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Study & Analysis of Dc to Dc Converter Using Simulink

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Abstract:*Every Electronic circuit is assumed to operate off some supply voltage which is usually assumed to be constant. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters. The dc-dc converter inputs an unregulated dc voltage input and outputs a constant or regulated voltage. The regulators can be mainly classified into linear and switching regulators. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage.Since a feedback loop is necessary to maintain regulation, some type of compensation is required to maintain loop stability. Compensation techniques vary for different control schemes and a small signal analysis of system is necessary to design a stable compensation circuit. State space analysis is typically used to develop a small signal model of a converter and then depending on the type of control scheme used, the small signal model of converter is modified to facilitate the design of the compensation network. In contrast to a state space approach, PWM switch modeling develops a small signal of switching components of converterSystem level models are implemented using the Simulink in Mat lab. Thefollowing study provides details of methodologies for designing each component or block used in the switching regulator. Finally, simulation results are presented for voltage and V2 control schemes and their performance results are compared and inferences are drawnon the performance of current mode control.*
Keyword:*Interleavers, iterative decoding, low-density parity-check codes, convolutional codes, turbo codes.*

I. Introduction

Switching regulators are preferred over linear regulators for their high efficiencyand providing step up, step down or inverter output unlike linear regulator which doesonly step down operation. In practice, the conversion efficiency of linear regulators islimited to only 30% and they find application in analog circuits to ensure nearly constantsupply voltage providing high power supply rejection ratio (PSRR).In switching regulator circuits, semiconductor switches control the dynamictransfer of power from input to output with very short transition times. Because of thisswitching action there is ripple added to output voltage. The output requirement is a dcvoltage with a minimum superimposition of ac ripple. Pulse width modulation (PWM) isthe most widely used method for controlling the output voltage. It maintains a constantswitching frequency and varies the duty cycle. Duty cycle is defined as the ratio of switchon time to reciprocal of the switching frequency (fsw). Since the switching frequency isfixed, this modulation scheme has a relatively narrow noise spectrum allowing a simplelow pass filter to sharply reduce peak-to-peak ripple at output voltage. This requirement is achieved by arranging an inductor and capacitor in the converter in such a manner as toform a low pass filter network. This requires the frequency of low pass filter to be muchless than switching frequency (fsw).

The following section discusses various converter topologies and their operation.Idealized circuits are considered for ease of understanding and explanation. The keydifference between each is the arrangement of the switch and output filter inductor andcapacitor

II. Buck Converter

Switch mode power converters are nonlinear and discontinuous in nature and are cumbersome to analyze directly using standard linear circuit theory due to their inherent large signal nature. Linearizing the converter circuit is essential to understanding converter circuit as it allows the designer to apply the control theory. Any model of converter circuits should readily accommodate both monitor and control circuitry. A typical dc-dc system incorporating a buck converter and feedback loop block diagram is shown in figure.1

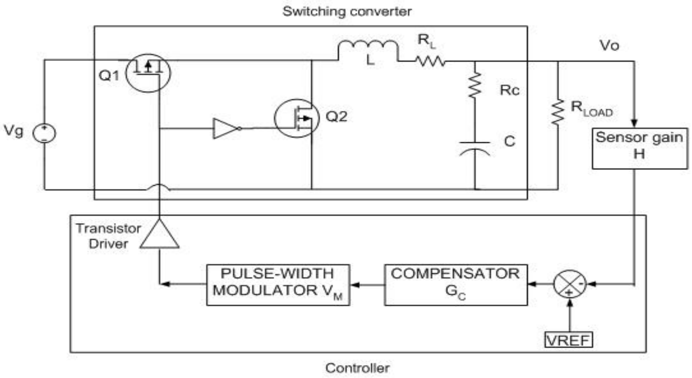

Figure 1: Buck converter regulator system

A dynamic switching converter model is helpful in analyzing how the variationsin the input voltage, the load current, or the duty cycle affect the output voltage.Traditionally, State space representation of dynamical systems is used to derive thesmall-signal averaged equations of PWM switching converters. However, in [4], asimplified model is developed by modeling only the non-linear switching action of aconverter as a three terminal circuit element. This model is easily applied to anyconverter topology. The following section summarizes the use of state space approach forbuck converter modeling, which can be generalized to any converter topology.

III. State Space Averaged Model Of Buck Converter

The first task is to write the state equation for the two switch positions. To get amore accurate small signal model, transistor on resistance, inductor resistance andcapacitance ESR are taken into account. The equivalent circuit when switch Q1 is on andQ2 is off is as shown in figure 2

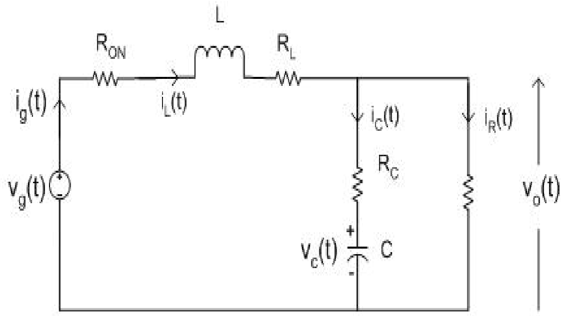

Figure 2: Buck converter ON state

IV. Control Schemes And Compensation Techniques

Negative feedback is employed to maintain voltage regulation regardless ofdisturbances in input voltage, vg(t), or load current, iload(t), or variations in componentvalues. The duty cycle is varied in the feedback loop to compensate for these variations.A typical block diagram of a Switching regulator is as shown in figure 3.

