HOW2POWER TODAY
Your Power Design Newsletter

Book Review

ISSUE: February 2024

Book Offers Further Instruction On Advanced Methods Of Circuit Analysis

The Fast Track to Determining Transfer Functions of Linear Circuits: The Student Guide, Christophe Basso, 267 numbered pages, 4 index pages, glossy soft cover, 8.5 × 11 inch, Faraday Press, ISBN 978-1-960405-19-7, 2023, $54.95.

Reviewed by Dennis Feucht, Innovatia Laboratories, Cayo, Belize

Author Christophe Basso has designed converter control ICs for ON Semiconductor in Toulouse, France and has written related books, such as *Transfer Functions of Switching Converters: Fast Analytical Techniques at Work with Small-Signal Analysis,*[1] which was previously reviewed in How2Power Today. This earlier work and the book under review here are compendiums of methods of passive and active circuit analysis that reduce the amount of mathematics that otherwise would be required when applying Kirchhoff's current and voltage laws (KCL, KVL) and Ohm's Law (ΩL).

Somewhat higher level than those basic circuit laws are the node-voltage and loop-current methods. Even higher-level laws are presented in undergraduate passive-circuits classes such as the maximum power-transfer theorem but they are few.

Whether you are fast or slow, the methods presented in this book are conceptually more abstract than basic circuit laws and are derived from them mathematically as theorems. They impose various conditions on the circuit that simplify the application of basic circuit laws and simplify analysis.

The history of development of higher "design-oriented" circuit theorems is shown in the figure (taken from reference[2]). Major advancements in this development tree are open-circuit time-constant (OCTC) methods for finding poles, leading to the Cochrun-Grabel method and the Extra-Element Theorem (EET) of R. D. Middlebrook that includes short-circuit time-constants (SCTCs). From these follow related theorems, the impedance EET and tabular *n*EET.

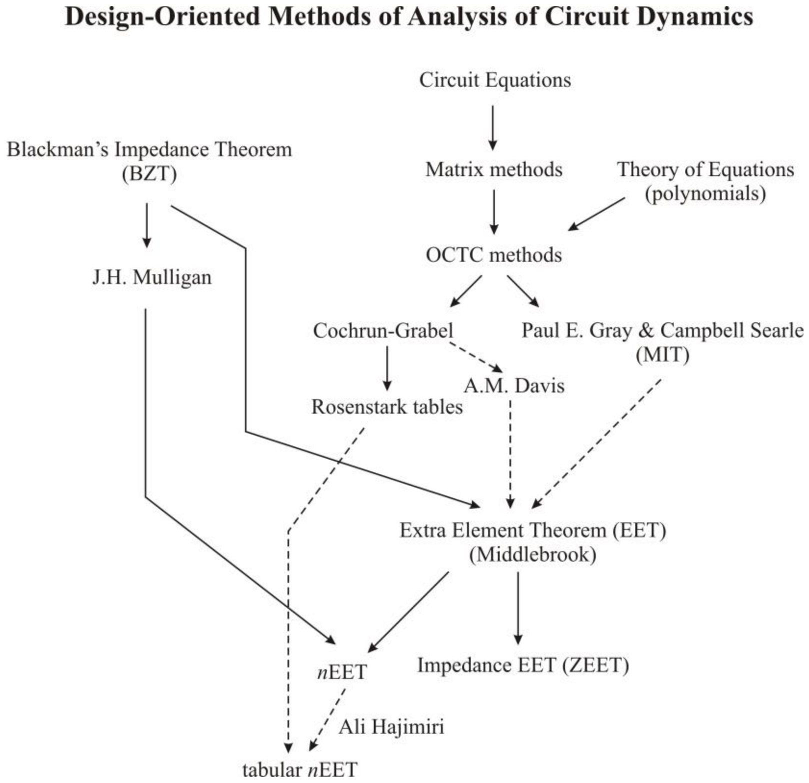

Figure. A historical development of higher (more abstract) circuit theorems and methods of the past.

Beyond the historical developments in circuit analysis depicted in the figure, there were other refinements and restatements of these theorems by Vatché Vorpérian.[3] And following his lead are Basso's books.

This book is a sequel to reference [1] in that it works out in some detail in chapters 5 through 7 the analyses of commonly-encountered circuits with one to three reactive elements. Before presenting these analyses, the first four chapters explain the techniques and the concepts supporting them with simpler examples.

The first chapter covers transfer functions, their poles and zeros from reactive elements connected across circuits as ports, their open- and short-circuit time-constants, and the normalized form of transfer functions as providing more insight into circuit poles and zeros than the canonical form. Port resistances with reactive elements removed (open) or other ports shorted provide time-constant resistances.

