MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
“IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”

ELECTRONIC SYSTEMS-2

COURSEWORK

Tutorial

Recommended by Methodical council of “Igor Sikorsky Kyiv Polytechnic Institute”
as a tutorial for bachelors
according to the educational program “Electronic components and systems”
specialty 171 Electronics

Compiler: K. S. Klen

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(protocol № 09/2022-2 from 26.09.2022)

The discipline "Electronic Systems - 2. Coursework" (ES) belongs to the cycle of professional and practical training of bachelors in the educational program "Electronic Components and Systems", is read during one semester (7) and is one of the final subjects of bachelor's training. The textbook should promote the practical mastering by students of the material of the credit module "Electronic Systems-1", which is taught according to the plan of bachelor's degree training of students of the Department of Electronic Devices and Systems in the fourth year in the seventh semester. The main purpose of the credit module is to form students' abilities to develop a set of skills in the field of design, development and analysis of PWM controllers, calculation of their parameters, basic technical characteristics and algorithms.

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Content

Introduction

The textbook contains requirements, recommendations and links to reference and support materials for students of the first bachelor's level of higher education of specialty 171 "Electronics" in the educational program "Electronic Components and Systems" course work (CW) in the discipline "Electronic Systems" (credit module 2).

The purpose of the CW is to form students' abilities to develop a set of skills in the field of design, development and analysis of PWM controllers, calculation of their parameters, basic technical characteristics and algorithms.

The task of the CD is to design, develop and simulate a PWM controller using Analog System Lab Kit PRO stand with the specified values of the input voltage; output current; frequency of regulation; type of modulation.

Successful solution of the problem of design, development and simulation of PWM controller depends on:

- correct calculation of modulation parameters and elements of the PWM controller;
- selection and configuration of PWM controller design functions in software environments;
- analysis of the results of the PWM controller by constructing time diagrams that explain the principle of operation.

1. Terms

The CW contains an explanatory note and graphic material, which includes an electrical structural diagram, an electrical schematic, timing diagrams explaining the principle of operation.

Course work is performed in groups of students up to 5 people.

The text of the explanatory note is written in the state language in printed form on A4 sheets in Times New Roman font, 14 points, line spacing 1.5 Lines.

The size of the explanatory note is from 20 to 30 pages.

2. Task analysis

Variants of group tasks are given in Appendix 1.

3. Requirements for the content and structure of the CW

The structure of the explanatory note is determined by the topic of the CW. The following structure and content are recommended:

Cover page

Contents

Annotation

Introduction (appointment of PWM controller, task formulation)

1. Block diagram of the PWM controller, the principle of operation and time diagrams

2. Schematic diagram of the PWM controller and calculation of its elements

3. Implementation of individual elements of the PWM controller based on the Analog System Lab Kit PRO stand

4. PWM controller modeling in a software environment

5. Analysis of PWM controller operation

Conclusions (analysis of the obtained results, recommendations for improvement)

List of used literature sources

Appendix

An example of the implementation of the CW is given in Annex 2.

4. Theoretical information

Pulse-width modulation

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. Along with maximum power point tracking (MPPT), it is one of the primary methods of reducing the output of solar panels to that which can be utilized by a battery. PWM is particularly suited for running inertial loads such as motors, which are not as easily affected by this discrete switching, because their inertia causes them to react slowly. The PWM switching frequency has to be high enough not to affect the load, which is to say that the resultant waveform perceived by the load must be as smooth as possible.

The rate (or frequency) at which the power supply must switch can vary greatly depending on load and application. For example, switching has to be done several times a minute in an electric stove; 100 or 120 Hz (double of the utility frequency) in a lamp dimmer; between a few kilohertz (kHz) and tens of kHz for a motor drive; and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel.

In electronics, many modern microcontrollers (MCUs) integrate PWM controllers exposed to external pins as peripheral devices under firmware control by means of internal programming interfaces. These are commonly used for direct current (DC) motor control in robotics and other applications.

