Test and Design of Switching Mode Regulators Using the Behavioral Averaged PWM Switch and a Program for Automatic Regulator Prototype Generation

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Abstract - **One of the most critical and time-consuming tasks in Power Electronics is the design and test of regulators used in compensation of switching converters. Methods of trial and error [2] are frequently applied to the small signal regulator design. In these methods relative stability indicators are not specified, and in general assintotical approximations are make over the frequency domain transfer functions. Because of the complexity level of the switching converters that are discrete circuits, many difficult are encountered in the design and test of these devices. In this paper we proposes a design procedure that uses the Behavioral Averaged PWM Switch (BAPS) [1] results and a Program for Automatic Generation of Regulator Prototypes, that make easy the theoretical design and simulation of closed-loop switching converters.**

I. INTRODUCTION

Many problems are detected in the classical methods, which make complicated, time consuming, and confer some imprecision to the switching converter regulator test and design. Among the factors that contributes to this fact are :

a) Utilization of trial and error methods [2].

b) Assintotycal approximation considered to the transfer functions employed to the switching regulator design [2].

c) Necessity of a massive test and generation of regulator small-signal prototypes, choosing distinct small-signal specifications for to searches a good large-signal result, once that the small-signal design do not assures the large-signal performance.

d) Complexity offered to inexpert users in analytical derivation of important frequency domain characteristics oriented to closed-loop analysis and design of switching regulators by means of classical models.

II. VENABLE EQUATIONS

These sets of equation [3], provide analytical design of the error amplifier in conventional switching converters. Using this method, cutoff frequency and phase-margin are chosen allowing the analytical calculation of parameters to the error amplifier, in accordance with the necessary phase bumping to converters compensation.

III. TEST AND DESIGN OF REGULATORS

In this work we present the following contributions :

I) Proposition of a method to simple and quick derivation and test of switching regulators, following alternative path illustrated in flowchart of figure 1 .

II) Use of the Behavioral Averaged PWM Switch for derivation of converter small-signal transfer function (G), as represented in figure 2.

III) Development of a Program for Automatic Regulator Prototype Generation, based on [3], that uses the small signal functions derived in the item II. This program provides the following capabilities :

a) Analytical derivation of the regulator using initial specification (phase margin and cutoff-frequency), and automatic assignation and calculation of error amplifiers represented in figure 3.

b) Derivation of error amplifier transfer function (H), open-loop gain (GH) and Nyquist plot to any initial specification as illustrated in figures 4 and 5.

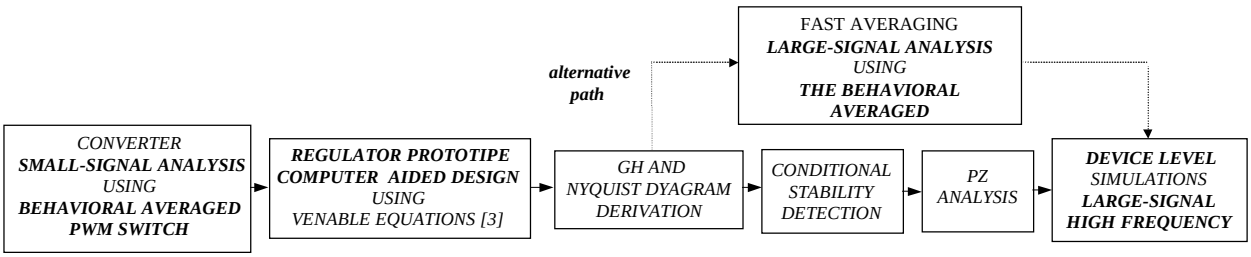


Figure 1 Method for quick derivation analysis and test of switching regulators

c) Comparison among small signal loop characteristics using calculated and commercial resistors as shown in figure 5.

d) Allows the introduction of practical, analytical or simulated transfer functions for make design.

e) Gives a fast small-signal design and increasing of possibility to the unit large-signal regulation.

