Review of the Ph.D. Thesis written by Nawfal Al-Zubaidi R-Smith, MSc.

Methods of Numerical Inversion of Laplace Transforms for Electrical Engineering and Their Applications

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The Ph.D. thesis submitted by Mr. R-Smith, MSc. represents a contribution to the numerical methods in Electrical Engineering, namely the Numerical Inversion of Laplace Transforms (NILT). It is requested that the NILT is applied to general, not only the classical rational-fraction forms of the Laplace transforms known from the theory of linear lumped circuits. There is no doubt that this topic is up-to-date, because the transient analysis of many linear and also some selected nonlinear problems of contemporary electrical engineering such as complicated RF systems with non-homogeneous transmission lines, systems described by fraction-order differential equations etc., can be effectively solved just via the NILT.

It should be noted that the topic of the dissertation has been properly selected also thanks to a long-term research conducted in the training Department: Mr. R-Smith, MSc. could pick up on the distinguished results of his supervisor just in the field of the NILT, and on the traditions of such research in FEKT (Professor Valsa and his cooperation with Professor Vlach from Waterloo University, Ontario, Canada).

From the point of view of the content, the thesis can be hypothetically divided into three parts. The first part (Section 1) is devoted to the state-of-the-art, the second part defines the dissertation objectives (Section 2), and the third part (Sections 3-6) describes the original contributions as a key part of the thesis.

I appreciate that the author built a nice classification of many hitherto published NILT methods, and that he defined the position of concrete known algorithms in this classification tree.

The following contributions of Mr. R-Smith, MSc. can be considered as most important and unambiguous:

1) Generalization of the 1D hyperbolic-based NILT method (Section 3.3) and some its applications (simulation of transmission lines and fraction-order models).
2) 2D hyperbolic-based NILT method (Section 5) and its application.
3) Utilization of the developed NILT for the analysis of nonlinear systems via Volterra series (Section 6.2).

The graphic design is pretty nice. The language is quite good with a minimum of misprints.

I have the following suggestions concerning the thesis.

Conceptual and formal imperfections

During the first reading of the thesis, it is difficult to identify what is the personal contribution of the author, for example if it is the hyperbolic NILT or its generalization. It would be useful to know author's contribution in the case of the paper [1].

The author should use the consistent notation, not a mix of different symbols from various papers without explanation (see Page 31, Eqs. 1.54 and 1.55).

What is the variable “a” in Eqs. (3.2) and (3.3)? The first occasion of the symbol in the text must be accompanied with its explanation. Similar note also holds for the functions Ksh and Kch in Eqs. (3.2), (3.3). See also Sections 5.2.2 and 5.2.3.

Technical ambiguities; disputative points

In my opinion, the work does not contain serious irregularities. Nevertheless, let me mention the following observations.

The Introduction and State-of-the-Art analyses do not contain some methods, for example one NILT hitherto developed and successfully used for transient analysis of lumped linear systems described by the rational fraction Laplace transform (RFLT): fully-numerical partial fraction expansion with the subsequent generation of the original as analytic function of time. The corresponding algorithm is not trivial, but it was developed and published many years ago with excellent results also for multiple poles. It is a pity that the author did not use it, because it would provide perfect data for benchmark testing of the hyperbolic NILT of complicated high-order RFLTs.

Section 1 does not describe the necessary details of the 1D NILT developed by Singhal and Vlach, which is based on Padé approximation. The thesis mention some details of this approach later, but only for 2D algorithms on Page 25. The Singhal approach also includes the NLI of the set of s-domain equations and the so-called Resetting Principle, which eliminates numerical errors when computing the originals which should be periodical in time. Such algorithms would be perfect to use for the comparison with the results presented e.g. in Fig. 3.9 on Page 53.

One very important application of the NILT is associated with the computer analysis of real circuits containing analog switches, particularly the switched-capacitor filters. I missed a note of this key application of the NILT, published by Vlach, in the Introduction.

The definition of the inverse Laplace transform on Page 13 is wrong (see Eq. 2).

In the evaluation of numerical errors of the Laplace inversion, the important issue is the error analysis for diverging or periodically oscillating original functions (for example, see $f_1(t)$ in Table 3.1 and Table 3.3), where the accuracy of the given algorithm can be easily evaluated via increasing the time towards infinity. In my opinion, the time interval used in Section 3 is too short (for example only 8 repeating periods is considered in Fig. 3.9), and a lot of space still remains for a more rigorous analysis.

The problem of verifying the results presented in Section 4, namely the behavior of fraction-order models, is that the exact solution is unknown. The utilization of the NILT combined with the Volterra kernels for solving nonlinear problems in Section 6 seems to be rather questionable because there are another well-established numerical methods which provide more accurate transient analysis of weak- and also strongly nonlinear problems. The author should explain the added value of his approach. To provide it, the analyzed simple nonlinear circuit in Fig. 6.5 should be replaced by some typical nonlinear system with well-known and preferably periodical steady-state response.

Positive aspects of the work

This dissertation summarizes a great extent of results of high-quality research in the field. The author proved his extensive knowledge of the state-of-the-art of the problem (see also the extensive list of references and their analysis in Section 1). He also demonstrated his good knowledge of the mathematical analysis, numerical models, algorithms, and their programming.

Conclusions:

My final statements are as follows:

a) The topic analyzed is undoubtedly up-to-date.

b) The dissertation objectives defined in Section 2 were fulfilled.

c) The scientific methods presented by the author and the methodology of the research correspond to the standards commonly used for the Ph.D. dissertations.

d) The dissertation brings novel results specified on Page 1 of this report under items No. 1), 2), and 3).

e) The key results were already published in two WoS Journals, 10 Int. conferences indexed in WoS/Scopus, and 7 other journals and conferences. I appreciate particularly the publications in Journal of Circuits, Systems and Computers and in IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences.

f) I agree with the ideas in Section 7, evaluating the contributions of the theses for electrical engineering, and with author's recommendations for future work.

The above comments and suggestions refer to some partial or formal imperfections that do not decrease the overall scientific value of the dissertation. I am convinced that Mr. R-Smith, MSc. proved his scientific qualification, and I recommend his dissertation for a defense.

My questions:

The SPICE programs, commonly used in Electrical Engineering, provide transient analysis of circuits described by their s-domain transfer functions. Do you know how the SPICE computes the numerical Laplace inversion? Is the type of this method discussed in your state-of-the-art?

Please suggest a method of verifying your results in Section 4 (transient analysis of fraction-type models).

Brno, November 4, 2018 Prof. Ing. Dalibor Biolek, CSc.