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform $f(t)$, with period T, low value $y_{\min}$, a high value $y_{\max}$ and a duty cycle D, the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt .$$

As $f(t)$ is a pulse wave, its value is $y_{\max}$ for $0 < t < D \cdot T$ and $y_{\min}$ for $D \cdot T < t < T$. The above expression then becomes:

$$\bar{y} = \frac{1}{T}\left(\int_0^{D\cdot T} y_{\max} dt + \int_{D\cdot T}^{T} y_{\min} dt\right) = \frac{1}{T}\left(D \cdot T \cdot y_{\max} + T(1-D)y_{\min}\right) = \\ = D \cdot y_{\max} + (1-D)y_{\min} .$$

This latter expression can be fairly simplified in many cases where $y_{\min} = 0$ as $\bar{y} = D \cdot y_{\max}$. From this, the average value of the signal $\bar{y}$ is directly dependent on the duty cycle D.

The simplest way to generate a PWM signal is the intersective method, which requires only a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the red sine wave in Fig. 1) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

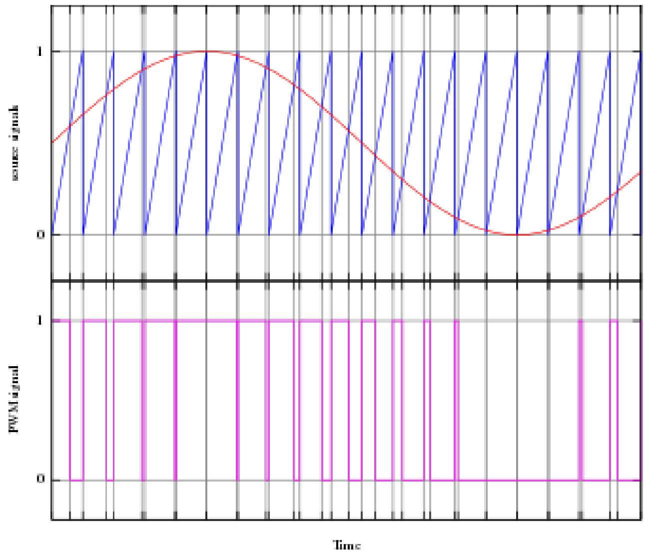


Fig. 1. A simple method to generate the PWM pulse train corresponding to a given signal is the intersective PWM: the signal (here the red sine wave) is compared with a sawtooth waveform (blue). When the latter is less than the former, the PWM signal (magenta) is in high state (1). Otherwise it is in the low state (0)

PWM can be used to control the amount of power delivered to a load without incurring the losses that would result from linear power delivery by resistive means. Drawbacks to this technique are that the power drawn by the load is not constant but rather discontinuous (see Buck converter), and energy delivered to the load is not continuous either. However, the load may be inductive, and with a sufficiently high frequency and when necessary using additional passive electronic filters, the pulse train can be smoothed and average analog waveform recovered. Power flow into the load can be continuous. Power flow from the supply is not constant and will require energy storage on the supply side in most cases. (In the case of an electrical circuit, a capacitor to absorb energy stored in (often parasitic) supply side inductance.)

High frequency PWM power control systems are easily realisable with semiconductor switches. As explained above, almost no power is dissipated by the switch in either on or off state. However, during the transitions between on and off states, both voltage and current are nonzero and thus power is dissipated in the switches. By quickly changing the state between fully on and fully off (typically less than 100 nanoseconds), the power dissipation in the switches can be quite low compared to the power being delivered to the load.

Modern semiconductor switches such as MOSFETs or insulated-gate bipolar transistors (IGBTs) are well suited components for high-efficiency controllers. Frequency converters used to control AC motors may have efficiencies exceeding 98%. Switching power supplies have lower efficiency due to low output voltage levels (often even less than 2 V for microprocessors are needed) but still more than 70–80% efficiency can be achieved.

Variable-speed computer fan controllers usually use PWM, as it is far more efficient when compared to a potentiometer or rheostat. (Neither of the latter is practical to operate electronically; they would require a small drive motor.)

