MODULAR DC-DC BUCK CONVERTER FOR EDUCATION: FROM DESIGN TO EXPERIMENTAL RESULTS

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Abstract — **This presentation describes the design, the simulation and implementation of a DC-DC buck converter for educational purposes, that illustrates some of the fundamental topics covered in a first power electronic course focused in power management and low-voltage applications. This DC-DC buck converter can be a low-cost solution for a power electronic starter kit, composed by four circuit modules, allowing hands-on experiments at laboratory classes. Each module can be configured and tested alone as a sub-circuit of the converter, or assembled one after the other in a top-down approach to build the buck converter and study it at diverse detail levels. This buck converter can also be presented as a cap-stone project of an electronic course, if each module is to be designed and implemented from scratch: in this framework, other aspects must be mitigated, like carefully PCB design to reduce switching noise interferences during laboratory measurements, or explore the design space of the project to achieve the solutions that optimizes each module under a specific criterion. Four modules are described in this presentation, namely the power-block, the gate-driver, the current-sensing and the last module is the PWM generator that can be preceded by the controller (compensator). The power-block is the one with fewer components, but its placing and routing requires a careful design, because this module is the one with heights' currents that are periodically switched. Three alternative designs for the gate-driver are presented, and one of them includes a level shifting function at both logic levels: this increases the complexity of the gate-driver, which is mandatory if the converter input voltage exceeds a specific value that depends on the active switch characteristics at the power-block. Two alternative designs for the current-sensing are presented, and both use a transducer to converter current into a differential voltage to be amplified and outputted as a unipolar one, allowing to be displayed in one channel of the oscilloscope: one current-sensing module comprises a small value resistor as a transducer, and the other module implementation uses a hall effect transducer. The last module (PWM generator plus the controller) outputs the PWM signal that asserters the state of the active switch, and it can be configured to operate in open-loop or close-loop operation by feed-back the converter output voltage. The design of the modules was validated through SPICE simulations using diverse device models, depending on a trade-off between simulation speed and accuracy. The experimental measurements, that are presented in this communication, also corroborate the simulations results.**

Keywords: **DC-DC Buck converter, Hard switching, Gate driver, Level shifter, Current-sensing, Energy efficiency, Open and close loop.**

I. EXTENDED ABSTRACT

The increase use of DC-DC converters in portable electronic equipment powered by batteries is the established way to implement a regulated voltage and attain high energy efficiency and autonomy. The total power consumption of the equipment is also increasing due to larger internal circuitry or dynamic power, that is used to cope with the never-end demand of extra, or faster, functionalities included in the equipment, aiming to achieve new buyers.

There are three fundamental DC-DC converter non isolated topologies (buck, boost and buck-boost) and all other topologies can be derived based on them [1-2]. The buck topology is the only one that has the linear counterpart, namely the linear voltage regulator. The replacement of a linear regulator by a DC-DC buck converter brings some new challenges to the circuit designers, because the buck converter is a non-linear circuit periodically switching a current that is higher than the average value of the current in a linear regulator. These challenges are explained in some power electronic courses focused in power management and low-voltage applications, where an educational buck converter starter kit can be an important resource for teaching power electronic topics through parsing hands-on experiments at laboratory classes [3-7].

Fig.1(*a*) shows the buck converter that is composed by four modules, namely the power-block, the gate-driver, the current-sensing and the last module is the PWM generator that can be preceded by the compensator. The power-block module implements a buck converter hard switching fundamental topology that requires the minimum number of components: one active switch (M_P), one passive switch (D_N), one inductor and one capacitor. The power-block module is mounted in a Printed Circuit Board (PCB) that has connections to the battery or other power supply (V_{BAT}) and the load at output (R): this module can be tested in laboratory

