Wavelet based detection of changes in the composition of RLC networks

Article

Published Version

To link to this article DOI: http://dx.doi.org/10.1088/1742-6596/472/1/012011

Publisher: Institute of Physics

Wavelet based detection of changes in the composition of RLC networks

2013 J. Phys.: Conf. Ser. 472 012011

(http://iopscience.iop.org/1742-6596/472/1/012011)

Wavelet based detection of changes in the composition of RLC networks

H.M. Paiva[1], M.A.Q. Duarte[2], R.K.H. Galvao[3] and S. Hadjiloucas[4]
[1]*Mectron - Odebrecht Organization São José dos Campos, SP, 12227-000, Brazil*
[2]*Department of Mathematics, Universidade Estadual de Mato Grosso do Sul (UEMS) 79540-000, Cassilandia, MS – Brazil*
[3]*Divisão de Engenharia Eletrônica, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, 12228-900 Brazil.*
[4]*School of Systems Engineering, The University of Reading, RG6 6AY, UK*

E-mails: s.hadjiloucas@reading.ac.uk ; kawakami@ita.br

Abstract. The current work discusses the compositional analysis of spectra that may be related to amorphous materials that lack discernible Lorentzian, Debye or Drude responses. We propose to model such response using a 3-dimensional random RLC network using a descriptor formulation which is converted into an input-output transfer function representation. A wavelet identification study of these networks is performed to infer the composition of the networks. It was concluded that wavelet filter banks enable a parsimonious representation of the dynamics in excited randomly connected RLC networks. Furthermore, chemometric classification using the proposed technique enables the discrimination of dielectric samples with different composition. The methodology is promising for the classification of amorphous dielectrics.

1. Introduction

In broadband dielectric spectroscopy studies of amorphous materials that lack discernible Lorentzian, Debye or Drude responses, we tend to observe a Jonscher-like admittance response of fractional order as a function of frequency [1-17]. We propose to model such response using a 3-dimensional random RLC network, as depicted in Figure 1. Large networks of resistors, inductors and capacitors can be employed as lumped-parameter representations to model the response of composite materials containing conductive, resonant and insulating grains. For fixed *R, L, C* values, the network response in the time and frequency domains depends on the fraction of each component type. An incidence matrix analysis is used to model the network of branches with nodes consisting of resistive and capacitive elements distributed across several interconnected layers. The present paper is concerned with a screening problem in which deviations from a typical network composition are to be detected. In a real setting, such deviations may arise as the consequence of faults in the production process of a composite material, which should be promptly corrected to avoid the loss of additional batches.

2. Results from simulating 3-dimensional *RLC* networks

In the current study, wavelet identification of these networks is performed to infer the composition of the networks. The analysis is carried out in terms of a wavelet decomposition of the transient response to a standard excitation.

As can be seen in Figures 2 and 3, an increase in the fraction of resistors (f_R) cannot be clearly detected from changes in the amplitude of the current waveforms $i_s(t)$.

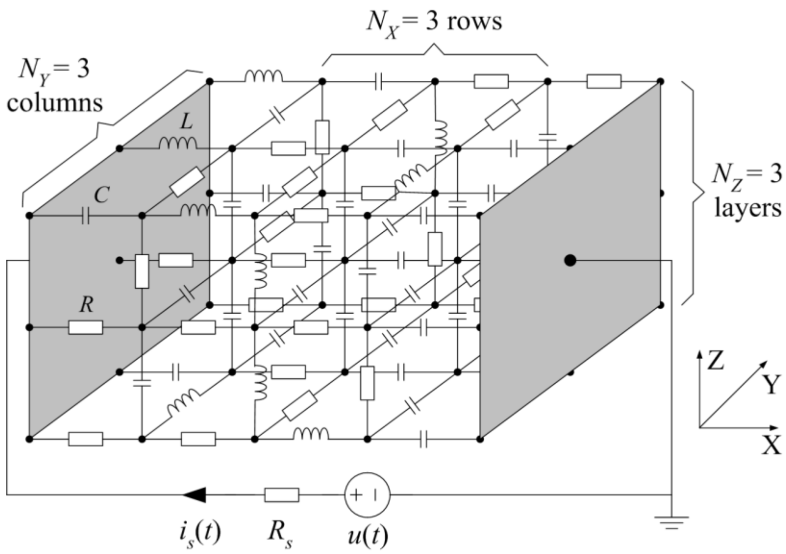


Fig. 1. Example of a 3-dimensional network with random allocation of *R, L, C* elements. The gray plates represent electrodes through which the network is connected to a nominal voltage source with resistance R_S.