Light dimmers for home use employ a specific type of PWM control. Home-use light dimmers typically include electronic circuitry which suppresses current flow during defined portions of each cycle of the AC line voltage. Adjusting the brightness of light emitted by a light source is then merely a matter of setting at what voltage (or phase) in the AC half-cycle the dimmer begins to provide electric current to the light source (e.g. by using an electronic switch such as a triac). In this case the PWM duty cycle is the ratio of the conduction time to the duration of the half AC cycle defined by the frequency of the AC line voltage (50 Hz or 60 Hz depending on the country).

These rather simple types of dimmers can be effectively used with inert (or relatively slow reacting) light sources such as incandescent lamps, for example, for which the additional modulation in supplied electrical energy which is caused by the dimmer causes only negligible additional fluctuations in the emitted light. Some other types of light sources such as light-emitting diodes (LEDs), however, turn on and off extremely rapidly and would perceivably flicker if supplied with low frequency drive voltages. Perceivable flicker effects from such rapid response light sources can be reduced by increasing the PWM frequency. If the light fluctuations are sufficiently rapid (faster than the flicker fusion threshold), the human visual system can no longer resolve them and the eye perceives the time average intensity without flicker.

In electric cookers, continuously variable power is applied to the heating elements such as the hob or the grill using a device known as a simmerstat. This consists of a thermal oscillator running at approximately two cycles per minute and the mechanism varies the duty cycle according to the knob setting. The thermal time constant of the heating elements is several minutes, so that the temperature fluctuations are too small to matter in practice.

Fig. 2 shows a simple PWM controller circuit that controls the switch operation in a DC/DC converter. A sawtooth signal with a fixed frequency and a fixed amplitude (V_R) is applied to the PWM comparator whose second input is fed from the output of an error amplifier(V_e) that compares a reference voltage to the output voltage (V_{OUT}). The output of the latch gives the required PWM signal. This control technique is known as the "voltage-mode" PWM control because only the voltage information is used.

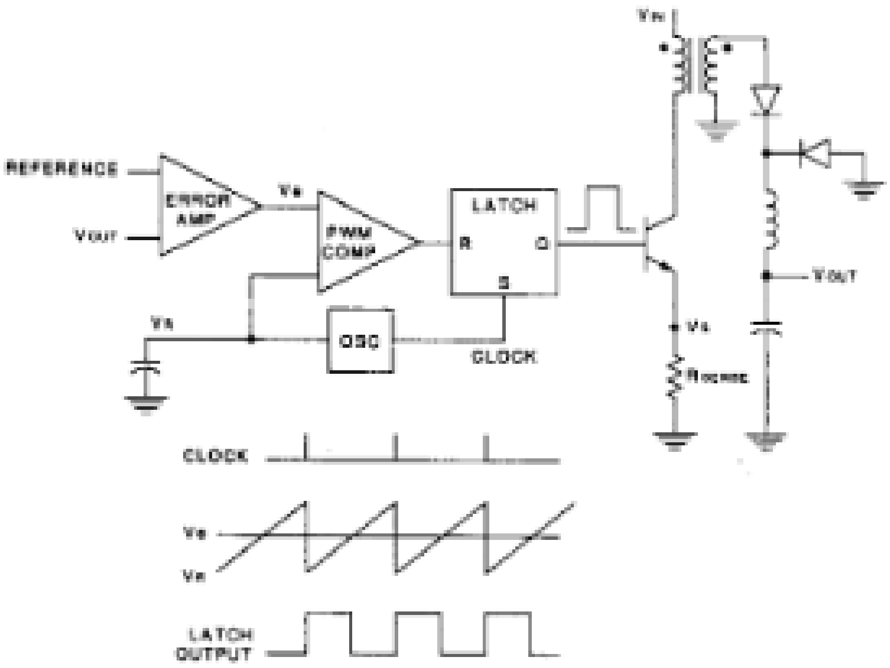


Fig. 2. Voltage-mode PWM control technique

It is shown that the utilization of both voltage and current feedback adds significant advantage to the stability of closed-loop PWM controllers. One way of adding the current information is to use the switching analog current waveform in place of the sawtooth generator. The analog voltage of the switching current waveform is usually provided with a small current-sense resistor placed in series with the switch. This control technique is called "current-mode" control and is shown in Fig. 3.

