

## An Efficient Solution of the Step-down Converter for Students Teaching

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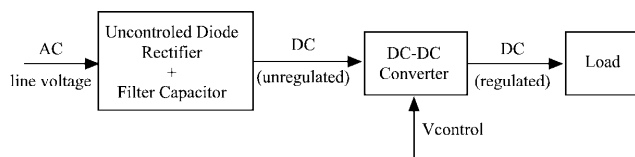
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### Introduction

DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drive applications. Switch-mode dc-dc converters (called SMPS – Switched Mode Power Supplies) are used to convert the unregulated dc input into a controlled dc output at a desired voltage level (Fig. 1).



**Fig. 1.** DC-DC converter system

The main features of SMPC are high efficiency and high power density. There are uses in many domains like Computer, telecom, automotive and domestic application.

Most power supplies are design to meet some or all the following requirements:

- regulated output;
- isolation;
- multiple outputs.

The basic dc-dc converter topologies, without electrical isolation, are the step-down and step-up converter [1].

In this paper we propose a solution to make more attractive for students the power electronics labwork. This solution wants to be more educative for students. One teacher have the success at his labwork when the students understand how work the study schema and what influence have some parts of scheme in good work of the converter.

### Step-down converter

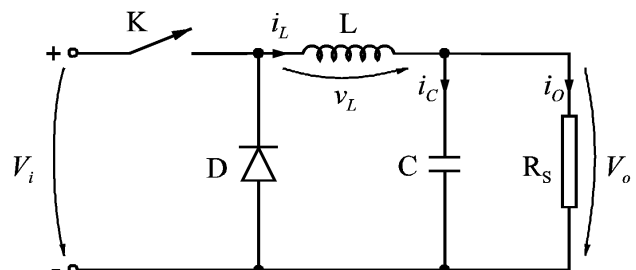
As the name implies [1], a step-down converter

produces a lower average output voltage than the dc input voltage  $V_d$ . This converter is realized to work for a pure resistive load, as show in Fig. 2. The average output voltage can be calculated in terms of the switch-duty ratio ( $\alpha = t_{ON}/T_s$ ):

$$V_o = \frac{1}{T_s} \cdot \int_0^{T_s} v_0(t) dt = \frac{t_{ON}}{T_s} \cdot V_i = \alpha \cdot V_i. \quad (1)$$

So, we can control  $V_o$  by varying the duty ratio, called Pulse Width Modulation (PWM). The switch control signal, which controls the state (on or off), in PWM switching, is generated by comparing a signal level control voltage  $v_{control}$  with a repetitive waveform (sawtooth waveform). The duty ratio is controlled by level of  $v_{control}$  and the switching frequency by frequency of the sawtooth waveform.

The output voltage fluctuation is very important. For minimized this fluctuation we can use a low-pass filter, consisting of an inductor and capacitor.



**Fig. 2.** Step-down converter

The Fig. 3 illustrates the steady-state waveforms for continuous conduction where the inductor current  $i_L$  flows continuously.

At boundary between continuous and discontinuous conduction, the inductor current  $i_L$  goes to zero at the end of the off interval. The average value of inductor current at

this boundary is:

$$(I_L)_B = \frac{[\alpha \cdot T_s + (1-\alpha) \cdot T_s]}{2T_s} \cdot (I_L)_{B \max} = \frac{(I_L)_{B \max}}{2}, \quad (2)$$

where  $(I_L)_{B \max}$  – peak value of inductor current, in this condition of conduction.