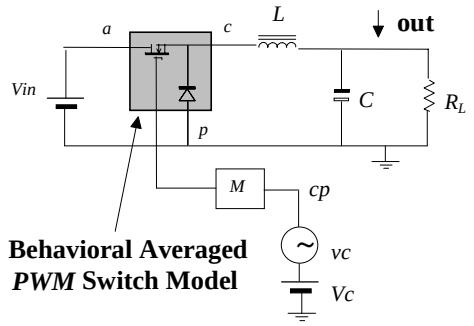
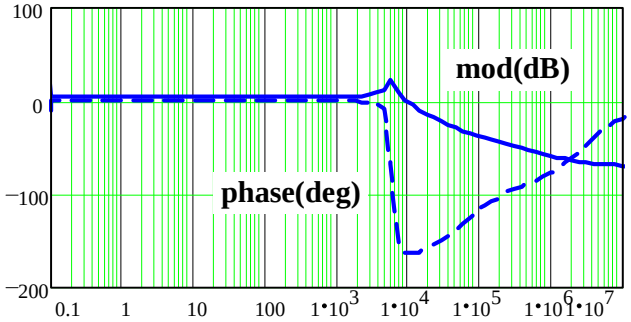
AC simulation	simulated transfer function
	

Figure 2 Converter small-signal analysis is employing the BAPS.

IV) Application in analysis of converters with complex transfer functions (including coupled elements) and also the influence of small-signal feedback parameters in the unit performance, as illustrated in figures 6, 7 and 8.

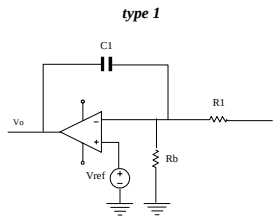
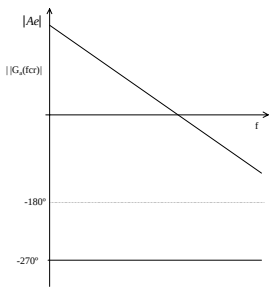
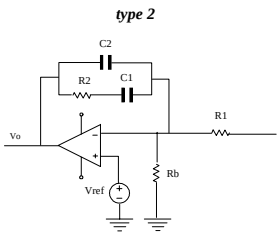
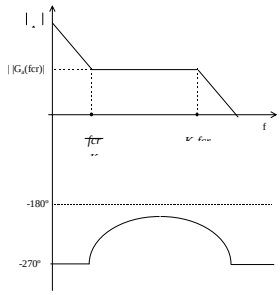
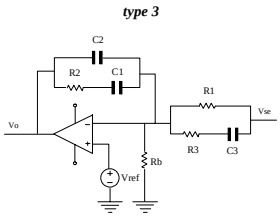
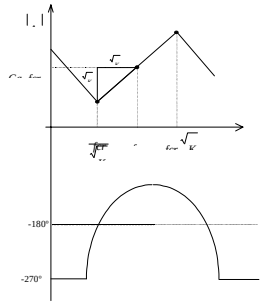
regulator circuits	regulator transfer functions	diagrams (-H)
	$A_e(w) = \dfrac{1}{sR_1C_1}$	
	$A_e(w) = \dfrac{(1+s\ C_1\ R_2)}{R_1\ (C_1\ +\ C_2)s\left(1+s\ \dfrac{C_1\ C_2}{(C_1\ +\ C_2)}R_2\right)}$	
	$A_e(w) = \dfrac{(1+s\ C_1\ R_2)\,.\,(1+s\,(R_1+R_3)C_3)}{sR_1(C_1\ +\ C_2)\left(1+s\ \dfrac{C_1\ C_2}{(C_1\ +\ C_2)}\ R_2\right)(1+s\ R_3\ C_3)}$	