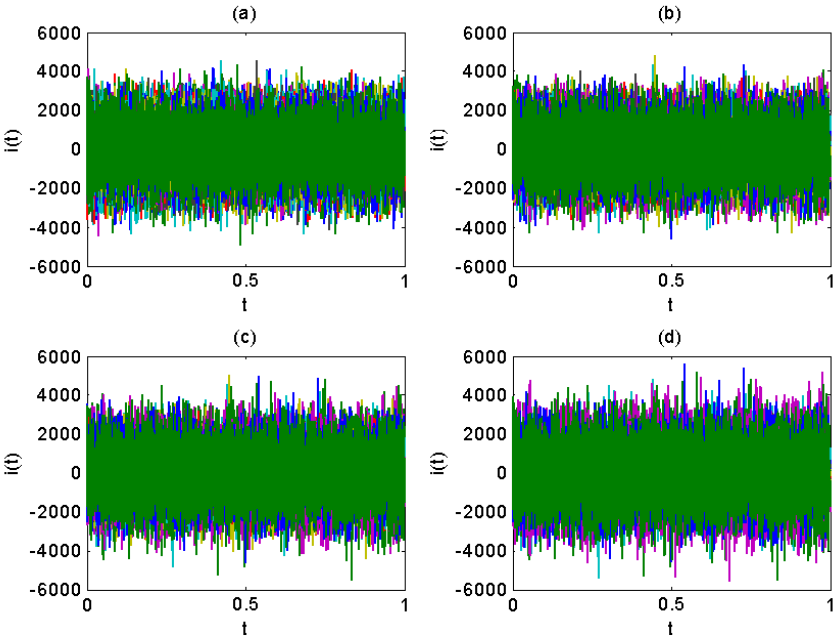


Fig. 2. Current waveforms obtained for 30 realizations of a 3-dimensional network with $N_X = 5$, $N_Y = 5$, $N_Z = 6$ and $R_S = 0.001$, $R = 0.1$, $C = 0.5$, $L = 0.02$ (normalized units) by using a random voltage excitation (white noise). The network composition was set to $f_R = 0.1$, $f_C = 0.45$, $f_L = 0.45$ in the nominal case (a). In the other cases, the resistor fraction was increased to $f_R = 0.2$ (b), $f_R = 0.3$ (c) and $f_R = 0.4$ (d), while keeping $f_C = f_L = (1 - f_R)/2$. The sampling frequency was set to 10^4 (normalized unit).

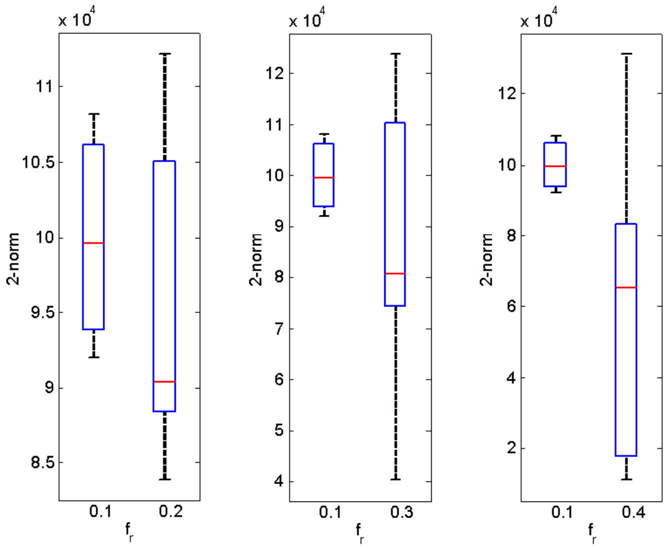


Fig. 3. Boxplots of the 2-norm of the current waveforms for the 30 network realizations. Each frame depicts the boxplot for the networks with nominal composition (left-hand side) and altered composition (right-hand side). On each box, the central red line corresponds to the median, the edges of the blue box indicate the 25th and 75th percentiles, and the black dotted segments extend to the most extreme data values which are not considered to be outliers.

However, by using the wavelet filter bank architecture depicted in Fig. 4 below, it is possible to obtain residues that change in a noticeable manner when f_R is increased as shown in Figures 5a-c.

