Zheliazkov Y.

CIRCUIT DESIGN OF BUCK-VOLTAGE CONVERTER WITH DIGITAL CONTROL SYSTEM

Об'єктом дослідження є процеси в електричній схемі т   величезні цифрові системи упр вління в пере-творюв чі. Одним з н йбільш проблемних місць є перед ч т змін енергії в перетворюв ч х струму т н пруги для досягнення відповідного зн чення числового ді п зону з мінім льним відсотком похибки.

В д ній роботі досліджується понижуючий перетворюв ч н пруги з цифровою системою керув ння, зокрем розглянуто порядок проектув ння електричної схеми. Опис но електричну схему з системою керу-в ння, як з допомогою цифрової системи з безпечує д ні з більш точною н пругою н виході конвертер , с ме: з вд ння відповідного числового ді п зону вихідної н пруги т вплив системи н роботу схеми.

В ході дослідження використовув вся н бір п р тних т прогр мних з собів, в тому числі периферійні пристрої, які дозволяють досить просто т швидко н л штув ти мікроконтролер н потрібний режим роботи т прогр мно ре лізув ти систему керув ння понижуючого перетворюв ч .

Про н лізов но послідовність вирішення т вибору певних ч стин електричної схеми, при побудові якої було використ но:

– мікроконтролер для прийому, обробки т вид чі інформ ції в електричному колі;
– керув ння др йвером т роботи н лого-цифрового перетворення в схемі;
– др йвер для керув ння ключ ми – тр нзистор ми;
– компоненти схеми понижуючого перетворюв ч .

Зроблено опис т вибір ч стин схеми з т кими п р метр ми т х р ктеристик ми:

– для понижуючого перетворюв ч – т кі елементи, як ключ, діод т конденс тор;
– мікроконтролер – відповідний ді п зон ч стоти т н пруги;
– др йвер – керув ння силовими ключ ми схеми з відповідними робочими п р метр ми.

Отрим но систему, як в перспективі ст не підґрунтям для пониження зн чення н пруги до відповідного рівня. Це пов'яз но з тим, що з пропонов ний метод м є ряд особливостей, зокрем цифрову систему регулю-в ння з дискретним кроком т   н лого-цифровим перетворюв чем в якості зворотнього зв'язку. З вдяки цьому з безпечується можливість отрим ння більш коректного зн чення пок зників. У порівнянні з н логічними понижуючими перетворюв ч ми, д ний конвертер м є пок зник н пруги з можливою незн чною похибкою.

Ключові слова: *понижуючий перетворюв ч, керов ний сигн л, г льв нічн розв'язк силової ч стини, цифрове керув ння.*

1. Introduction

There is often happens situation, in which voltage value of the internal source can be low or big for reliable working process. For example, in order wireless charging systems could transfer voltage in range of 5–7 volts for certain devices or 70–80 volts for certain autos. Actually, voltage value could be not enough or more level, than it is necessary. In order to solve this problem it is possible to use electrical filters and additional resistors with other components. The problems of it are great volume and big weight, exploitation conditions for connection system comes wrong. Therefore, it is efficiently to use buck-converter in order to receive certain value. Analogic researches were made in [1] for boost-voltage converter with digital system control and in [2] for buck-boost converter with voltage feedback control. Therefore, *the objects of research* are processes in electrical scheme and enormous digital control systems in converter. *The aim of the article* is projecting, researching and practical realization of semiconducting voltage buck converter with digital system control.

2. Methods of research

2.1. Calculation of parameters in buck converter scheme.
There is in Fig. 1 an electrical principle scheme of the buck voltage converter. Power circuit of converter has transistor VT_1. If the key switched on, output current, which flows through the inductance coil (L), rises. Inductance coil is coupling magnetic field energy. If the key switched off, coupled electrical energy in the inductance coil will be send to the capacitor (C) and load (R_L). Bypass diode (VD_1) lets the pass for the current to flow.

In order to realize the scheme it is important to calculate nominals of the elements in the buck converter [3, 4].

