Keng Wu 吳耿志

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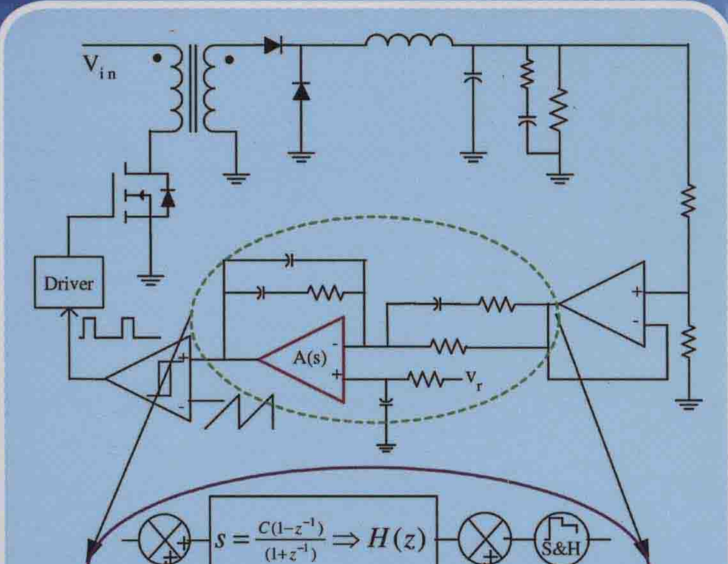

POWER CONVERTERS WITH DIGITAL FILTER FEEDBACK CONTROL

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To
Shwu
Stephanie
戴雪月

BIOGRAPHY

Keng C. Wu, a native of Chiayi, Dalin, Taiwan, received a BS degree from Chiaotung University, Taiwan, in 1969 and an MS degree from Northwestern University, Evanston, Illinois in 1973.

He was a lead member of the technical staff of Lockheed Martin, Moorestown, New Jersey; a well recognized expert in high reliability power supply, power systems, and power electronics product design, including all component selection, board layout, modeling, large scale system dynamic study, prototype, testing and specification verification; and an author of four books: "*Pulse Width Modulated DC-DC Converters*" January 1997; "*Transistor Circuits for Spacecraft Power System*" November 2002; "*Switch-mode Power Converters: Design and Analysis*" Elsevier, Academic Press, November 2005; and "*Power Rectifiers, Inverters, and Converter*" November 2008. He also holds a dozen U.S. patents, was awarded "Author of the Year" twice (2003 and 2006, Lockheed Martin), and presented a three-hour educational seminar at IEEE APEC–2007.

PREFACE

There are two sayings; neither depicts the disheartening anguish that power supply industries had encountered in the face of digital advances. One goes like this, "Everything is going digital, but power supply," and the other, "Everything is going digital, power supply must follow." Taking it at its face value, the former is downright dispirited, while the latter a bit condescending. But both also carry some truth.

Here is the fact. Analog, audio, magnetic cassette tapes had been buried by digital, optical CDs. Analog, video, magnetic VHS tapes had been wiped out by digital, optical DVDs. Analog, landline telephones had been replaced by digital, wireless cell phones. Similarly, motor control has witnessed the inroad of digital techniques, such as space vector modulation and *d–q* decomposition. Therefore, at least 10–15 years ago, the expectation was that the switch-mode power supply (SMPS) will also be taken in by the digital tide.

However, it did not happen.

What could have been causing such a disappointment?

It is not that components suitable for the task were not available. It is not because of the lack of professionals well versed in the trade of SMPS design. It is not due to shrinking market. And, of course, it is not the lack of support from academics in digital signal processing.

What is missing is a scaffold linking them all.

Modern power supply in general, and SMPS in particular, are nonlinear feedback systems. Conventional, analog feedback systems with a single loop had been well studied and understood. Analytic tools and techniques for ensuring loop stability were readily available. And, thanks to late Prof. Robert Middlebrook and the power electronics group at the California Institute of Technology in the 1980s, deriving gain function for the nonlinear power stage was made feasible. A fact shared by all those advances is that they are effective only in the environment of analog domain and not all need to be, or can be, translated to the digital realm.

It turns out that only the error amplifier, which always resides in a feedback loop, and perhaps part of a modulator, which follows, needs to be converted into digital form. The rest, including the power stage, the switch driver, and many filters remains in analog form.

The saying that ONLY error amplifier needs to be moved to the digital form actually masks the degree of difficulties in disguise. This overly simplistic view ends up costing the power supply industry more than a decade in an attempt to transition to digital control.

Moving analog controlling amplifiers to digital entails more actions than what one would anticipate. It is not a one-man show and requires at least four sets of skill.

First, the analog controller ensuring feedback stability must be designed and its transfer function identified. Extracting and expressing the function in *s*-parameter takes skill.

Next, the analog function is converted to the digital z-transform plane. Digital signal processing (DSP) insights abound for treating digitized data streams obtained from low-level analog signals. Performing similar tasks for high-level power processing does not, however, enjoy the ease of harvesting the low-hanging fruits.

Then, all designs shall be simulated to verify or confirm the performance of the analog system and its digital equivalent. Newer tools capable of performing mixed signal simulation and accepting the functional model, rather than physical model, are required, as is experienced staff.

The last, results of the second step must be coded and implemented with a selected microcontroller. Professionals well trained in the conventional analog system may not master the new skill. New generation of digital experts are needed at this step.

Therefore, it is the attempt, better the goal, of this writing to expound the four steps.

Given the extreme challenges, and the utmost purpose of serving the industrial sector, it is considered better to proceed based on example.

Part I employs a forward converter and follows all four steps in sequence. Both voltage-mode and current-mode control are covered. Part II presents the flyback converter. Part III gives precision linear regulators and current regulators intended for driving LED array or charging battery. Part IV covers boost topology. Part V treats special converters, including resonant.

For all parts, the presentation is geared toward those who are already experienced in analog power processing. Therefore, minimal time will be spent in topics considered basic in that subject, for instance filters, operational amplifiers, pulse-width modulators, solid-state switch drivers, and basic transfer functions.

Ideally, a wholesome digital loop shall include both the digital filter/amplifier and the digital PWM. However, this writing for the time being does not vigorously cover the latter since, in terms of criticality, the digital filter occupies higher priority.

As mentioned before, a single individual, the principal writer included, simply cannot master all skill sets required for digital power supply design. Alex Krasner, a young, brilliant engineer helps cover MATLAB SIMULINK simulations and last chapter on digital implementation. In addition, Rizwan Ahmad, a Technology VP, reviewed the manuscript. Their efforts are gratefully appreciated.

Last, but not the least, heartfelt gratitude are also extended to Elsevier editorial team, Lisa Reading and Peter Jardim.

Keng Wu
Princeton, NJ, September 2015

NOTE TO THE READER

In this writing, simulations based on difference equations (MathCAD Professional 2000) and SIMULINK (MATLAB 2007a) are extensively invoked. The former requires complex key entries that are prone to typographical errors while the latter yields drawings that are short in meeting high-quality print requirement.

In order to mitigate both shortcoming and to serve reader, simulation files and source codes are collected and posted on the publisher's website (http://booksite.elsevier.com/9780128042984). MathCAD Professional 2000 and MATLAB 2007a are required to view these files.

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