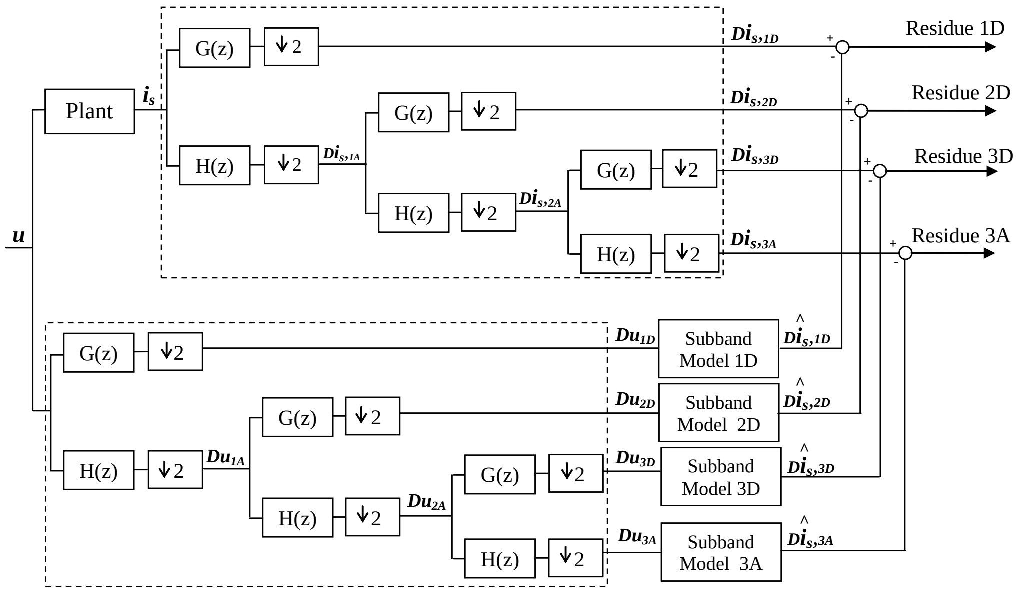
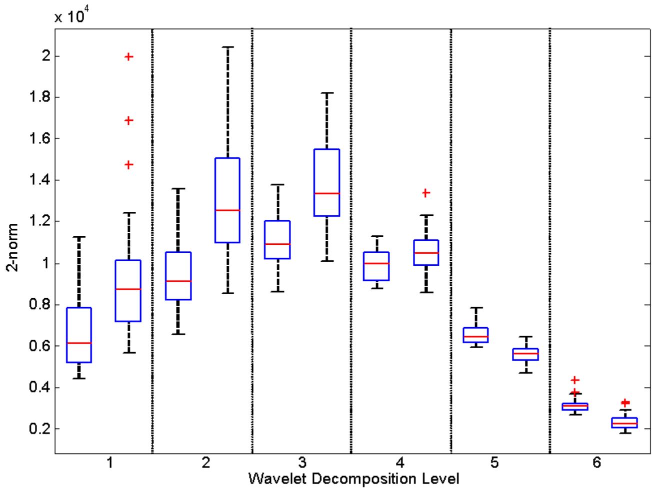
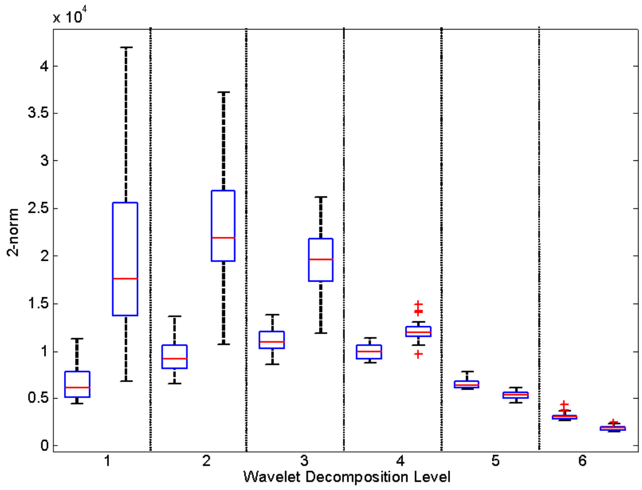


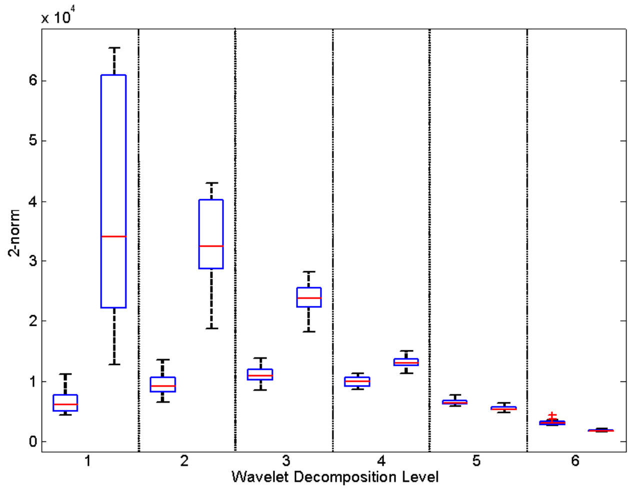
Fig. 4. Wavelet filter bank architecture employed in the generation of residues [18]. The db8 wavelet was employed in all calculations.