Calculation would be finished with a certain parameters: maximal output current $I_{out.max} = 0.46$ A, frequency switching $f_{sw} = 10$ kHz, inductive current ripple factor $LIR = 0.3$, range of input voltage $U_{in} = 7 - 24$ V and output voltage $U_{out} = 5$ V.
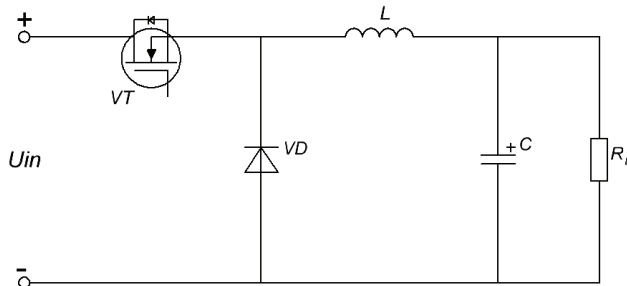

Fig. 1. Scheme of the buck converter

Inductance calculation is an important moment during converter projecting, insofar as there is dependence on values of maximal input $U_{in.max}$ and output U_{out} voltage:

$$L = (U_{in.max} - U_{out}) \frac{U_{out}}{U_{in.max}} \frac{1}{f_{sw}} \frac{1}{LIR \cdot I_{out.max}},$$

$$L = (24 - 5) \text{ V} \frac{5 \text{ V}}{24 \text{ V}} \frac{1}{10^4 \text{ Hz}} \frac{1}{0.3 \cdot 0.46},$$

where f_{sw} – frequency switching transistor; LIR – inductive current ripple factor; $I_{out.max}$ – maximal value of output current.

Peak current of the inductance coil I_{peak} solves as:

$$I_{peak} = I_{out.max} + \frac{\Delta I_{ind}}{2},$$

$$I_{peak} = 0.46 \text{ A} + \frac{0.3 \cdot 0.46 \text{ A}}{2} = 0.53 \text{ A},$$

where $\Delta I_{ind} = LIR \cdot I_{out.max}$ – variable inductance value.

Output capacitor with a maximum available amplitude swing of ripples of the output voltage ΔU (accept $\Delta U = 100$ mV):

$$C_{out} = \frac{L}{(\Delta U + U_{out})^2 - U_{out}^2} \left(I_{out.max} + \frac{\Delta I_{ind}}{2} \right),$$

$$C_{out} = \frac{2.87 \text{ mH}}{(100 \text{ mV}+5)^2 - 5^2} \left(0.46 + \frac{0.138}{2} \right)^2 = 0.8 \text{ mF}.$$

Capacitance of the input capacitor, including of the load current I_L and swing of ripples of the output voltage $U_{out.ripple}$:

$$C_{out} = \frac{I_L}{2\pi f_{sw} U_{out.ripple}},$$

$$C_{in} = \frac{0.46 \text{ A}}{2 \cdot 3.14 \cdot 10^4 \text{ Hz} \cdot 40 \text{ mV}} = 183 \text{ uF}.$$

Duty cycle of the open state power key relative period of the pulse width modulation:

$$D = \frac{U_{out}}{U_{in}} = \frac{5 \text{ V}}{12 \text{ V}} \approx 0.42 \approx 42 \text{ %}.$$