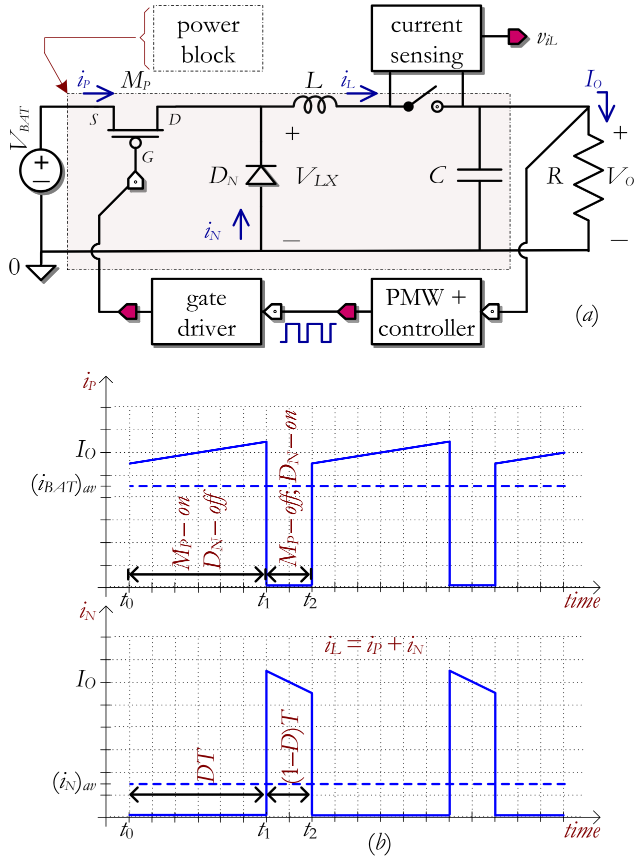

Fig 1: Buck converter: a) hard switching or fundamental topology; b) waveforms for CCM.

without any other module, by connecting a bench signal generator, configured to source a Pulse Width Modulation (PWM) signal with a constant duty-cycle, that drives the active switch. Furthermore, the power-block PCB also has other three connections: 1) to the gate-drive module that can drive the active switch when its state is asserted by a specific chip that outputs a PWM signal without enough current driving strength for M_P; 2) to the current-sensing module that provides the transduction and signal condition for inductor current measurement, i_L, in an oscilloscope without a current-probe accessory (this accessory is the straightforward process to display $i_L = i_P + i_N$, illustrated in Fig.1(*b*), but it is expensive and only accessible in specific laboratories); 3) also the connections to the module that includes the chip outputting the PWM signal that defines the M_P state, which can be configured to a constant duty-cycle (buck converter in open-loop), or can include some additional components to implement a buck converter compensator inserted in a feedback loop by monitoring the converter output voltage: in this configuration, the module adjusts the PWM duty-cycle, D, targeting a constant output voltage of the buck converter, despite variations on V_{BAT} or other perturbations.

This DC-DC buck converter can be a solution for a low-cost power electronic starter kit, allowing hands-on experiments at laboratory classes [3-6], or can also be presented as a capstone project of an electronic course, if the focus points include the exploration of the project design's space to achieve the optimized solution under a specific criterion or, for example, the mitigation of noise interferences during laboratory measurements [7]. The buck converter main features are as follows. Input voltage: $7.5V \leq V_{BAT} \leq 30V$; output voltage and current: $V_O \leq 27V$ and $I_O \leq 2A$; Voltage mode controller or open-loop operation, that is user configurable. The measured maximum efficiency of our converter is 85%, which is far below from the state of art, because its design is not optimized for the efficiency criteria. The main goal of the design was the achievement of a power electronic starter kit, allowing measurement of internal variables (for example, V_{LX} and i_L without current-probe accessory) and following a top-down approach for learning the converter functionality (the study of some details can be postponed until the attachment of some modules to the power-block). Other design goal was to allow the usage of a SPICE simulator as a learning tool, and this recommends components with available simulation model (sooner or later in the design process, accuracy in the model can be tradeoff by simulation speed). It is also recommended, in practice, the over-dimensioning of some components in order to accommodate robustness to tolerate some misusage by the user.

The design and experimental evaluation of each module of this buck converter are addressed in this presentation that is organized as follows: section 2 provides some more details of the power-block module. Section 3 addresses the gate-drive circuit, where three dissimilar alternatives are analyzed. Section 4 describes the current-sensing, and section 5 the PWM generator and controller. Section 6 presents the conclusions of this work.

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