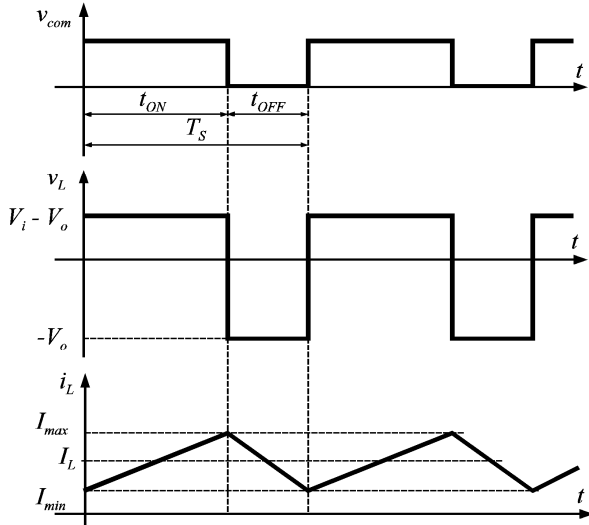


Fig. 3. Continuous conduction in step-down converter

In discontinuous-conduction mode the output voltage is

$$V_o = \frac{\alpha_1 + \alpha}{\alpha_1} \cdot V_i, \quad (3)$$

where  $\alpha_1 = \frac{t_1}{T_s}$ , as show in Fig. 4.

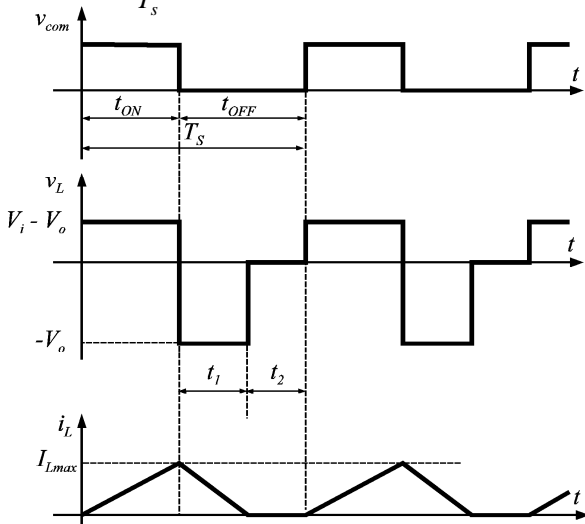


Fig. 4. Discontinuous conduction in step-down converter

The output voltage ripple depends on value of capacitance, which can be calculated by considering the waveforms presented in Fig. 5. Assuming that all of the ripple component in  $i_L$  flows through the capacitor and its average component flows through the load resistor, the shaded area in Fig. 5 represents an additional charge  $\Delta Q$ .

Therefore, the peak-to-peak voltage ripple,  $\Delta V_o$  can be obtained as:

$$\Delta V_o = \frac{\Delta Q}{C} = \frac{\Delta I_L T_s}{8C} = \frac{T_s V_o}{8C \cdot L} (1-\alpha) T_s, \quad (4)$$

and

$$\frac{\Delta V_o}{V_o} = \frac{T_s^2 (1-\alpha)}{8C \cdot L} = \frac{\pi^2}{1} (1-\alpha) \left( \frac{f_c}{f_s} \right), \quad (5)$$

where  $f_s = \frac{1}{T_s}$  – switching frequency,  $f_c = \frac{1}{2\pi\sqrt{LC}}$ .

Voltage ripple can be minimized by selecting a corner frequency  $f_c$  of the low-pass filter at the output such that  $f_c \ll f_s$ .

