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Ultra High Frequency Circuit Identification through Gene Expression Programming

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Abstract – **The characterization of linear electrical components for frequencies up to a few MHz can be performed through impedance spectroscopy techniques that include the determination of the impedance frequency response and the algorithms that identify the equivalent circuit components. However, at higher frequencies some extra challenges are present since it is not practical to measure the impedance frequency response and s-parameters must be used. Although the conversion between s-parameters and equivalent impedance is well known, the application of the circuit identification algorithms is not straightforward.**

This paper presents a new procedure to perform circuit identification, through impedance spectroscopy, for components that operate at UHF. The s-parameters are measured and the equivalent circuit is obtained by using evolutionary algorithms, namely genetic algorithms and gene expression programming. The procedure is validated through experimental characterization of an RFID device.

I. INTRODUCTION

The techniques used in impedance spectroscopy [1] have evolved over time and recently have included the use of evolutionary algorithms [2]. These techniques can be used to characterize sensors or materials by finding circuits that correctly model their behavior under different working conditions [3] through the fitting of its measured impedance frequency response. Recent examples include applications in biomedical applications [4], corrosion analysis [5] and fuel cell characterization [6].

The procedure usually includes the determination of the impedance frequency response of the object under test either through a commercial impedance measurement instrument or, by applying a sinusoidal waveform voltage to the object and acquiring the voltage and current across it [7]. Both magnitude and phase of the equivalent impedance can be obtained by the application of sine-fitting algorithms to the acquired voltage and current waveforms [8].

However, the application of impedance spectroscopy techniques is mostly applied to devices or materials operating at frequencies up to a few MHz since it is not practical to measure impedance response at higher frequencies. At higher frequencies the device needs to be inserted into a microstrip line with connectors and a vector network analyzer (VNA) measures its frequency response in terms of s-parameters. However, the measurements now include the effect of the connectors and line and do not directly reflect the behavior of the device under test. Therefore a de-embedding procedure has to be applied to obtain the frequency response of the device under test (DUT).

In this paper, a new technique to characterize devices that operate in the UHF band is presented. This characterization is useful when a model of the device is needed for the design of a system which includes the device, for example on the design of an antenna which includes an RFID device [9]. It relies on a previous characterization of the microstrip line and associated connectors, for de-embedding the DUT from the microstrip line and in the use of gene expression programming [10], along with a genetic algorithm, to obtain an equivalent circuit. These algorithms include a cost function which compares the measured s-parameters with the s-parameters of the equivalent circuits. The proposed procedure is tested and validated by finding an equivalent circuit of an RFID device.

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II. IMPEDANCE IDENTIFICATION PROCEDURE

Impedance identification consists on finding an electric circuit topology and associated component values that exhibit a frequency response which approaches the frequency response of the device under test (DUT). Recently, this has been accomplished through the use of gene expression programming (GEP) together with a genetic algorithm (GA) [3]. This section describes how the previous procedure can be adapted for the characterization of components when the frequency range is increased onto the ultra-frequency since the measured frequency response is obtained in terms of s-parameters.

A. Measurement procedure

The first step in finding an appropriate equivalent circuit consists on measuring the frequency response of the DUT in the frequency range of interest. As the frequency range includes UHF, it is more appropriate to perform the measurement in terms of the DUT s-parameters using a vector network analyzer (VNA). Therefore, the DUT needs to be soldered onto a microstrip line that includes the connectors to the VNA as shown in Fig. 1. However, the measured s-parameters now include the contribution of the microstrip line and the connectors which needs to be taken into account while searching for an equivalent circuit of the DUT. One way to accomplish this is by modelling the transmission line and connectors as a 3-port network where ports 1 and 2 correspond to the connectors to the VNA while the DUT is connected to port 3, as shown in Fig. 2.

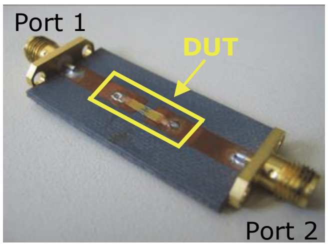

Fig. 1. Tested device inserted into a microstrip line.

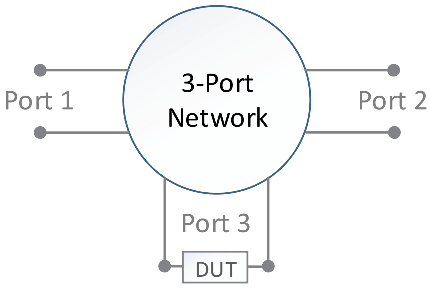

Fig. 2. Equivalent 3-port network with the DUT connected to the third port.

