

APEC 2009 – Professional Seminar Proposal

« Stability Analysis and Loop Control in Switching Power Supplies »

Speaker details

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Abstract

Switch Mode Power Supplies are widely used in nowadays equipments, ranging from a few tens of watts in consumer applications to several hundred of watts and above in industrial applications. Despite the various architectures found in this field, they all share the need for a control circuit that maintains one or several delivered variables within a defined range. Because of extreme time pressure on their shoulders, engineers do not often take the necessary time to understand and analyze the constraints brought by the design of a robust control loop.

Targeting practicing engineers and graduating students, this seminar describes how to efficiently compensate a power converter whether it is operated from a dc or an ac source. The seminar starts by teaching how to optimally select the cross over frequency and the phase margin in relationship with your design specifications. Then, the presentation shows how poles and zeros must be placed depending on the kind of transient response you expect. Using

Mathcad[®] and SPICE, the author maintains a permanent link between what theory dictates and what the market reality is. In particular, the compensation schemes are first described with an operational amplifier and then further modified to cope with a TL431.

The seminar balances analytical aspects and real case examples to show how to design a stable power supply. It targets an audience with an intermediate background in the presented subject.

Outline of the presentation

❑ Feedback generalities (4 slides, 5 minutes)

The introduction starts by describing the need for a feedback loop. Generalities on what is expected from a dc-dc power supply are presented and the basic equivalent “plant” schematic approach is disclosed.

❑ Building an oscillator (13 slides, 15 minutes)

Then, the presentation carries on with the way an oscillator works, e.g. by feeding a portion of the output signal back to the input. The necessary conditions are listed to build an oscillator and experimental results are shown which illustrate the effects of gain and phase at the 0-dB point. Obviously, what is needed is not an oscillator and the design parameters such as phase and gain margins are introduced to make sure we do not build an oscillator.

❑ Poles and zeros (22 slides, 20 minutes)

To make sure the audience is able to follow the concepts used in the presentation, the next set of slides describe the analytical meanings of poles and zeros and what it means when they appear in the left-half plane or the right-half plane. I described the phase boost or lag brought by left-half plane zeros and pole and I smoothly introduce the concept of right-half plane zero, followed by experimental waveforms. At this point, the audience is aware of what poles and zeros are and what their impact is on a Bode plot.

❑ Phase margin and quality coefficient (10 slides, 10 minutes)

When studying closed-loop systems, most of the engineers are told to respect a 45° phase margin at the 0-dB cross over frequency. A lot of them are unable to explain where this 45° number comes from and how it was derived. I show in the next 10 slides how to link an open-loop phase margin to a closed-loop transient response quality coefficient. The final outcome is that a good design goal should be closer to 70° than 45° .

❑ Undershoot and crossover frequency (16 slides, 15 minutes)

Most of the experimented designers select the cross over frequency to be $1/5^{\text{th}}$ or $1/10^{\text{th}}$ of the switching frequency. However, there is a relationship between the converter output impedance and its cross over frequency. I show how to precisely select the cross over frequency based on the output capacitor and the required undershoot specification.

❑ Compensating the converter (33 slides, 30 minutes)

This section enters the real subject of compensating the converters. I start by describing the various compensator types built around operational amplifiers and how they manage to boost the phase. There is an analytical description of the phase boost brought by a given structure, further backed up by a SPICE simulation. I also show the effects of pushing the zeros too far in the lower portion of the spectrum. An interesting case study also demonstrates how ac-decoupled systems can lead to oscillatory responses when wrongly analyzed.

❑ Current-mode converters (22 slides, 20 minutes)

Most of the previous design examples dealt with voltage-mode control (VM). This set of slides introduces the current-mode control (CM) transfer function and its inherent instability problems. Output impedance and overall performance between VM and CM are discussed and commented.

❑ Automated pole-zero placement (13 slides, 10 minutes)

This part introduces the k factor technique by deriving its origins and showing how to efficiently use it. However, as any automated process, it sometimes lead to poorly compensated converters (in particular when operating in CCM VM) and there is a need for another technique.

❑ Manual pole-zero placement (10 slides, 10 minutes)

This manual technique differs from the k factor option by letting the designer select its cross over frequency and chose how to manually place the poles and zeros to adequate places. Simulations templates are provided to show and comment the effects of various poles and zeros positions.

❑ Compensating with a TL431 (20 slides, 20 minutes)

Most of the text books use an operational amplifier (op amp) to show how to build a compensation network. In reality, an op amp is rarely used and replaced by a TL431 driving an optocoupler. The TL431 includes an on-board reference voltage associated with an open-collector op amp. Its particular architecture requires to arrange the external components in a way that differs from that of an op amp application. The set of slides shows how to build type 1, 2 and 3 compensators using a TL431.

❑ Watch the optocoupler! (11 slides, 10 minutes)

The optocoupler represents a safe way to bring the secondary-side isolated information to the primary non-isolated section. However, the optocoupler takes place in the loop return and can affect the phase margin originally wanted. An explanation on the way an opto operates is provided and its characterization is illustrated.

❑ Multi-output converters (14 slides, 10 minutes)

Multi-output converters are often built to power different kind of loads scattered in a common enclosure. This is the case for a DVD power supply but also for a PC power converter. How to characterize the transfer function of such a converter is the object of the upcoming slides.

❑ Input filter considerations (10 slides, 10 minutes)

The high-frequency pulses absorbed by a switching power supply can pollute the source from which it operates. To avoid this problem, an EMI filter is often inserted between the source and the switching converter. If no precautions are taken during the design stage, it is very likely that the added input filter degrades the design margin adopted at the

beginning. This set of slides explains why instability can occur and what precautions must be taken to make sure the final design remains stable further to the filter insertion.

- ❑ A real case example (16 slides, 15 minutes)

Most of the illustrations given in the presentation are obtained either through analytical derivations using Mathcad[®] or by using small-signal SPICE models. How these assumptions deal with real case measurements? This what these slides show, capturing transfer functions from real boards and showing how they compare with simulation models.

- ❑ Conclusion (1 slide)

Total presentation time is roughly 200 minutes or 3 hours and 20 minutes, leaving time for questions and answers.

About the author

Christophe Basso is an Application Engineering Director at ON Semiconductor in Toulouse, France, where he leads an application team dedicated to developing new offline controllers specifications. He has originated numerous integrated circuits among which the NCP120X series has set new standards for low standby power converters.

SPICE simulation is also one of his favorite subjects and he authored a second book, “Switch-Mode Power Supplies: SPICE Simulations and Practical Designs”, published by McGraw-Hill in 2008. His work was positively reviewed in several magazines and in a recent PELS newsletter. He holds 6 patents on power conversion and often publishes papers in conferences and magazines including EDN and PCIM.

Christophe has over 17 years of power supply industry experience. Prior to joining ON Semiconductor in 1999, Christophe was an application engineer at Motorola in Toulouse. Before 1997, he worked as a power supply designer at the European Synchrotron in Grenoble, France, for 10 years. He holds a BSEE from the Montpellier University and a MSEE from the Institut National Polytechnique of Toulouse, France.