2.2. Choice of microcontroller in electrical scheme. It was selected integral scheme PIC16F877A as microcontroller in Fig. 2 [5, 6]. This scheme is very convenient for a work, coding of this controller is not so difficult. One of the main advantages is that it can be write-erase as many times as possible because it uses FLASH memory technology. It has a total number of 40 pins and there are 33 pins for input and output.
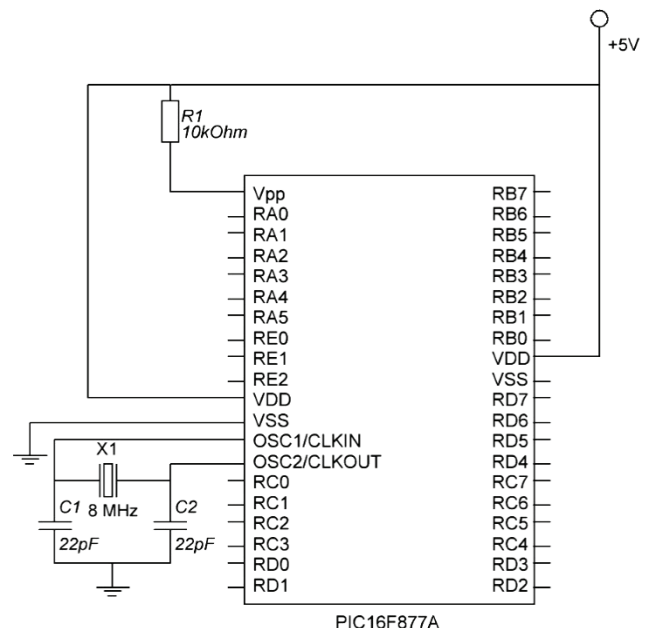

Fig. 2. Scheme of microcontroller PIC16F877A with a peripheral part

PIC16F877A finds its applications in a huge number of devices. It is used in security, remote sensors and safety devices, home automation and many industrial instruments. An enormous EEPROM is also featured in it which makes it possible to store some of the information permanently like transmitter codes and receiver frequencies and some other related data. The cost of this controller is not expensive and its handling is also easy. It is flexible and can be used in areas where microcontrollers have never been used before as in microprocessor applications and timer functions etc. It works in a range until 20 MHz and in a range of voltage 4.2–5.5 V.

2.3. Choice of the driver in electrical scheme. It was selected IR2184S as driver in Fig. 3, as it is driver MOSFET of the high voltage in the integrated scheme [7–9]. It can control by the keys in the half-bridge and bridge schemes of the low resistance both with high and low level. Schemes of the drivers are using MOSFET with high and low level.

Gate drive supply range from 10 to 20 V, output source capability is equal to 1.4 A and sink current capability is equal to 1.8 A, time to switch on $t_{on} = 120nS$ and to switch off $t_{off} = 94nS$, tolerant to negative transient voltage, operates up to 600 V.

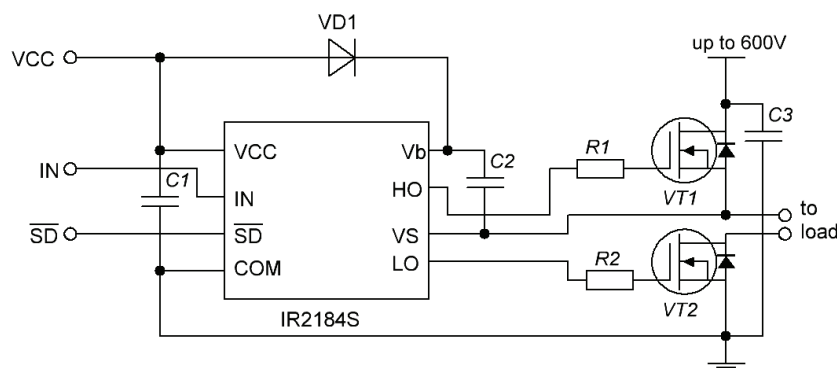**Fig. 3.** Integrated scheme of the driver IR2184S

3. Research results and discussion

3.1. The result of engineering of the electrical scheme.
After the selection of the certain elements and engineering of controlling system there was projected in Fig. 4 electrical scheme with components and microcontroller, which takes part in a work of buck converter and control of digital signals. There is PIC16F877A.

As a basis, there was taken [10]. With this set of bundled hardware and software, it is quite quick and easy to set up the microcontroller to the certain operating mode and to implement the buck converter control programmatically.

In order to provide galvanic isolation of the power circuit and controlling system, transmission impulse of controlling was made with the using of the half-bridge driver IR2184S.