The 3-port network can be characterized by simulation of the microstrip line and connectors in an electromagnetic simulation software which yields its 3×3 s-parameter matrix

$$\mathbf{S_3} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}. \tag{1}$$

The insertion of the DUT equivalent impedance Z_{DUT} into port 3 results into a 2-port network with

$$\mathbf{S_2} = \begin{bmatrix} S_{11} + \Gamma \dfrac{S_{13}S_{31}}{1-\Gamma S_{33}} & S_{12} + \Gamma \dfrac{S_{13}S_{32}}{1-\Gamma S_{33}} \\ S_{21} + \Gamma \dfrac{S_{23}S_{31}}{1-\Gamma S_{33}} & S_{22} + \Gamma \dfrac{S_{23}S_{32}}{1-\Gamma S_{33}} \end{bmatrix} \tag{2}$$

where $\Gamma = (Z_{DUT} - Z_0)/(Z_{DUT} + Z_0)$ is the reflection coefficient at port 3 and Z_0 is the characteristic impedance of connecting lines [11]. Therefore, it is possible to compute the s-parameters of the resulting 2-port network shown in Fig. 2 for a given model of the DUT. The challenge consists on finding the model of the DUT such that the s-parameters of the structure in Fig. 2 fit the s-parameters measured from the circuit in Fig. 1. This is accomplished through the use of an evolutionary algorithm composed by GEP and GA.

B. Evolutionary algorithms

The search for an equivalent circuit of the DUT can be performed with evolutionary algorithms. Gene expression programming is used to search for a suitable circuit topology while a genetic algorithm is used to search for the component values of each circuit topology which is tested. Initially, a pool of 20 candidate circuit topologies is randomly generated, where each candidate is coded into a linear gene [3]. Each circuit is fed to a genetic algorithm to search for the component values that best fit the measured impedance response. At this point, each candidate circuit has a fitness value which assesses how good the circuit frequency response fits the measurements. Then the GEP algorithm creates a new pool of candidate circuits by evolving the current set of circuit topologies, through the application of its usual operators (e.g., replication, mutation, recombination and transposition [10]). The fittest circuits have a higher probability of evolving into the new population following the principle of the survival of the fittest. The algorithm stops when either the maximum number of generations is reached or a circuit with a fitness value better than a predefined threshold is found.

To search for the component values of each candidate circuit, a genetic algorithm is used. A set of genes is randomly generated where the gene is composed by the values of each component in the circuit topology under analysis [3]. The fitness of each gene is computed through a cost function that assesses, in a least-squares sense, how good the gene is. The set of genes is evolved through reproduction and mutation into a new generation.

The cost function used by these algorithms is usually defined in terms of the measured versus estimated impedance frequency response. However, in this case, since the measurements are s-parameters, the cost function is defined as

$$\varepsilon = \frac{1}{N_f}\sum_{i=1}^{2}\left(\sum_{k=1}^{N_f}\left|\frac{S_{1i_{meas}}(f_k)-S_{1i_{est}}(f_k)}{S_{1i_{meas}}(f_k)}\right|^2\right) \quad (3)$$

where the measured and estimated S_{11} and S_{12} are compared for the different measured frequencies f_k (in a total of N_f frequencies). It should be noted that only S_{11} and S_{12} are used in (3) due to the symmetry and reciprocity conditions. This cost function presents many local minima and the parameter space where the search is performed is very wide which makes traditional search methods unsuitable for the task. This is the reason for using GA in the search for the component values. However, although GA is efficient in finding the global minimum region, it is slow in converging to the actual minimum. Therefore, once GA finds the global minimum region, a traditional search algorithm is used to converge to the absolute minimum.

III. MEASUREMENT RESULTS

This section presents the results of the characterization of the device shown in Fig. 1. The DUT is an RFID passive component and its frequency response was measured, in terms of s-parameters, in the frequency range [0.5; 4] GHz. The GEP and GA algorithm obtained the circuit shown in Fig. 3 as an equivalent circuit to the RFID device under test.

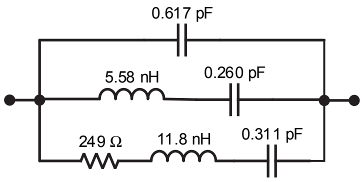

Fig. 3. DUT equivalent circuit obtained by the GEP algorithm.

The measured s-parameters parameters of the DUT inserted into the microstrip line, as presented in Fig. 1, are shown by the black lines in Figures 4 to 7. The red lines correspond to the estimated s-parameters when the DUT is modelled by the circuit in Fig. 3. Comparison between the measured and estimated parameters shows that, although the cost function only considered the S_{11} and S_{12} parameters, all the s-parameters fit quite well the measured frequency response. These results show that the DUT equivalent circuit obtained by the GEP-GA algorithm shown in Fig. 3, correctly model the behavior of the DUT at least up to 4 GHz.