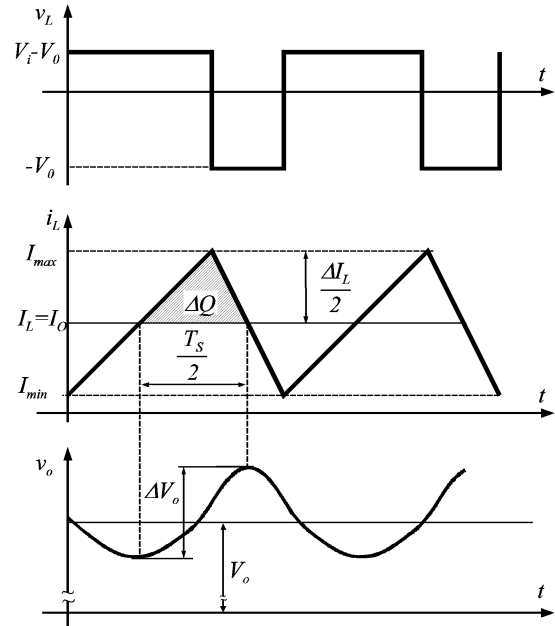


Fig. 5. The output voltage ripple in a step-down converter

## Experimental results

It's very important for the students at this labwork, to understand how works this converter and to observe what influence have the inductor value  $L$ , the switching frequency  $f_s$ , the duty cycle  $\alpha$  and the output current value  $I_o$  to the converter performances.

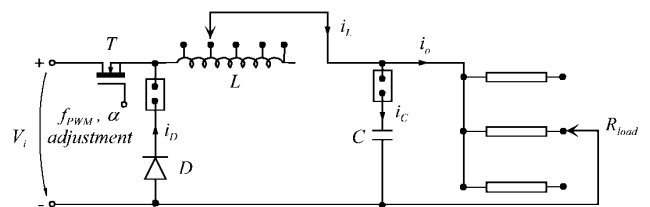


Fig. 6. Experimental schema of the step-down converter

For that we realized a converter step-down especially for power electronics laboratory. As shows in the figure 6 the electrical schema has facilities for changing the inductor value  $L$ , the switching frequency  $f_s$  and the duty cycle  $\alpha$ . Further more, they can choose to connect or not the capacitor  $C$  and/or diode  $D$ , respectively to select different values for resistive load.

In Fig. 7 we present the inductor current  $i_L$  at different switching frequency in two situations: with filter capacitor  $C$  (Fig. 7a) and without filter capacitor  $C$  (Fig. 7b).