(a)



(b)



(c)

Fig. 5. Boxplots of the 2-norm of the sub-band residues for the 10 network realizations. Each frame corresponds to a fixed wavelet decomposition level, with a boxplot for the networks with nominal composition on the left-hand side and the networks with altered composition a) (f_R = 0.2), b) (f_R = 0.3) and c) (f_R = 0.4) on the right-hand side. Outliers are indicated with red cross marks.

Wavelet filter banks have been extensively used in signal processing of time domain or frequency domain signals obtained in broadband spectroscopy studies [19-28], so the current application is a direct extension of these works providing an additional link between experimental studies and modelling using *RLC* networks. Further refinement of the technique may be possible by applying feature selection techniques, such as the successive projection algorithms [29-31], to the output of each sub-band of the wavelet models.

3. Conclusion

The results reveal that the proposed optimization procedure is indeed of value to improve sensitivity with respect to changes in the network composition. In a Chemometrics context, the reduced order models enable a simplified representation of the network dynamics, which can be used to infer the composition of the materials. This is of interest from a quality control perspective. The methodology is promising in classification of amorphous dielectrics.

Acknowledgment

The authors acknowledge CNPq for the provision of post-doctoral and research fellowships and FAPESP for the provision of grants 2011/13777-8 and 2011/17610-0 that enabled this work to be performed.

References

[1] Jonscher A K, 1977 “The universal dielectric response”, *Nature*, **267**, No. 5613, pp. 673-679.
[2] Lewis T J, 1977 “The dielectric behaviour of non-crystalline solids”, *Dielectric and Related Molecular Processes*, **3**, pp. 186-218.
[3] Hurt R L, and Macdonald J R, 1986 “Distributed circuit elements in impedance spectroscopy: a unified treatment of conductive and dielectric systems”, *Solid State Ionics*, **20**, 111-124.
[4] Macdonald J R, 2000 “Comparison of the universal dynamic response power-law fitting model for conducting systems with superior alternative models”, *Solid State Ionics*, **133**, 79-97.
[5] Tuncer E, Nettelblad B, and Gubanski S M, 2002 “Non-debye dielectric relaxation in binary dielectric mixtures (50-50): Randomness and regularity in mixture topology”, *J. Appl. Phys.*, **92**, 4612–4624.
[6] Bouamrane R and Almond D P, 2003 “The emergent scaling phenomenon and the dielectric properties of random resistor-capacitor networks”, *J. Phys. Condensed Matter*, **15,** (24), 4089–4100.
[7] Panteny S, Stevens R and Bowen C R, 2005 “The frequency dependent permittivity and AC conductivity of random electrical networks,” *Ferroelectrics*, **319**, 199-208.
[8] Almond D P, Bowen C R and Rees D A S, 2006 “Composite dielectrics and conductors: simulation, characterization and design”, *J. Phys. D: Appl. Phys.*, **39**, 1295-1304.
[9] Almond D P, Duncan G K, West A R, 1983 “The determination of hopping rates and carrier concentrations in ionic conductors by a new analysis of ac conductivity,” *Solid State Ionics*, **8**, (2), 159–164.
[10] Almond D P, Hunter C C, West A R 1984 “The extraction of ionic conductivities and hopping rates from ac conductivity data, *Journal of materials science*,” **19**, 3236-3248.
[11] Almond D P, West A R 1983 “Impedance and modulus spectroscopy of “real” dispersive conductors,” *Solid State Ionics* **11**, (1), 57–64.
[12] Almond D P, West A R 1983 “Mobile ion concentrations in solid electrolytes from an analysis of ac conductivity,” *Solid State Ionics* **9–10**, (1), 277–282,.
[13] Tuncer E and Macdonald J R, 2006 “Comparison of methods for estimating continuous distributions of relaxation times”, *J. Appl. Phys.*, **99**, 074106.
[14] McCullen N J, Almond D P, Budd C J, and Hunt G W, 2009 “The robustness of the emergent scaling property of random RC network models of complex materials”, *J. Phys. D: Appl. Phys.*, **42**, (6), 64001.1– 64001.8.