3.2. The results of the experiment.
Electric principle scheme in Fig. 4 was projected and modulated in the programmed application *Proteus*, which model represented.

In Fig. 5 there is a general form of buck converter realization in program.

In Fig. 6 there is represented realization of the model of buck converter with a digital controlling system in programmed application *Proteus* that relates to the electrical principle scheme in Fig. 4.

Fig. 7 is represented researching of the graphics of projected buck converter with a defined voltage of input voltage 12 V and output voltage – 5 V. In order to support constant output voltage, regulator changes porosity of the controlling signal. An enormous, in Fig. 7, a demonstrated signal of the pulse width modulation (PWM) that flows to MOSFET transistor IRF540 and output voltage in Fig. 7, b.
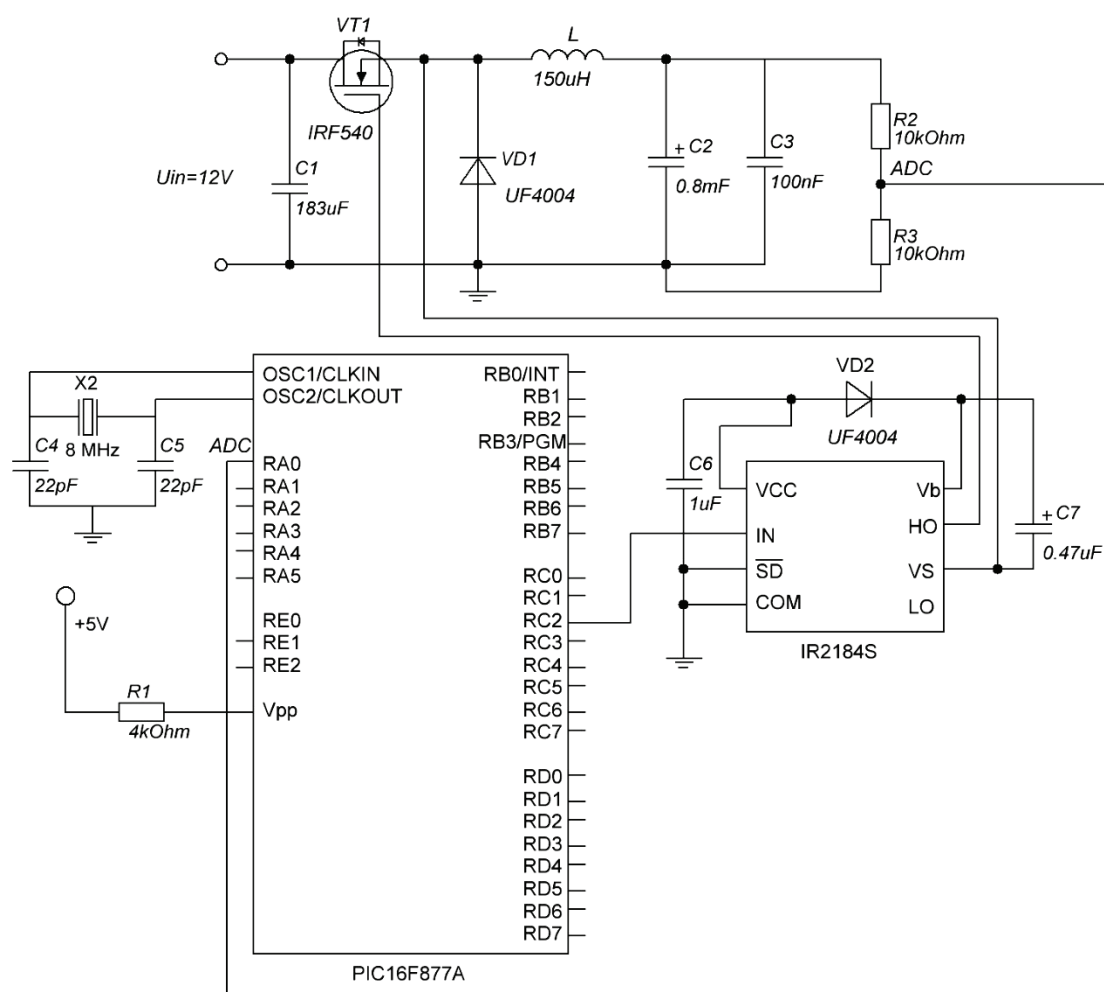