Circuits are illustrated in color, sometimes with pictures of test equipment as sources and component pictures as comprising a network (circuit). Active circuits start as op-amps, but on page 31, a simple common-emitter NPN BJT circuit is shown as an example, with a two-element hybrid-π model—a good place to start in incrementally modeling BJTs.

Chapter 2 introduces design-oriented methods. At frequency extremes of $s = 0$ Hz (or 0+ Hz for incremental circuits) and $s \to \infty$, capacitance and inductance are either open-circuit or short-circuit. Circuits like the RC integrator and differentiator demonstrate how to determine the pole from the OCTC and the zero (for the differentiator) from the SCTC.

Expanding to second-order (two-reactance) circuits, the time-constants (TCs) are determined by the Cochrun-Grabel method (C-G) for poles as a triangular table. The EET expands the method to include zeros. Basso has his own nomenclature for designating the TCs, and it is equivalent to C-G, the EET, and the nomenclature used in reference [2].

Chapter 3 is about finding circuit zeros, the frequencies (or corresponding time-constants) where the output is zero. Basso's method of finding zeros is that of the EET—of adjusting sources to null the output. At first this might seem obfuscating, but in the method, it is quite simple. The procedures follow what was originally introduced by Middlebrook in the Extra-Element Theorem (EET) which produces both the poles and zeros of the circuit transfer function.

The latter part of chapter 3 works through the extended and rather complicated (though important) example of a BJT with external emitter resistance. Basso is careful to include numerous steps to not leave any reader behind. (This is also worked out in reference [2] under "General Single-Stage CE Gain" by following a different path in the construction of the formidable transfer function, applying the same circuit theorems.)

Chapter 4, "Generalized Transfer Functions," has an emphasis on SCTCs for finding zeros and higher-order coefficients in the denominator (poles) and numerator (zeros) polynomials. It completes the general procedure which is powerful in determining complicated yet exact transfer functions for even some of the most common circuits in designs, yet often is left without in-depth analysis in the electronics literature because of the extensive amount of algebra required.

Chapters 5 through 7 present many detailed circuit solutions beginning with first-order (one-reactance) circuits in chapter 5. These circuits have no resonance and are easier to derive. Basso also includes the time-domain step response that models what is seen while probing the circuit driven by a square-wave, and Bode plots are presented for frequency-response analysis. Everything is in living color.

Chapter 6 is more complicated, with non-minimum-phase circuits and resonances. Yet second-order circuits have second-degree (quadratic) equations and can be solved with the quadratic formula, thereby factoring the poles or zeros into the desired normalized form of transfer functions.

The third-order circuits of the last chapter pose the polynomial factoring problem. Although there is a method for solving cubic equations, it is not a simple formula like the quadratic equation, and the book resorts to simulation. It is often possible for real circuits with widely separated poles or zeros to approximate them as lower-degree polynomials, though approximations do not appear in the book; it is about exact derivations.

Appendix A summarizes the method discussed throughout the book.

What does not appear in the book about transfer functions is a comparison of nodal versus OCTC time-constants. They are not the same and this can be a confusing topic when learning circuit dynamics. Another omitted topic is analysis of a generalized amplifier, with general input, output, and feedback impedances and a quasistatic G_m gain. When solved, the three time-constants have equivalent circuits that make analysis of the amplifier simpler.

Another high-level theorem is Miller's theorem, but less common is the frequency-dependent version of it. Finally but not least important is the high-frequency modeling of BJT and feedback amplifiers that reveals why spurious oscillations occur in circuits. These topics go somewhat beyond the range of what is covered in this book, which remains focused on transfer-function derivations.

This is another good book from Basso who patiently explains (in color) each procedure step-by-step, then applies it to various examples. It is somewhat like the old Schaum's Outline Series books which served the same role.

I recommend this book for anyone who has not yet mastered dynamic circuit analysis at the component level. The topic will not go away. Basso uses simulations to check the equations for agreement, but simulations do not give insight into the effects of circuit parameters on the behavior of the circuit. Mathematical analysis does.

References

1. *Transfer Functions of Switching Converters: Fast Analytical Techniques at Work with Small-Signal Analysis* by Christophe Basso, Faraday Press, 2021, reviewed in How2Power Today.
2. *Circuit Dynamics: Design-Oriented Analysis*, Dennis L. Feucht, Innovatia, 2013, page 1.
3. *Fast Analytical Techniques for Electrical and Electronic Circuits*, Vatché Vorpérian, Cambridge University Press, 2002.

About The Author

Dennis Feucht has been involved in power electronics for 40 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.

To read Dennis' reviews of other texts on power supply design, magnetics design and related topics, see How2Power's Power Electronics Book Reviews.