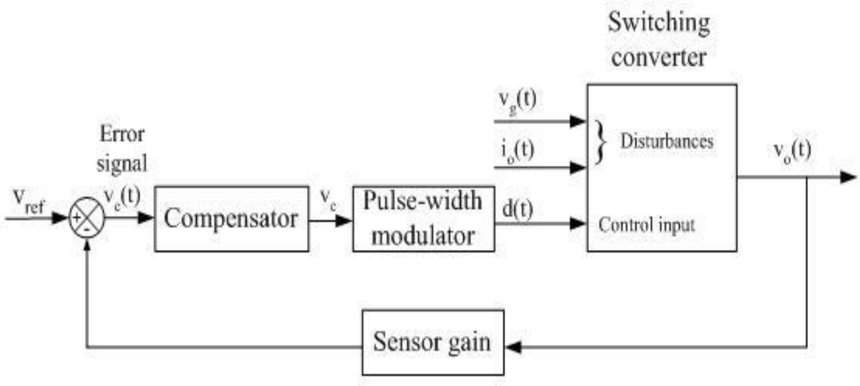

Figure 3: Block diagram of feedback system

A voltage reference is used to compare with the output voltage. Sensor gain isused to scale down the output to be equal to voltage reference. The error signal generated is fed to the compensator which is the key part to be designed to ensurestability of total feedback loop. Compensator design affects the overshoot, steady stateerror and transient response of the loop. The PWM block compares the compensatoroutput with another ramp signal to give the variation in duty cycle. The source fromwhere the ramp signal is generated leads to different control schemes. The three mostcommon control schemes are voltage mode control, current mode control and V2control.

4.1. BASIC CONTROL OPERATION

The switching converter along with feedback controller in its simplest form is asshown in the figure 4.2. An internal oscillator operating at switching frequency (fsw) andgenerates narrow pulses at the start of each switching cycle. The output of the switchingconverter is subtracted from the reference signal to generate an error signal. This errorsignal is compared with a ramp signal to generate a pulse to reset the flip-flop andmaintain a steady state duty cycle.

For any variations in the input voltage or output load current, the error signaleither increases or decreases. If the output voltage increases, the error signal increasesand the reset pulse is generated earlier to reduce the duty cycle and eventually lower theoutput voltage. Similarly, if the output voltage decreases, the error signal decreases andthe reset pulse is generated at later duration to increase the duty cycle and bring theoutput voltage back into equilibrium.

4.2. FREQUENCY RESPONSE OF BUCK CONVERTER

The first step in designing the feedback loop after selecting the components of theconverter is to plot the open loop response of buck converter. The transfer function ofoutput voltage to duty cycle can be derived in the small signal analysis of buck converter. The transfer function reveals a left half plane zero associated withESR of capacitor and a double pole at approximately resonant frequency of LC.

Typically, the transfer characteristic peaks at resonant frequency. The magnitude of this35peak is given by the quality factor. Ignoring the inductor series resistance and transistoron resistance, a simple expression for Q can be derived in terms of L, C, R and ESR ofcapacitor. It can be easily deduced that Q gets lowered as a result of ESR of the capacitor.

VII. Analysis of Simulink Implementation and Design

The complexity of device models and switching nature of switching convertersmake simulation difficult due to converge in Pspice. Simulink is a windows orienteddynamic modeling package that is an extension to Matlab. The advantage is that modelsare entered as block diagrams after corresponding mathematical equations are developedfor the target system. Matlab uses ordinary differential equation solver (ode45) to solvesets of linear and non-linear differential equations which in this case are emulated byblock diagrams. Thus to simulate an electrical system such as DC-DC converter, one hasto write equations for various blocks in the system and construct an equivalent blockdiagram using icons in simulink. The parameters for individual icons can be set for theprocess. Finally, a choice of equation solver and simulation time is made. The output ofsystem could be observed or recorded into file.

Simulink also provides the feature of writing S-functions which implements theequations of a block. The disadvantage in using s-functions is that no bode plots can beobserved if an s-function is in the block diagram.

VIII. Simulink Models

8.1. BUCK CONVERTER

Referring back to the equations for buck converter in its two switch positions in chapter 3, a simulink model can readily be constructed as shown in figure 5.1.