Figure 3 Basic error amplifiers proposed in Venable studies

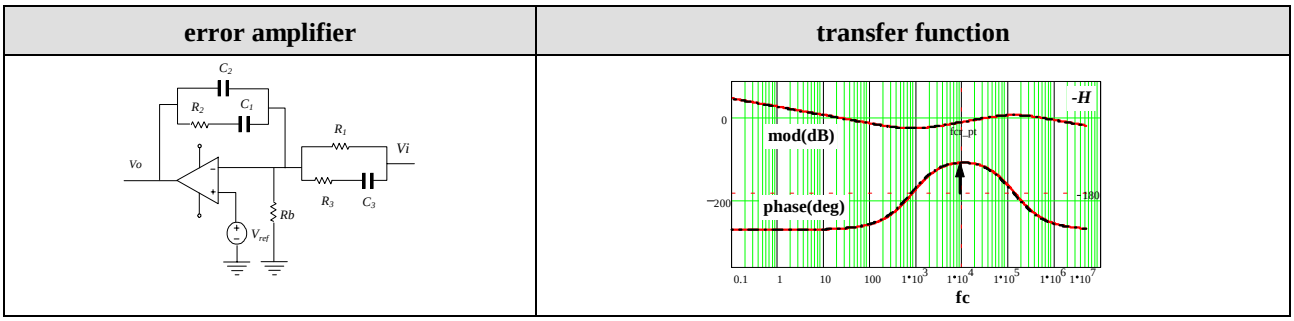


Figure 4 Error amplifier prototype designed for a cutoff frequency of 10KHz and P.M. of 60º

