Universidad Carlos III de Madrid

Escuela Politécnica Superior

Bachelor's degree in Telecommunication Technologies

Bachelor Thesis

Caracterización de Materiales para Sensores de Radiofrecuencia

Extended Abstract

Author: Javier Carnerero-Cano

Tutor: Francisco-Javier Herraiz-Martínez, Ph.D.

Director: Marta Gil-Barba, Ph.D.

Department of Signal Theory and Communications

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Contents

List of Acronyms

ADS®	Advanced Design System ®
AGMSRR	Alligned-Gap Multiple Split-Ring Resonator
BT	Bachelor Thesis
BW	Bandwidth
CGMSRR	Centered-Gap Multiple Split-Ring Resonator
CPW	Coplanar Waveguide
CST®	Computer Simulation Technology ®
RF	Radio-Frequency
SRR	Split-Ring Resonator
VNA	Vector Network Analyzer

Extended Abstract

Knowledge of dielectric permittivity is essential for whatever field in electromagnetism, microelectronics, RF (Radio-Frequency), optics and, in general, in information transmission problems from an electromagnetic point of view. When commercial dielectrics are used for a particular application, they are characterized by the manufacturer, who employs a particular technique for measuring their permittivity. However, when it is necessary to know non-commercial materials permittivity, specific characterization techniques have to be applied in order to estimate accurately its value.

The specific application where arises this BT (Bachelor Thesis) is in the design of RF sensors based on metamaterial structures, in areas such as industrial or biomedical. These last sensors have applications such as substances or biomolecules detection [1]. In this context, the application of measurement techniques is necessary.

The main goal of this work is to investigate and corroborate accurate characterization techniques of dielectric permittivity in microwave range, in order to apply them to substrates (e. g. quartz, glass, pure silicon, etc.) that have certain advantages when they are used as substrate for that sensors [2], [3]. They are low-loss paramagnetic materials whose relative dielectric permittivity, ε_r, is unknown a priori and it is wanted to know. For example, an interesting case in glass is that it can be used as substrate in protein detection with techniques such as mass spectrometry and surface plasmon resonance [4], [5].

An exhaustive methodology has undertaken for the selection of the suitable technique. First of all, current measurement techniques has been analyzed and discussed. Within it, two possible classifications have been established: the first, according to the sampling technique, and the second, according to the calculation method. In both, different methods have been discussed by comparing their advantages and disadvantages. From the point of the sampling, measurement methods based on planar technologies have been chosen because they are accurate, economical, easily manufacturable, and they allow applying both resonant (for single frequencies measurements) and non-resonant techniques (for BW measurements). Regarding the calculation method, analytical techniques have mostly been applied given that computation is quick and simple. On the other hand, an example of application of two types of SRR structures (AGMSRR and CGMSRR) in the characterization of substrate samples has been shown [6]. There is a compromise between increased sensitivity for AGMSRR, or possibility of miniaturization for CGMSRR. The samples permittivity can be calculated using the method of least squares, from the percentage change in the resonance frequency due to the dielectric characteristics of the medium that the substrate induces. The errors obtained by this method are quite low.

After that, the simulation performances of four selected techniques based on planar technologies have been compared. Three resonant techniques (double T-resonator based on microstrip technology [7], ring resonator based on microstrip technology [8], and resonant line based on CPW technology) and one non-resonant technique (double line based on microstrip technology [9]) have been studied. They have been simulated by using two different electromagnetic softwares: CST® and ADS® Momentum. It has been verified that the resonant techniques are more accurate than the non-resonant at a specific frequency. The simulation global results for the ε_r achieved in the resonant techniques are shown in Table 1.

Method	Software	mean(|error ε_r|) (%)	std(|error ε_r|) (%)
Double T-resonator	CST®	3.387	2.973
	ADS®	2.412	2.219
Ring resonator	ADS®	1.106	0.827
Coplanar line	CST®	5.561	8.438
	ADS®	1.600	0.852

Table 1: *Global simulated results for ε_r.*

As it can be seen, we have obtained low errors. The ring resonator has been the method that has achieved the better simulation performance, followed by the CPW (in ADS®). In the particular case of the double T-resonator, the error grows along with ε_r. On the other hand, the double microstrip line has given us a general idea of the permittivity behavior in the simulated BW (0 GHz – 5 GHz). Its accuracy is lower at discrete frequencies than the required for this project: only in the range between 2.5 GHz and 5 GHz the average error is kept below 5%. Then, we have discarded it for manufacturing. Furthermore, in the case of the coplanar line, the order of magnitude of its $tan\delta$ has been estimated, although its accurate characterization is very difficult. From the point of view of the software, in our case, ADS® Momentum has provided better results for resonant techniques than CST®.