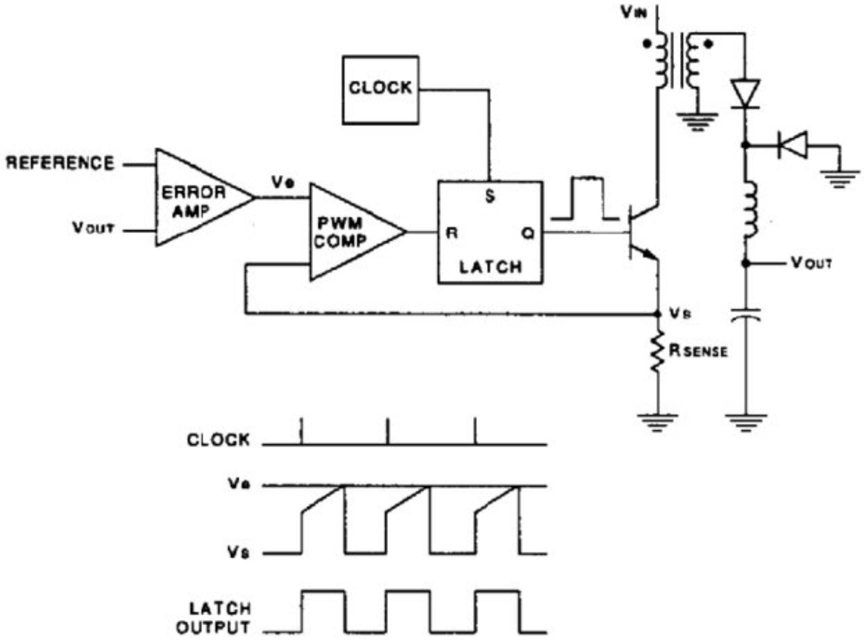
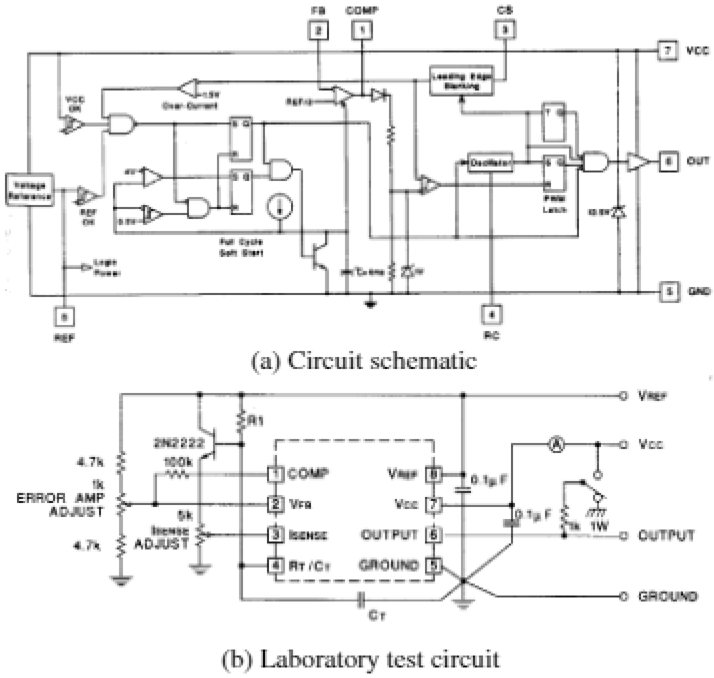