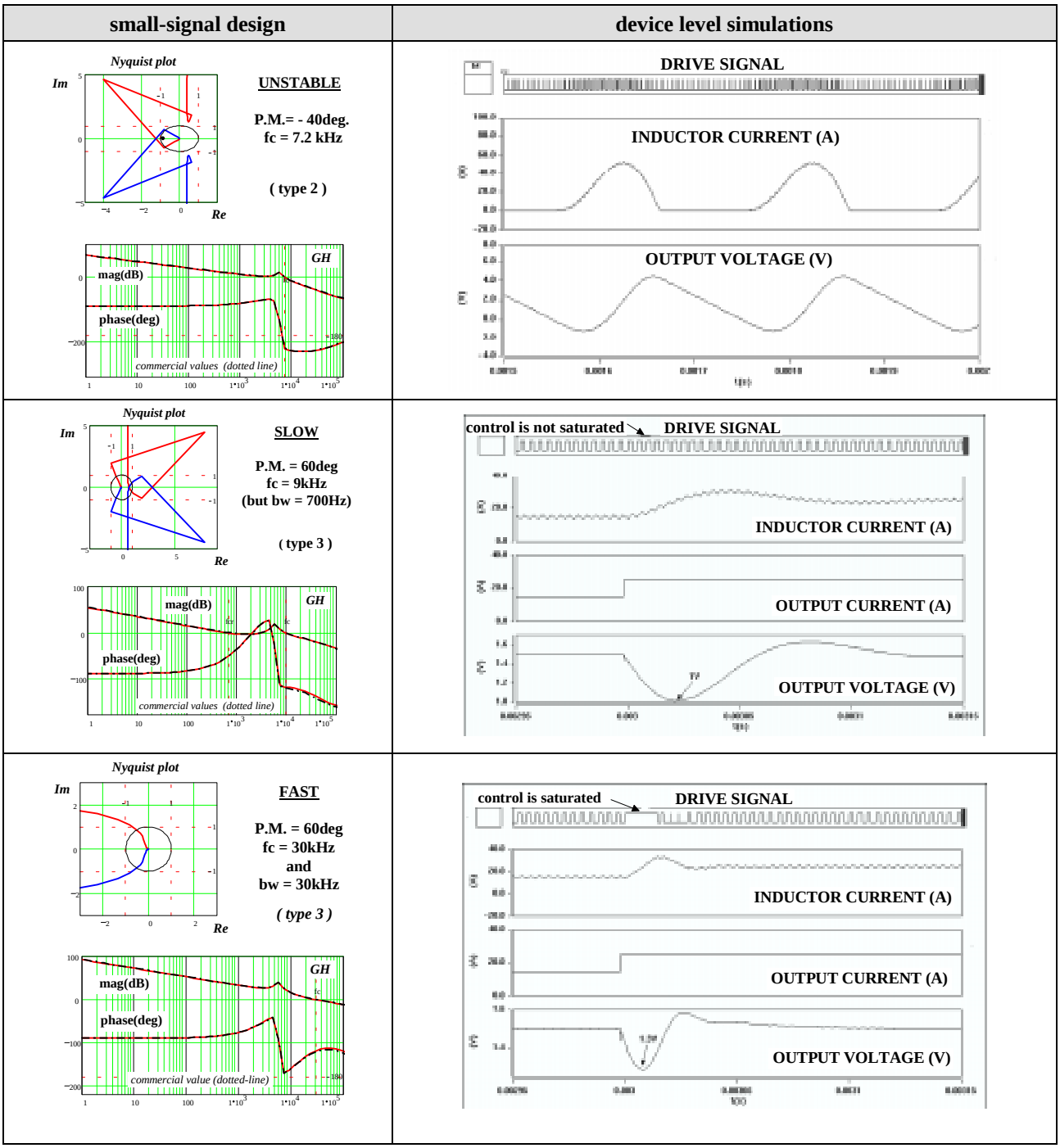


Figure 5 Computer-aided open-loop gain GH and Nyquist diagram derivation

As example, making an AC simulation of a two output Forward converter with coupled inductors using the Behavioral Averaged PWM Switch, we detect an smallest phase when the inductors are better coupled as illustrated in figure 6. These phenomena make most easy the converter compensation.

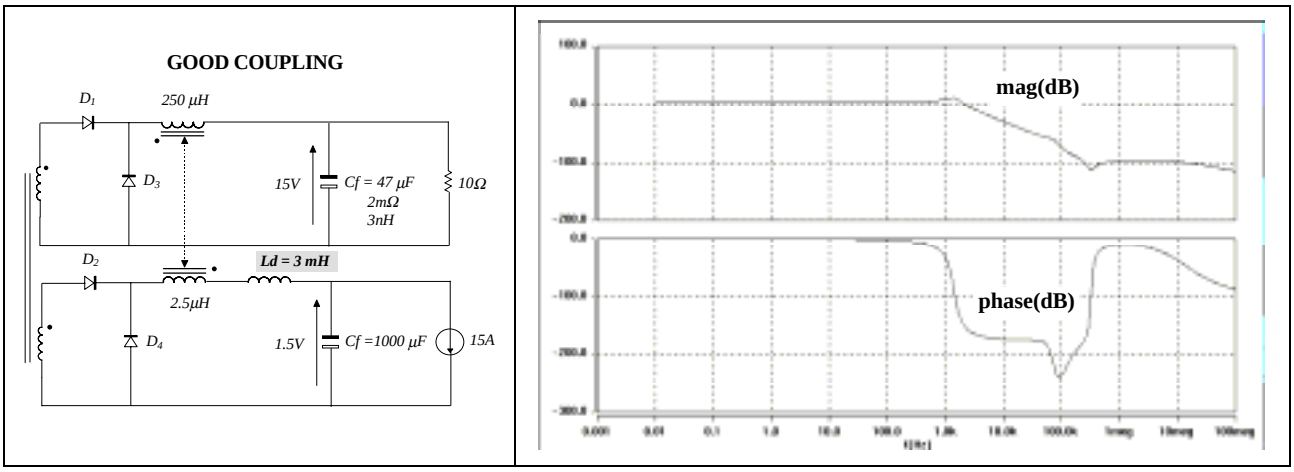


Figure 6 Computer-aided analysis using Behavioral Averaged PWM Switch model

V) Use of the Behavioral Averaged PWM Switch to an *fast large-signal test of switching units*, that allows easy circuit configuration, employing a behavioral simulator, and a good accuracy-speed tradeoff due to the utilization of averaged description.

Making a transient simulation with the Behavioral Averaged PWM Switch as in figure 7, we can see that a phase margin modification introduces a change in the peak value and in phase shifting of an open-loop switching converter transient response.

Also the Behavioral Averaged PWM Switch are applicable to the absolute stability analysis as in [4] that is based in the state-plane derivation and upon the Lyapunov criteria (see figure 8).

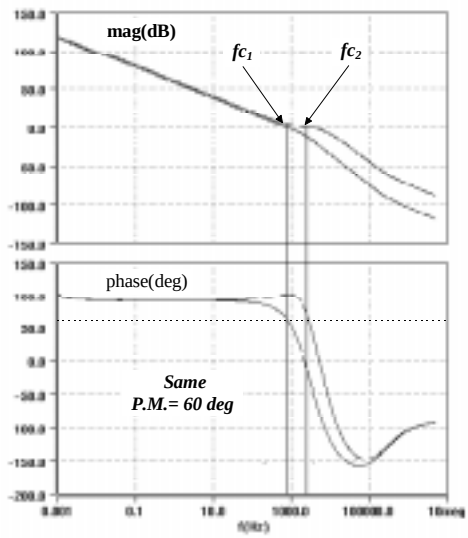
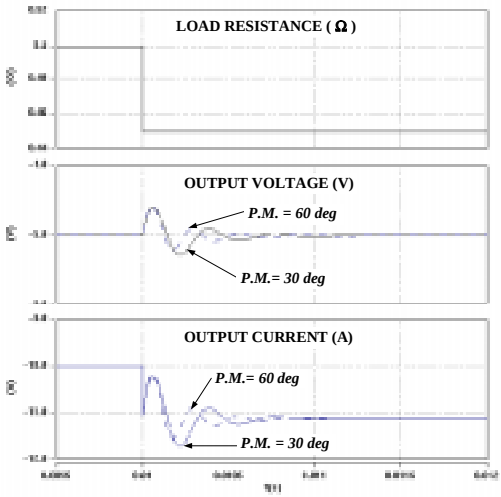
specification	BAPS frequency domain analysis	BAPS time domain simulations
Phase margin		