In the experimental measurements stage, it has been confirmed that both the double T-resonator and the ring resonator techniques (Figure 1) allow to accurately determine the ε_r of the selected RF substrates (Table 2). The coplanar line option has been discarded for our purpose since the ε_r obtained from the measurements has a higher average error than the intended. Regarding the $tan\delta$, it has been experimentally confirmed that it is very difficult to estimate its order of magnitude so, in that sense, the methods should be optimized.

Method	mean(|error ε_r|) (%)	std(|error ε_r|) (%)
Double T-resonator	2.613	2.208
Ring resonator	3.607	0.188
Coplanar line	19.204	15.732

Table 2: *Global measured results for ε_r.*

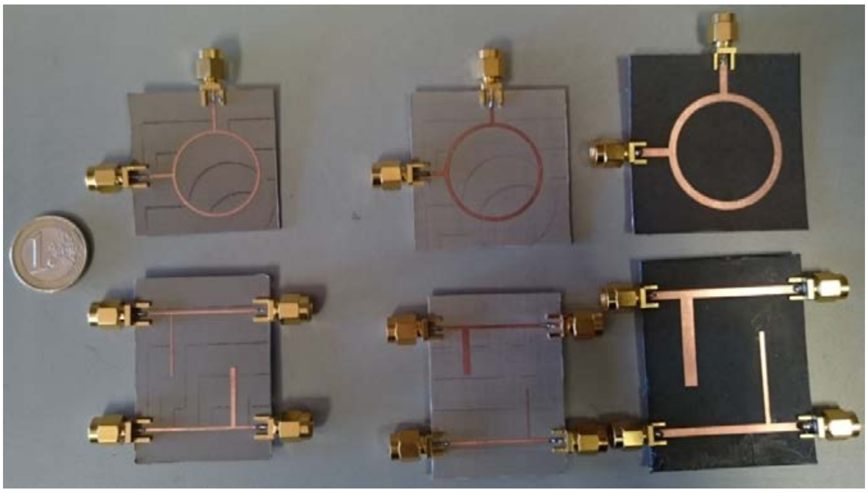

Figure 1: *Picture of the manufactured ring resonator and T-resonator prototypes.*

Taking into account all previous considerations, we can conclude that the obtained successful results satisfy the main goals defined in this BT

As a complementary study of this work, a proof of concept of the ring resonator technique for characterization of borosilicate glass and quartz substrates has been exposed. A problem we have faced is that non-commercial substrates must be metallized. The technique we could apply for metallization was the use of metallized Kapton® fixed with adhesive to our substrate. It has been found that the introduction of the Kapton® layer causes a modification of the effective permittivity and a shift in the resonance frequency. Thus, the permittivity obtained for the borosilicate glass and quartz have not been optimal. This issue should be analyzed in greater detail in order to be able to correct it.

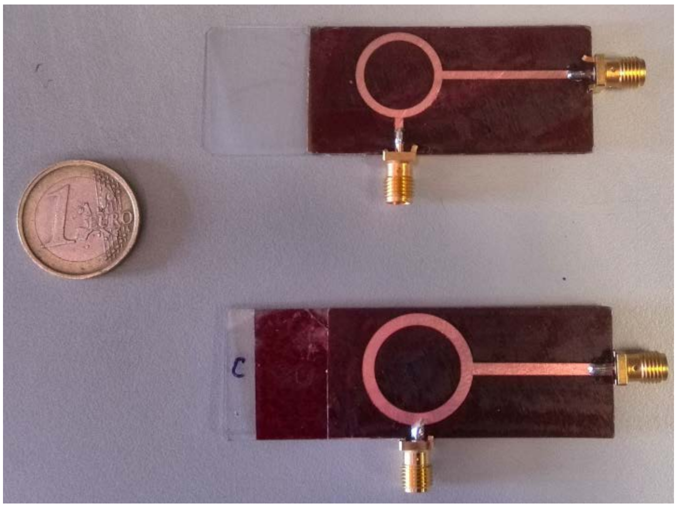

Figure 2: *Picture of the manufactured ring resonator prototypes for borosilicate glass and quartz substrates, with Kapton® layer.*

The possible future work lines that have been derived from this BT are:

- Verifying the functionality of the techniques based on planar technologies in other microwave ranges.
- To explore methods for characterization of higher loss substrates.
- To investigate accurate techniques for determining substrate loss tangent.
- Studying solutions for the problem of the influence of the Kapton® layer on the effective dielectric constant, in order to characterize non-commercial substrates. It would be advisable to perform the substrate metallization by other methods that do not generate so large deviations in the resonance frequency.
- To Research, optimize and corroborate experimentally the characterization techniques of samples based on SRR particles.
- To design and optimize RF sensors based on metamaterials structures and their applications making use of substrates like pure silicon, quartz and glass.

Keywords

Biomolecule, dielectric, dielectric permittivity, electrical characterization of materials, metamaterials, microwave integrated circuit, radio-frequency, sensor, substrate.

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