Fig. 3. Current-mode PWM control technique

The fundamental challenge of DC/DC converter design is to simultaneously realize, two difficult objectives: good electrical performance and low cost. A large number of fully integrated PWM circuits, available from a number of manufacturers are designed to meet these objectives. In particular, fixed frequency PWM controllers are by far the devices that are widely used. There have been many ways of implementing fixed frequency PWM control. The basic ingredients of all PWM integrated circuit controllers contain an adjustable clock for setting the oscillator frequency, an output voltage error amplifier, a voltage reference, a signal generator for providing a sawtooth waveform synchronized with the clock, and a comparator to compare the error amplifier output signal with the sawtooth signal. The output signal from the comparator is used to drive the controlled switch directly or through a discrete or integrated drive circuit. There has been a large number of PWM integrated circuit manufacturers using different technologies such as all bipolar, BiCMOS or all CMOS which provide all the necessary features to implement fixed frequency control with a minimal external parts count. Moreover, these control chips contain features such as current limiting, over-voltage protection, input under-voltage protection plus primary and auxiliary functions that may improve the performance of the controller. An example of a typical PWM chip is shown in Fig. 4a. Fig. 4b shows the circuit configuration used in testing the performance of the chip. The operating frequency of these chips range from a few kHz to a fewMHz.



(a) Circuit schematic

(b) Laboratory test circuit

Fig. 4. PWM current-mode control chip

System Lab Kit overview

ASLK PRO has been developed at Texas Instruments India. This kit is designed for undergraduate engineering students to perform analog lab experiments. The main idea behind ASLK PRO is to provide a cost efficient platform or test bed for students to realize almost any analog system using general purpose ICs such as OP-Amps and analog multipliers.

ASLK PRO comes with three general-purpose operational amplifiers (TL082) and three wide-bandwidth precision analog multipliers (MPY634) from Texas Instruments. There are also included two 12-bit parallel-input multiplying digital-to-analog converters DAC7821, a wide-input non-synchronous buck-type DC/DC controller TPS40200, and a low dropout regulator TPS7250 from Texas Instruments.

A portion of ASLK PRO is left for general-purpose prototyping which can be used for carrying out mini-projects.

The kit has a provision to connect ±10V DC power supply (Fig. 5). The kit comes with the necessary short and long connectors.