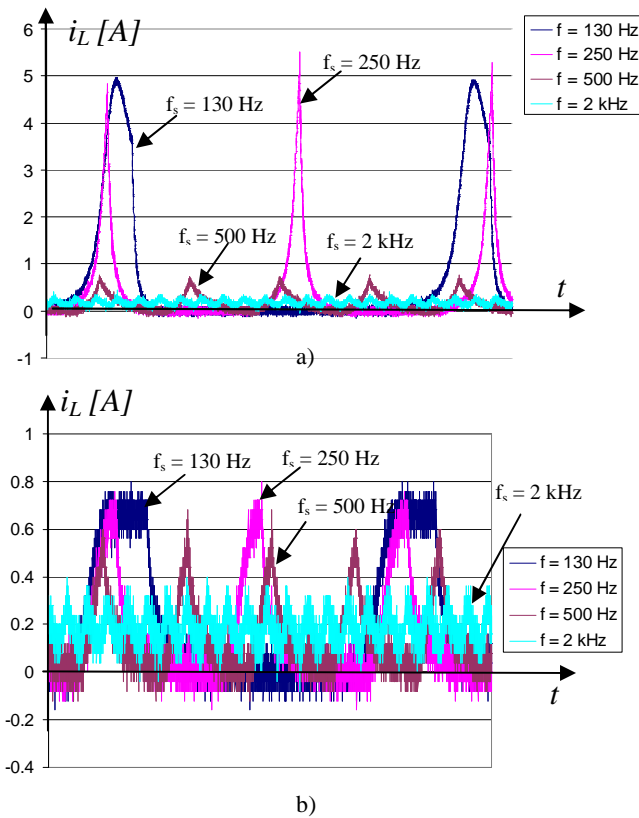


Fig. 7. The inductor current with and without capacitor  $C$

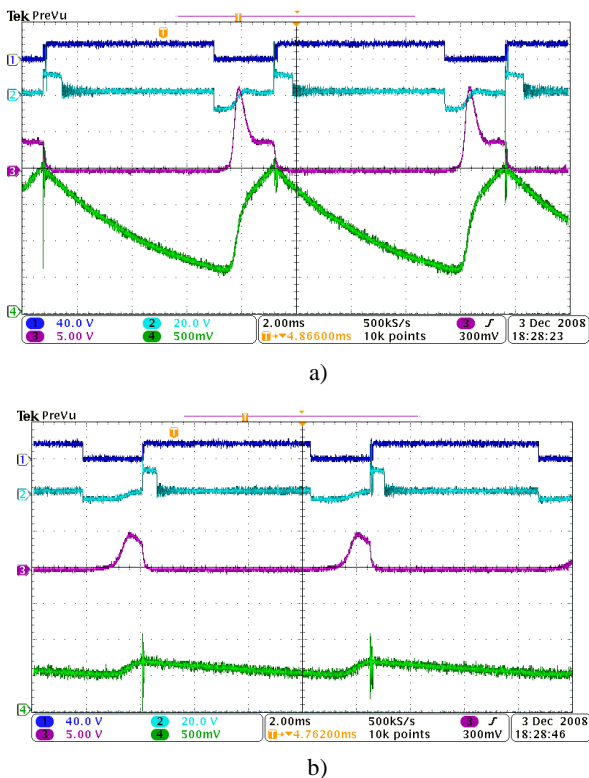


Fig. 8  $v_{comp}$ ,  $v_L$ ,  $i_L$  and  $v_o$  waveforms at low frequency

In these tests, the students can observe how big the peak current (5A), at low switching frequency, is with

filter capacitor. Further more, they can analyze how much influence has the switching frequency to inductor current ripple.

Another test, presented in Fig. 8 and 9, is the influence studying of the switching frequency  $f_s$  and the load  $R$  to inductor current  $i_L$  (waveform Ch. 3) and output voltage  $v_o$  (waveform Ch. 4).

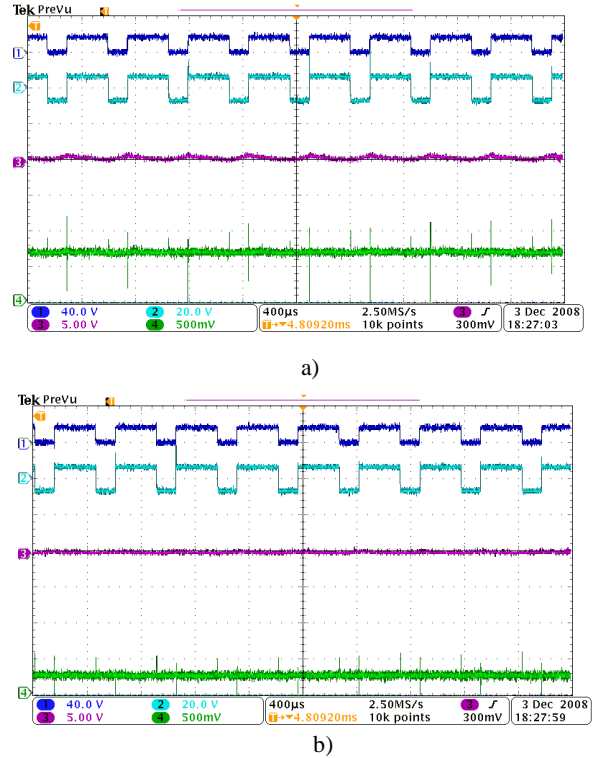


Fig. 9.  $v_{comp}$ ,  $v_L$ ,  $i_L$  and  $v_o$  waveforms at high frequency

The students can observe that the ripple output voltage is high at low frequency and at high load current. If the load resistance is constant and the switching frequency increases (Fig. 10a), the ripple output voltage is reduced considerable.