[15] Almond D P, Budd C J, Freitag M A, Hunt G W, McCullen N J, Smith N D, 2012 "The Origin of Power-Law Emergent Scaling in Large Binary Networks," *arXiv:1204.5601v1* [cond-mat.dis-nn]

[16] Galvão R K H, Kienitz K H, Hadjiloucas S, Walker G C, Bowen J W, Soares S F C, Araújo M C U, 2013 "Multivariate analysis of random three-dimensional RC networks in the time and frequency domains," *IEEE Trans. Dielectr. Electr. Insul.,* **20**, (3), 995-1008.

[17] Galvão R K H, Hadjiloucas S, Kienitz K H, Paiva H M and Afonso R J M, 2013 "Fractional Order Modeling of Large Three-Dimensional RC Networks," *IEEE Transactions on Circuits and Systems I*, **60** (3), 624-637.

[18] Paiva H M, Galvão R K H, and Rodrigues L, 2009 "A Wavelet-Based Multivariable Approach for Fault Detection in Dynamic Systems", *Controle & Automação*, **20**, (4), 455-464.

[19] Zaengl W S, 2003 "Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment, Part I: Theoretical Considerations", *IEEE Electr. Insul. Mag.*, **19**, (5), 5-19.

[20] Galvão R K H Hadjiloucas S, Bowen J W and Coelho C J, 2003 'Optimal discrimination and classification of THz spectra in the wavelet domain,' *Optics Express*, **11**, 1462-1473.

[21] Hadjiloucas S, Galvão R K H, Bowen J W, Martini R, Brucherseifer M, Pellemans H P M, Haring Bolivar P , Kurz H, Digby J, Parkhurst G M, and Chamberlain J M 2003 'Measurement of propagation constant in waveguides using wideband coherent THz spectroscopy,' *Journal of the Optical Society of America B* **20**, 391-401.

[22] Hadjiloucas S, Galvão R K H, Becerra V M, Bowen J W, Martini R, Brucherseifer M, Pellemans H P M, Haring Bolivar P, Kurz H, and Chamberlain J M, 2004 'Comparison of state space and ARX models of a waveguide's THz transient response after optimal wavelet filtering,' *IEEE Transactions on Microwave Theory and Techniques MTT*, **52**, (10), 2409-2419.

[23] Galvão R K H, Hadjiloucas S, Becerra V M and Bowen, J W 2005 'Subspace system identification framework for the analysis of multimoded propagation of THz-transient signals,' *Measurement Science and Technolgy*, **16**, 1037-1053.

[24] Hadjiloucas S, Walker G C, Bowen J W Becerra V M Zafiropoulos A and Galvão R K H, 2009 'High signal to noise ratio THz spectroscopy with ASOPS and signal processing schemes for mapping and controlling molecular and bulk relaxation processes,'*Journal of Physics: Conference Series*, **183** 012003.

[25] Evagorou D, Kyprianou A, Lewin P L, Stavrou A, Efthymiou V, Metaxas A C, and Georghiou G E, 2010 "Feature extraction of partial discharge signals using the wavelet packet transform and classification with a probabilistic neural network", *IET Sci., Meas. Techn.*, **4**, (3), 177-192.

[26] Hadjiloucas S, Walker G C, Bowen J W and Galvão R K H, 2011 'System identification algorithms for the analysis of dielectric responses from broadband spectroscopies', *Journal of Physics: Conference Series*, **310** 012002.

[27] Hao L, Lewin P L, Hunter J A, Swaffield D J, Contin A, Walton C and Michel M, 2011 "Discrimination of Multiple PD Sources Using Wavelet Decomposition and Principal Component Analysis", *IEEE Trans. Dielectr. Electr. Insul.*, **18**, (5), 1702-1711.

[28] Li J, Cheng C, Jiang T and Grzybowski S, 2012 "Wavelet De-noising of Partial Discharge Signals Based on Genetic Adaptive Threshold Estimation", *IEEE Trans. Dielectr. Electr. Insul.,* **19**, (2), 543-549.

[29] Soares S F C, Gomes A A, Galvão Filho A R, Araújo M C U and Galvão R K H, 2013 "The successive projections algorithm", *Trends in Analytical Chemistry*, **42**, 84-98.

[30] Galvão R K H, Araújo M C U, Fragoso W D, Silva E C, José G E, Soares S F C and Paiva H M, 2008 "A variable elimination method to improve the parsimony of MLR models using the successive projections algorithm", *Chemom. Intell. Lab. Syst.*, **92**, 83-91.

[31] Paiva H M, Soares S F C, Galvão R K H and Araújo M C U, 2012 "A graphical user interface for variable selection employing the Successive Projections Algorithm", *Chemom. Intell. Lab. Syst.*, **118**, 260-266.