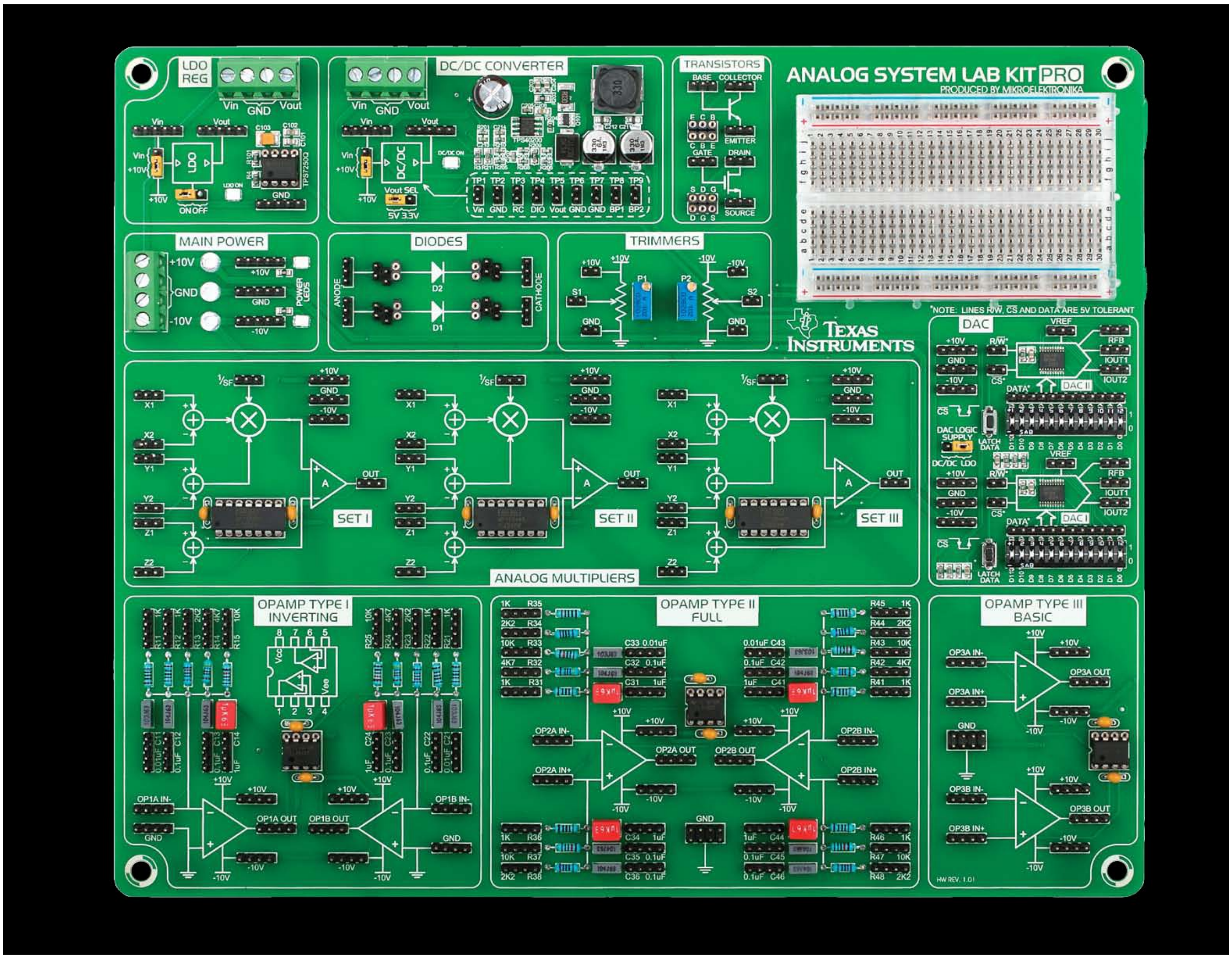


Fig. 5. Photo of ASLK PRO

There are three TL082 OP-Amp ICs labelled 1, 2, 3 on ASLK PRO. Each of these ICs has two amplifiers, which are labelled A and B. Thus 1A and 1B are the two OP-AMps on OP-AMP IC 1, etc. The OP-amps are marked TYPE I, TYPE II and TYPE III on the board. The OP-Amps marked TYPE I can be connected in the inverting configuration only. With the help of connectors, either resistors or capacitors can be used in the feedback loop of the amplifier. There are two such TYPE I amplifiers. There are two TYPE II amplifiers which can be configured to act as inverting or noninverting. Finally, we have two TYPE III amplifiers which can be used as voltage buffers.

Three analog multipliers are included in the kit. These are wide-bandwidth precision analog multipliers from Texas Instruments (MPY634). Each multiplier is a 14-pin IC and operates on internally provided ±10V supply.

There are two digital-to-analog converters (DAC) provided in the kit, labeled DAC I and DAC II. Both the DACs are DAC7821 from Texas Instruments. They are 12-bit, parallel-input multiplying DACs which can be used in place of analog multipliers in circuits like AGC/AVC. Ground and power supplies are provided internally to the DAC. DAC Logic Supply Jumper can be used to connect logic power supplies of both DAC I and DAC II to either LDO or DC/DC converter located on the board. Using Tri-state switches you can set 12-bits of input data for each DAC to desired value. Click the Latch Data button to trigger Digital-to-analog conversion.

There are included a wide-input non-synchronous DC/DC buck converter TPS40200 from Texas Instruments on ASLK PRO. The converter provides an output of 3.3V over a wide input range of 5.5-15V at output currents ranging from 0.125A to 2.5A. Using Vout SEL jumper you can select output voltage to be either 5V or 3.3V. Another jumper allows you to select whether input voltage is provided from the board (+10V), or externally using screw terminals.

There are included two transistor sockets on the board, which are needed in designing an LDO regulator, or custom experiments.

A specialized LDO regulator IC (TPS7250) has been included on the board, which can provide a constant output voltage for input voltage ranging from 5.5V to 11V. Ground connection is internally provided to the IC. Using ON/OFF jumper you can enable or disable LDO IC. Another jumper allows you to select whether input voltage is provided from the board (+10V), or externally using screw terminals.

There are two 1kX trimmers (potentiometer) in the kit to enable the designer to obtain a variable voltage if needed for a circuit. The potentiometers are labeled P1 and P2. These operate respectively in the range 0V to +10V, and -10V to 0V.

The kit has a screw terminals to connect ±10V power supply. All the ICs on the board are internally connected to power supply.