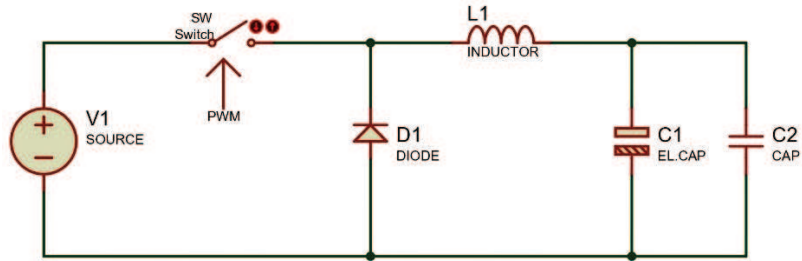**Fig. 4.** Electric principle scheme with converter of the controlling and regulating system

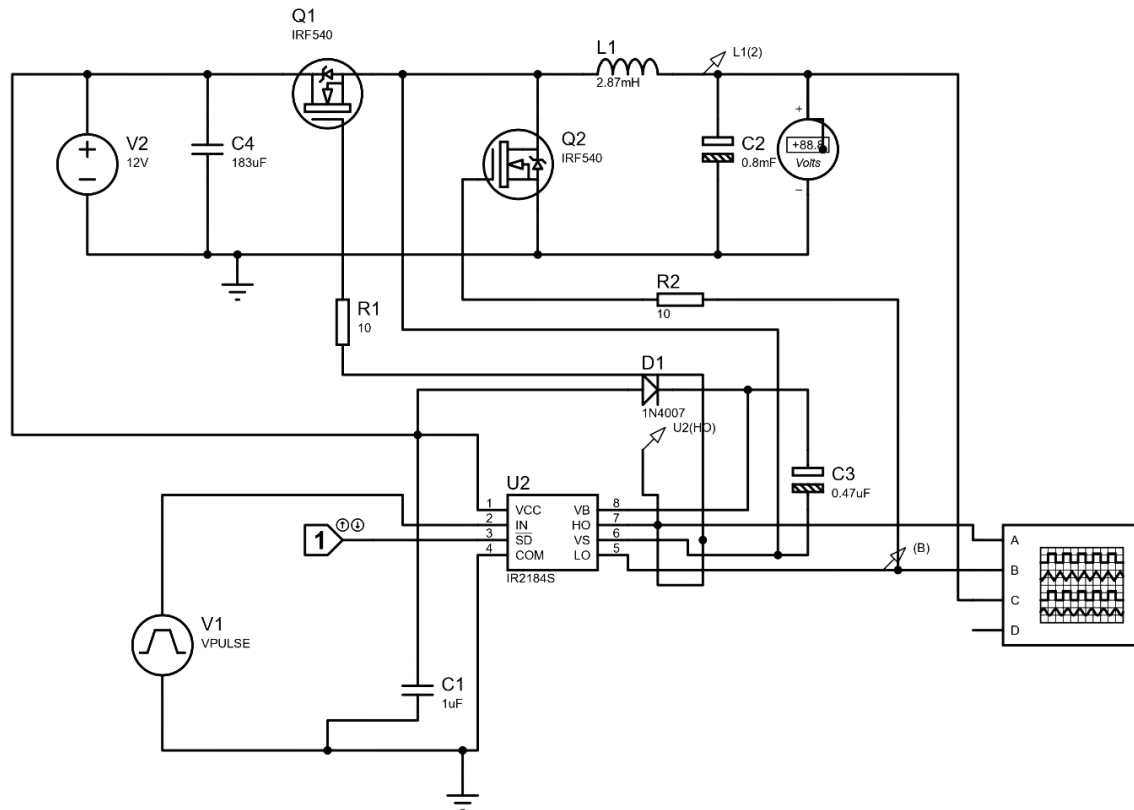**Fig. 5.** General form of buck converter realization in program *Proteus*