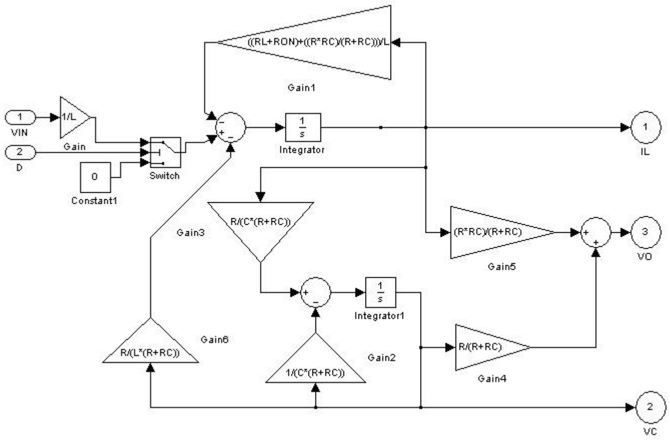

Figure 4: Simulink model of buck converter

To facilitate subsequent simulation, and feedback controller design and verification, the inputs to buck converter sub-block are, input voltage Vg and duty ratio d. The outputs are inductor current, capacitor voltage and output voltage. The non-idealities of transistor ON resistance and inductor series resistance are appropriately included. To validate the correctness of the simulink model, the results from simulink simulations of buck converter were compared to pspice simulations.

8.2. OTA

A single pole dominant model of an OTA is shown in figure 5.2. The model has the input parameters as transconductancegm, output conductance go and load capacitance CL. The simplified model estimates gain, bandwidth, and slew rate requirement of OTA.

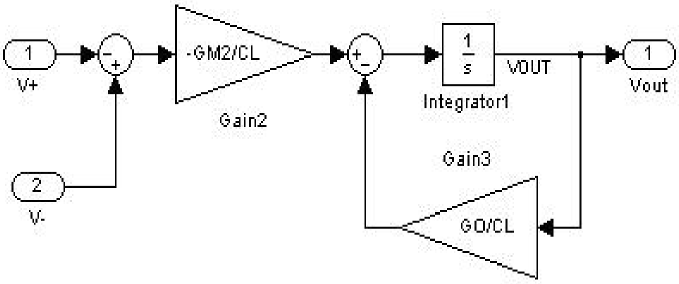

Figure 5: Simulink model of OTA

8.3. COMPARATOR

A comparator model implemented in simulink is as shown in figure 5.3. The model has the input parameters of open loop gain Avol, offset voltage Vos, Propagation delay Td.

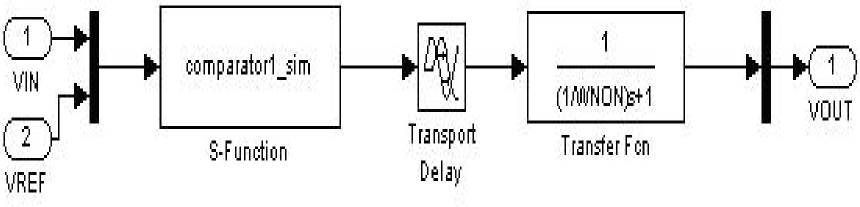

Figure 6: Simulink model of comparator

8.4. GATE DRIVE CIRCUITRY

The drive circuit is required to control the switching of the power MOSFET.During turn on both drain and source are maintained at a high input voltage and to keepthe transistor on, the gate voltage should be greater than input or source voltage. Thisessentially means that drive circuitry is also at high potential, which can cause damage toa low voltage PWM IC. To circumvent the problem, a pulse transformer is used to isolatethe logic circuitry from power MOSFET operating at high voltages. Another advantageof pulse transformers is that it maintains constant Vgs during turn on and has the capability to either step up or step down.Pulse transformer based gate drive circuits can deliver only AC signals as the fluxcore must reset every half cycle. The Inductor Volt second principle reviewed results in large voltage swings if a narrow reset pulse, i.e., a large duty cycle isrequired.

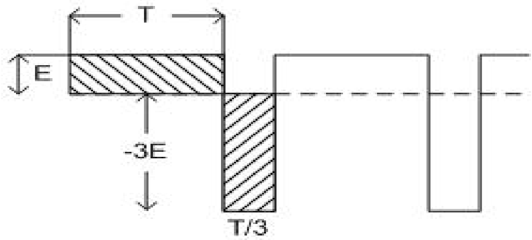

Figure 7: Volt-Seconds characteristics of Transformers

Or restated this means that area under the curve during positive and negative segments of a full cycle must be equal as shown in figure 6.1. This limits the use of pulse transformers to 50% duty cycle as the large voltage swings may be higher than voltage rating of the semiconductor switches and logic devices.

IX. Conclusion

DC-DC converters and their design remain an interesting topic and new controlschemes to achieve better regulation and fast transient response are continuallydeveloped. Step down switching regulators are the backbone of electronic equipmentsthat employ IC's running at supply voltages lower than 5V. A key challenge to designswitching regulators is to maintain almost constant output voltage within acceptableregulation.
Pspice is the industry standard for design and simulation of electronic circuits.But the problem of convergence and time for simulation makes it inconvenient forcomplex systems such as a DC-DC converter to be simulated. In this Study and analysis of DC to DC Converter, MatlabSimulink is preferred over Pspice for its enhanced equation solver.

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