There are included two diode sockets on the board, which can be used as rectifiers in custom laboratory experiments.

The top right portion of the kit is a general-purpose area which can be used as a proto-board. ± 10V points and GND are provided for this area.

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Appendix 1

Task variants

Form № U 6.01
Approved By order of the Ministry of Higher Education of the USSR
of August 3, 1984 № 253

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Department of Electronic Devices and Systems

Discipline Electronic systems

Specialty 171 Electronics (Electronic Components and Systems Specialization)

Course IV Group DS-71 Semester 7

TASK № 1
for coursework of students

____
(Students names)

1. Project (work) topic Design and develop a UC3844 PWM controller based on the Analog System Lab Kit PRO stand
2. Deadline for students to submit a completed project (work) 16.12.2020
3. Initial data for the project (works) Nominal value of input voltage 15 V; The maximum value of the output current is 1 A; The maximum value of the control frequency is 500 kHz; type of modulation - PWM I kind
4. Contents of the calculation-explanatory note (list of questions to be developed) 1.Introduction. 2.Description of the scheme (with timing diagrams). 3.Scheme development. 4.Implementation of circuit elements on the Analog System Lab Kit PRO stand. 5. Simulation of circuit operation in Proteus or Matlab Simulink software environment. 6.Conclusions. 7.List of used sources (with links to the text)
5. List of graphic material (with the exact indication of obligatory drawings) 1.Electrical structural diagram. 2. Electrical principle schematic . 3.List of items.
6. Date of issue of the task __.09.202_ y.

Form № U 6.01
Approved By order of the Ministry of Higher Education of the USSR
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National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Department of Electronic Devices and Systems

Discipline Electronic systems

Specialty 171 Electronics (Electronic Components and Systems Specialization)

Course IV Group DS-71 Semester 7

TASK № 2

for coursework of students

(Students names)

1. Project (work) topic Design and develop a TL494 PWM controller based on the Analog System Lab Kit PRO stand

2. Deadline for students to submit a completed project (work) 16.12.2020

3. Initial data for the project (works) Nominal value of input voltage 10 V; The maximum value of the output current is 1 A; The maximum value of the control frequency is 500 kHz; type of modulation - PWM I kind

4. Contents of the calculation-explanatory note (list of questions to be developed) 1.Introduction. 2.Description of the scheme (with timing diagrams). 3.Scheme development. 4.Implementation of circuit elements on the Analog System Lab Kit PRO stand. 5. Simulation of circuit operation in Proteus or Matlab Simulink software environment. 6.Conclusions. 7.List of used sources (with links to the text)

5. List of graphic material (with the exact indication of obligatory drawings) 1.Electrical structural diagram. 2. Electrical principle schematic . 3.List of items.

6. Date of issue of the task __.09.202_ y.

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National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Department of Electronic Devices and Systems

Discipline Electronic systems

Specialty 171 Electronics (Electronic Components and Systems Specialization)

Course IV Group DS-71 Semester 7

TASK № 3

for coursework of students

(Students names)

1. Project (work) topic Design and develop a UC3844 PWM controller based on the Analog System Lab Kit PRO stand

2. Deadline for students to submit a completed project (work) 16.12.2020

3. Initial data for the project (works) Nominal value of input voltage 15 V; The maximum value of the output current is 1 A; The maximum value of the control frequency is 500 kHz; type of modulation - PWM II kind

4. Contents of the calculation-explanatory note (list of questions to be developed) 1.Introduction. 2.Description of the scheme (with timing diagrams). 3.Scheme development. 4.Implementation of circuit elements on the Analog System Lab Kit PRO stand. 5. Simulation of circuit operation in Proteus or Matlab Simulink software environment. 6.Conclusions. 7.List of used sources (with links to the text)

5. List of graphic material (with the exact indication of obligatory drawings) 1.Electrical structural diagram. 2. Electrical principle schematic . 3.List of items.

