Circuit Analysis Book Makes It Easier To Derive Transfer Functions

Linear Circuit Transfer Functions: An Introduction to Fast Analytical Techniques, Christophe P. Basso, Wiley, IEEE Press (http://www.wiley.com/), ISBN: 978 111 923 637 5, glossy hardback, 445 numbered pages, 2016.

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Christophe Basso is an engineer at ON Semiconductor in Toulouse, France, an IEEE senior member, and a major contributor to How2Power. He has written a book that is not about power electronics as such but applies to it quite deeply in that most of the circuitry in power converters and motor drives is linear and analog, especially the control circuits. These circuits can be the most difficult aspect of power-electronics design and some methods for simplifying their analysis are welcomed. Basso's book addresses this interest.

The book explains how to go from circuit structure, as given in a circuit diagram, to a transfer function in the complex-frequency or *s*-domain. Basic circuit analysis, using the node-voltage or loop-current methods with Kirchhoff's Laws and Ohm's Law can produce a transfer function, though the algebra can be horrendous at times. And even then, if the polynomials are not factored, the poles and zeros are not known. After the poles and zeros of a circuit have been identified, its dynamic behavior has essentially been found. This book presents simplifying methods for finding the poles and zeros without having to solve the basic circuit equations.

This book continues an ongoing tradition of invoking higher circuit theorems that clarify and simplify linear circuit analysis. Higher-level theorems or methods are possible because linear transfer functions are of the form

$$\frac{x_o}{x_i} = K \cdot \frac{b_m \cdot s^m + b_{m-1} \cdot s^{m-1} + \cdots + b_1 \cdot s + 1}{a_n \cdot s^n + a_{n-1} \cdot s^{n-1} + \cdots + a_1 \cdot s + 1}$$

where the factored roots of the numerator are the *zeros* and those of the denominator are the *poles*. Not only do circuits have this form of transfer function, the coefficients of the zero and pole polynomials are also related to the zeros and poles in specific ways. (The mathematics of the theory of equations develops this.)

When the coefficients are expressed as 1/frequency, or as *time constants*, τ_k, then because the constant term (1) is unitless, each other polynomial term must be also. This implies that a_k must have k time constants multiplied (in one or more terms in the coefficient) to cancel the $1/s^k$ unit in s^k. The highest-degree pole polynomial term is thus of the form

$$(\tau_n \cdot \tau_{n-1} \cdot \cdots \cdot \tau_1) \cdot s^n \Rightarrow a_n = \tau_n \cdot \tau_{n-1} \cdot \cdots \cdot \tau_1 .$$

Similarly, the linear term ($a_1 \cdot s$) coefficient is constrained to be of the form

$$a_1 = \tau_n + \tau_{n-1} + \cdots + \tau_1 .$$

These τ terms relate to circuit elements in the familiar form of $\tau = R \cdot C$ or $\tau = L/R$.

Suppose a circuit has only capacitive reactances. If all the *C*s are removed (that is, their ports open-circuited), then for C_1, the resistance of the circuit at its port is the *R* of the *open-circuit time constant* (OCTC) of C_1, or τ_1. If all other *C*s are removed, then their value is zero and a_1 reduces to τ_1. The higher-level methods are based on shorting and opening reactances to manipulate the coefficients into forms that can be used to find the τ_k and hence the poles and zeros.

Basso's book is all about these simplifying methods of circuit analysis associated with R. D. Middlebrook's Extra Element Theorem (EET), itself a refinement of a long history (found in my 10-part article series at *EDN* titled "Design-Oriented Circuit Dynamics", starting in January 2013) of such methods, tracing back to Blackman, Mulligan, Cochrun and Grabel, and Paul E. Gray and Campbell Searle at MIT. In chapter one (the first of five chapters in this book), Basso first establishes the basic circuit concepts of ports, time constants, voltage and current dividers, Thévenin's and Norton's Theorems, and driving-point impedance.

In chapter two, transfer functions are examined, including the basic response dynamics associated with them. Chapter three introduces, explains and gives detailed examples of the use of the EET. Chapter four continues

this with examples having two reactances and culminates in chapter five, with an extension of the EET, the *n*EET. The book ends with a glossary of key expressions and an index.

While computer circuit simulation can give accurate behavioral results of circuit response for a particular circuit, for design it is better to be able to include circuit elements as parameters so that their effect on behavior can be made more explicit and the design optimized. Basso has contributed to that effort with this book. He emphasizes learning through detailed, step-by-step examples which do not leave the reader wondering how to go from one step to the next.

This book is suitable for an advanced circuits course in that each chapter has an extensive set of problems, a summary of the high points, and references. These methods are simple enough to learn that eventually they should be worked into the undergraduate curriculum. Engineers in industry can also benefit from them. A few hours of learning can result in many hours saved while designing.

Basso is native French yet the book is not translated from French but rather written in English, and the grammar and idioms are indistinguishably English. (I know; I edited out a little of the *francais*. Basso has a fluent command of English, more than I can say for my French.) This book is a welcome addition to circuit analysis from one of us who is driven to contribute to its conceptual clarification and simplification. Thanks, Christophe, for writing it, and in English!

About The Author

Dennis Feucht has been involved in power electronics for 25 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.