.8722	0.0239
5	92,0	84	2.0997	0.0352
6	95,7	75.2	2.456	0.0377
7	76,2	71.6	2.9686	0.0310
8	81,6	108.6	2.5284	0.0422
9	276,2	472,1	1.6334	0.0425

Tab. 1 : Measured parameters for different paper family.

Table 1 describes the 9 families under test. The corresponding extracted electromagnetic parameters are reported on the same table. We study the frequency variation of these parameters. Results are given Fig. 4. One can notice that the permittivity is moderate : less than 4.5 for all the tested samples. On the other hand the loss factors lie between some 0.001 to some 0.1. Most of these substrates can be considered as candidate for RFID tags.

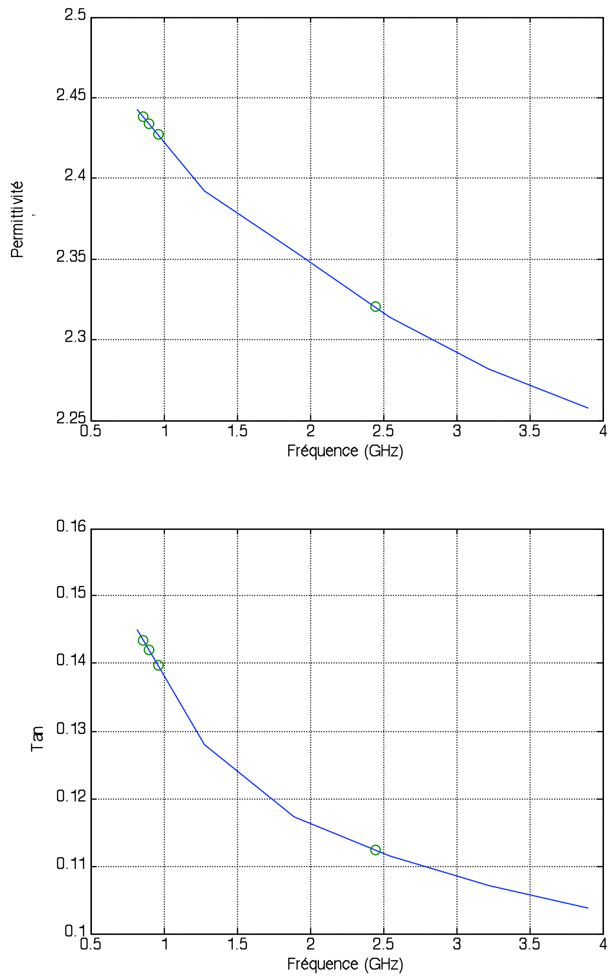

Fig. 4. Evolution of relative permittivity and losses factor versus the frequency

The paper as a substrate is quite sensitive to the humidity and temperature. Tab. 2 summarizes some of the results regarding the variability of the electromagnetic parameters of the paper.

4. CONCLUSION

This study confirms the potentiality to use the paper as a substrate in different RF application including the RFID tags. It demonstrates also the diversity of paper family as well as the variability of electromagnetic parameters under temperature and humidity variation. The developed measurement method is very flexible and can be applied to numerous substrates.

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M	**Temperature/ Humidity**	**Permittivity**	**tanδ**	**α (dB/m)**	**Δλg/ΔT (m/°C)**	**Δf (MHz)**
860 MHz	23,8°C / 41%	2.5044	0.1435	17.7644	1.0805e-005	0,24007
	18,1°C / 60%	2.5058	0.1529	18.9334		
	41°C/ 16%	2.3816	0.1380	16.6594		
900 MHz	23,8°C / 41%	2.4972	0.1420	18.3699	8.1479e-006	0,19787
	18,1°C / 60%	2.4983	0.1510	19.5385		
	41°C/ 16%	2.3842	0.1350	17.0646		
960 MHz	23,8°C / 41%	2.4863	0.1398	19.2488	5.5924e-006	15,421
	18,1°C / 60%	2.4871	0.1480	20.3811		
	41°C/ 16%	2.3882	0.1305	17.6103		

Tab 2. Variability of electromagnetic parameters under temperature and humidity changes