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Department of Electronic Devices and Systems

Discipline Electronic systems

Specialty 171 Electronics (Electronic Components and Systems Specialization)

Course IV Group DS-71 Semester 7

TASK № 4

for coursework of students

(Students names)

1. Project (work) topic Design and develop a TL494 PWM controller based on the Analog System Lab Kit PRO stand

2. Deadline for students to submit a completed project (work) 16.12.2020

3. Initial data for the project (works) Nominal value of input voltage 10 V; The maximum value of the output current is 1 A; The maximum value of the control frequency is 500 kHz; type of modulation - PWM II kind

4. Contents of the calculation-explanatory note (list of questions to be developed) 1.Introduction. 2.Description of the scheme (with timing diagrams). 3.Scheme development. 4.Implementation of circuit elements on the Analog System Lab Kit PRO stand. 5. Simulation of circuit operation in Proteus or Matlab Simulink software environment. 6.Conclusions. 7.List of used sources (with links to the text)

5. List of graphic material (with the exact indication of obligatory drawings) 1.Electrical structural diagram. 2. Electrical principle schematic . 3.List of items.

6. Date of issue of the task __.09.202_ y.

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Department of Electronic Devices and Systems

Discipline Electronic systems

Specialty 171 Electronics (Electronic Components and Systems Specialization)

Course IV Group DS-71 Semester 7

TASK № 5

for coursework of students

(Students names)

1. Project (work) topic Design and develop a UC2844 PWM controller based on the Analog System Lab Kit PRO stand

2. Deadline for students to submit a completed project (work) 16.12.2020

3. Initial data for the project (works) Nominal value of input voltage 15 V; The maximum value of the output current is 1 A; The maximum value of the control frequency is 500 kHz; type of modulation - PWM I kind

4. Contents of the calculation-explanatory note (list of questions to be developed) 1.Introduction. 2.Description of the scheme (with timing diagrams). 3.Scheme development. 4.Implementation of circuit elements on the Analog System Lab Kit PRO stand. 5. Simulation of circuit operation in Proteus or Matlab Simulink software environment. 6.Conclusions. 7.List of used sources (with links to the text)

5. List of graphic material (with the exact indication of obligatory drawings) 1.Electrical structural diagram. 2. Electrical principle schematic . 3.List of items.

6. Date of issue of the task __.09.202_ y.

Appendix 2

NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
"IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE"
FACULTY OF ELECTRONICS
DEPARTMENT OF ELECTRONIC DEVICES AND SYSTEMS

COURSE WORK
in "Electronic systems-2" credit module

on the topic:

"PWM CONTROLLER DEVELOPMENT ON THE ANALOG SYSTEM LAB KIT PRO STAND"

DONE BY: BRIGADE №__

STUDENTS NAMES:

GROUP: DS-___

KYIV-202_

Content

Technical assignment

1. The basis for development

The basis for the development is the assignment for the course work (CW), which is issued

«__» __________ 202__.

2. Name and scope

PWM controller based on the Analog System Lab Kit PRO stand.

3. Goal and purpose of development

Design, develop and model a PWM controller based on the Analog System Lab Kit PRO stand.

4. Source of development

Course of lectures on the credit module "Electronic Systems -1". Modeling of digital filters by means of software environments.

5. Technical task

The technical task according to a variant is resulted.

Introduction

Must occupy at least ¾ of an A4 sheet.

1. The principle of operation of the PWM controller.

Describe in detail the principle of operation of the PWM controller with timing diagrams and block diagram.

2. Calculation of the main elements of the PWM controller.

Give the calculation formulas and results of calculations of the main elements of the PWM controller. Give a schematic diagram.

3. Implementation of individual elements of the PWM controller based on the Analog System Lab Kit PRO stand.

Provide the implementation of some selected elements of the PWM controller on the basis of the Analog System Lab Kit PRO stand with a photo report and time diagrams.

4. PWM controller modeling in a software environment.

Simulate the PWM controller in the selected software environment and provide time diagrams.

Conclusions

A PWM controller with the following parameters is designed in this CW:

– nominal value of input voltage __ V;

– the maximum value of the output current __ A;

– the maximum value of the control frequency ___ kHz;

– type of modulation - PWM __ kind.

The design was carried out in the software environment _________, where modeling and evaluation of its effectiveness was also performed.

References

Provide a list of used literature sources (at least 10).