Fig. 6. Model of buck converter with a digital controlling system in programmed application *Proteus*
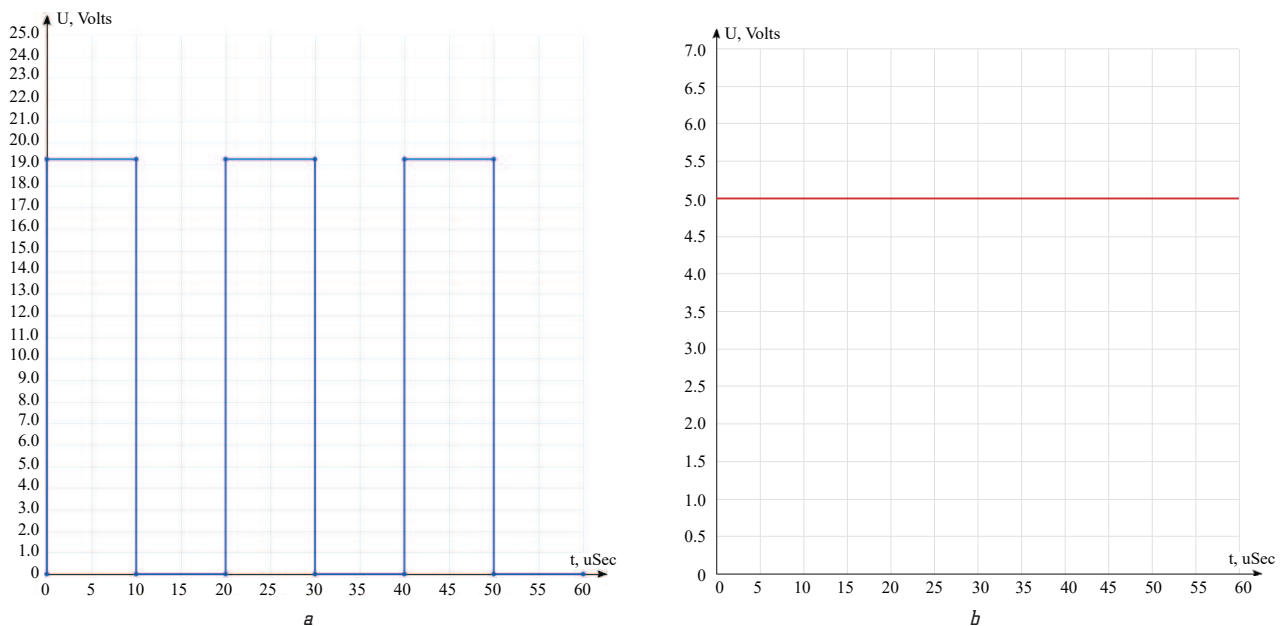

Fig. 7. Controlling signals of converter: *a* – pulse width modulation; *b* – output voltage

All over the elements are playing a main role in the converter. To be sure, there was considered capability of the scheme to work without capacitor C_{out}. It is obviously, that output capacitor rectify voltage and the voltage is rippling in output of converter.

4. Conclusions

There was developed principle of the technical realization of the semiconducting buck voltage converter. It can be used in a lot of devices. There was analyzed capability to create power supply equipment based on PWM for the input voltage of the discrete current. There also was researched that for practical realization of the buck voltage converter, which was based on inductive-capacitive converter, it is conveniently using of the digital system controlling. According to the certain graphics in Fig. 7, *a* and Fig. 7, *b*, scheme was successfully tested.

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Zheliazkov Yehor, Department of Electronic Devices and Systems, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, e-mail: yehor.zheliazkov@i.ua, ORCID: http://orcid.org/0000-0002-3651-7840