Figure 7 Studying the phase margin effects in time domain response

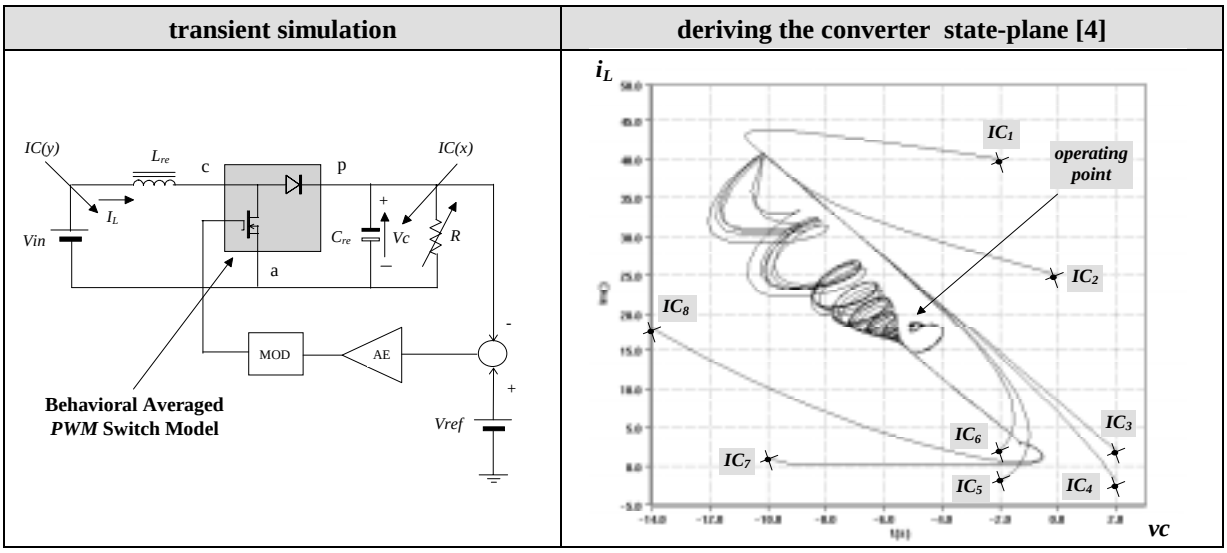


Figure 8 Fast large-signal switching converter test using Behavioral Averaged PWM Switch model

CONCLUSIONS

A procedure oriented to design of *switching regulators error amplifier* that uses the *Behavioral Averaged PWM Switch* and a *Program for Automatic Generation of Regulator Prototypes* was described in this paper. The main features of this method is to solve some problems of regulator design as *time consume*, small-signal analysis and *large-signal test*.

With this method a *massive test and generation of regulator small-signal error amplifier prototypes is possible*, allowing distinct *small-signal specifications, for search a good large-signal result*, once that the *small-signal design not always* assures the *large-signal performance*.

REFERENCES

[1] Canalli V.M, Cobos J.A.,Oliver J.A.,Uceda J., *"Behavioral Large Signal Averaged Model for DC/DC Switching Power Converters"*, Power Electronics Specialists Conference 1996, pp. 1675-1681.

[2] Unitrode, *"Unitrode Power Supply Design Seminar"*.

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[4] Middlebrook R.D.,Cuk S.,Erickson R.W.,*"Large-Signal Modelling and Analysis of Switching Regulators"*, Power Electronics Specialists Conference1982, pp. 240-250.