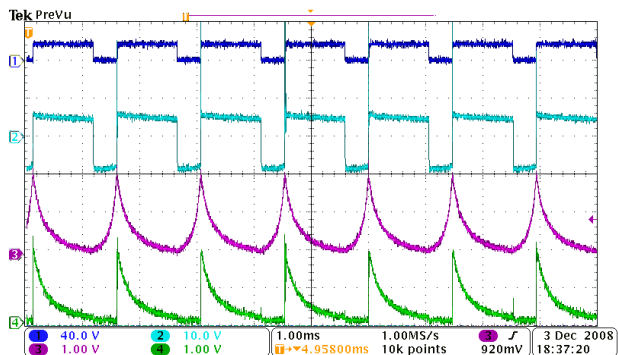
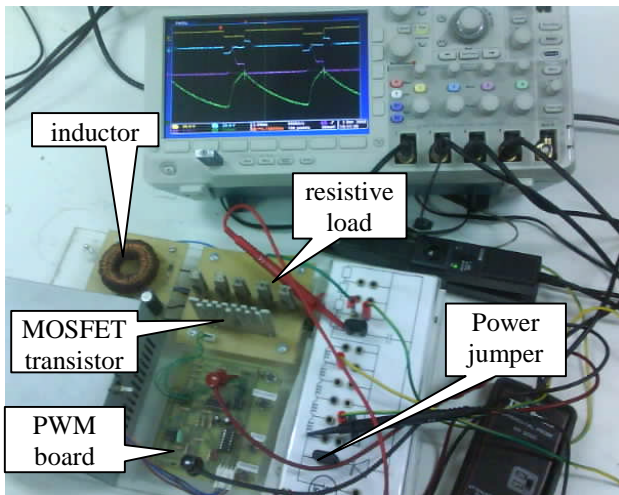


Fig. 10.  $v_{comp}$ ,  $v_L$ ,  $i_L$  and  $i_D$  waveforms

Also the Fig. 8 and 9 present discontinuous conduction and the Fig 10 shows the steady-state waveforms for continuous conduction. It can see the inductor current (in Fig. 10 Ch. 3) flows continuously.

The students can observe too, that the inductor  $L$  and switching frequency  $f_s$  influence the region of continuous

conduction, operating range and linearity of the step-down converter.



**Fig. 11.** The experimental arrangement

### Conclusions

This paper presents a step down converter used in power electronics laboratory. This converter is realized by authors and it was designed especially for this activity. The main features of this converter are:

1. Permits very easy adjustment of different parameters, like:  $f_s$ ,  $\alpha$ ,  $L$ ,  $R$ ;

2. Aids the students to understand how this converter works (because they can observe any current or voltage with the oscilloscope);

3. Reduces the time to make the changes in converter circuit (adjust value of inductor  $L$  or resistance load, connect or disconnect the filter  $L$  and/or  $C$ ) using the power jumpers as shown in Fig. 11 and 12.

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A solution for the experimental study of the steady-state characteristics from the step-down (buck) converter circuits by the students is presented. The main feature of the proposed solution consists in possibility to observe the influence of the inductor value  $L$ , the switching frequency  $f_s$ , the duty cycle  $\alpha$  and the output current  $I_o$  to the converter. Il. 11, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

**M. Рага, Г. Рага, Д. Милици, И. Граур.** Эффективный понижающий преобразователь напряжения для обучения студентов // *Электроника и электротехника*. – Каунас: Технология, 2009. – № 3(91). – С. 77–80.

Приведен экспериментальный анализ понижающего преобразователя напряжения. Показаны способы исследования его характеристик. Основное преимущество предложенного варианта – возможность наблюдать влияние индуктивности  $L$ , частоты  $f_s$ , скважности импульса  $\alpha$  и выходного тока  $I_o$  на работу преобразователя. Ил. 11, библи. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

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Pateikta žeminančio įtampos keitiklio grandyno, skirto studentams pastoviosios būsenos charakteristikoms tirti, eksperimentinė analizė. Esminis pasiūlytojo varianto pranašumas – galimybė stebėti induktyvumo  $L$ , komutavimo dažnio  $f_s$ , impulso skverbties  $\alpha$  ir išėjimo srovės  $I_o$  įtaką keitikliui. Il. 11, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).