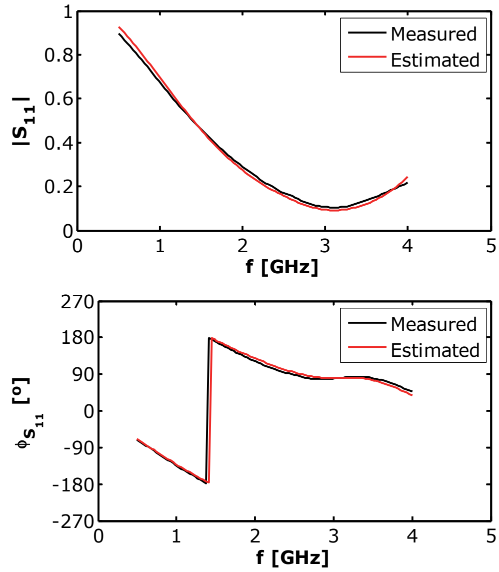

Fig. 4. Comparison between measured and estimated S_{11} parameters. Estimated parameters correspond to the parameters of the DUT modelled by the circuit in Fig. 3.

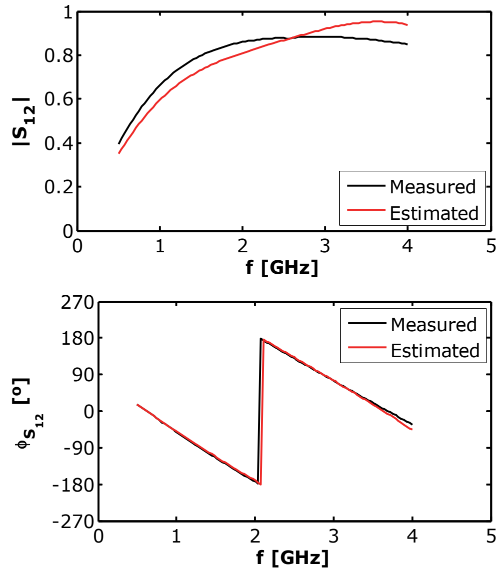

Fig. 5. Comparison between measured and estimated S_{12} parameters. Estimated parameters correspond to the parameters of the DUT modelled by the circuit in Fig. 3.

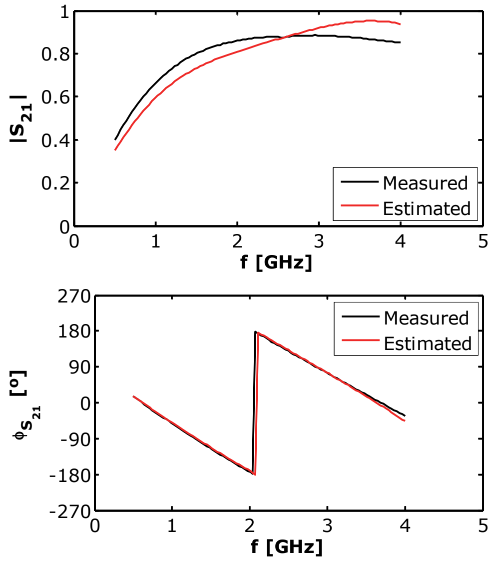

Fig. 6. Comparison between measured and estimated S_{21} parameters. Estimated parameters correspond to the parameters of the DUT modelled by the circuit in Fig. 3.

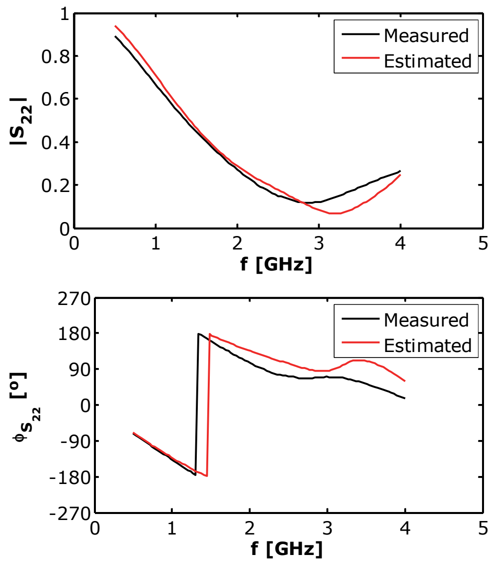

Fig. 7. Comparison between measured and estimated S_{22} parameters. Estimated parameters correspond to the parameters of the DUT modelled by the circuit in Fig. 3.

IV. CONCLUSIONS

In this paper, a procedure to characterize an unknown device in the UHF range was presented. A GEP and GA algorithm was adapted to be applied to the measured s-parameters. An RFID device was characterized by the described procedure and the frequency response of the characterized component was compared to the measurements.

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