The Analysis of DCDC BUCK Circuit based on Arduino

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Abstract. With the development of the times, digitally controlled power supplies are becoming the trend of today's DC power supplies. This paper details a step-down circuit with Mosfet switch controlled by Arduino. This power supply and DC-DC adopts advanced semiconductor technology and digital control technology, featuring small size, light weight, simple and easy adjustment, high efficiency, wide voltage range and complete shutdown of zero-point adjustment. First, this paper details the structure, principle, and many features of the Arduino platform. Second, this paper explains the principle of BOOST circuit for boost and BUCK circuit for buck with equations and structure diagrams, and presents real-life applications. By reading this article, beginners will have a basic understanding of the use of Arduino and know what the exact principles of this circuit are, as well as circuit design and software programming ideas.

Keywords: Arduino; DC-DC; DC Power Supply; Semiconductor; Digital Control Technology.

1. Introduction

As a result of advances in technology, there are now a variety of methods available for adjusting the voltage. There are many methods for accomplishing bucking, ranging from the time-honored resistor voltage divider to the more recent linear bucking and most recently, the use of transistor components in conjunction with passive devices in order to achieve bucking. This article presents a detailed introduction to a Buck circuit that is controlled by Arduino. It has the characteristics of small size, light weight, simple and convenient adjustment, low power consumption, high efficiency, wide buck range, and complete shutdown from zero regulation. A detailed explanation of the architecture, principles, and many features of the Arduino platform that is employed in this project is provided in the second chapter of this book. A third chapter takes care of explaining the principle of the DC chopper circuit with the intention of being able to step boosts and bucks, using formulas and structure diagrams, as well as suggesting possible applications in reality. As a result of reading this article, beginners will have a basic understanding of the use of Arduino, and they will know what the specific principles of this circuit are, as well as the ideas of circuit building and software programming in general.

1.1 Hardware Module Functionality

The Arduino platform is a development platform that uses AVR microcontrollers as the primary control device for its development platform. It also features an abundance of open-source software that is available at a reasonable price and an abundance of open-source hardware. An Arduino has a USB port, a DC connector, 14 digital I/O pins (6 of them support PWM), an ICSP connector, and 6 analog input pins on it, along with a USB port and a DC connector. The USB port can be used for power supply as well as burning programs [1]. DC connectors are dedicated to power supplies. 14 I/O pins can be used as inputs to read logic values or as outputs to control the connected modules. The ICSP connector is also capable of burning programs on a computer. The analog input pins read analog signals and convert them to digital values [2]. The Arduino platform supports a wide range of input modules. The Arduino platform supports a variety of input modules such as switch buttons, distance sensors, temperature sensors, gyroscopes, SD card readers, WiFi modules, and many more. Furthermore, Arduino supports an abundance of output modules, such as LCD screens, speakers, motors, servos, and so on. Further, Arduino's PWM output can be further customized in order to provide more tailored outputs to users [3].

1.2 Software Programming

The computer software that runs on Arduino is developed in the Arduino code. C and C++ served as the foundation for this programming language. In contrast to C, many of the parameters associated with the main control are automatically set in a manner that makes writing programs in a shorter amount of time much easier for developers. Programming Arduino requires the use of a unique Arduino IDE in order to be able to do so. IDE software and core libraries are both open-source, allowing users to modify them easily [4]. Each and every Arduino program must contain a Setup function, which is invoked when the device is powered on in order to configure the environment, as well as a Loop function, which is identical to the while (1) function in C. The majority of the software is contained within the Loop function. In this paper, the program will be used to control the on-time and switching period to control the average output voltage to achieve the effect of boost or buck.

2. Principle of DC Voltage Converter Circuit

This study will construct and simulate a buck chopper circuit and a boost chopper circuit, which are the most fundamental types of DC chopper circuits, in order to gain an understanding of their fundamental functioning principle.

2.1 DC Step-Down Circuit

The following diagram figure 1 shows the schematic of the buck chopper circuit.

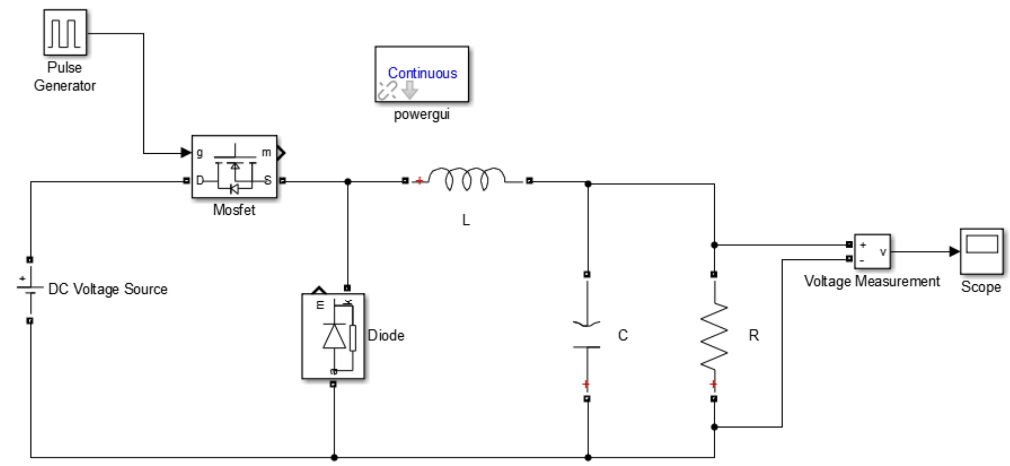

Figure 1. Buck chopper circuit

In the above figure 1, the flyback diode D provides a channel for the current inductor in the load after M is turned off, and the gate voltage in the Mosfet is a pulse wave with period T. ton is the on time, in which the power supply E is supplied to the load. toff is the off time, in which the control M is turned off. When one cycle is over, M is driven on again, and then the circuit will repeat the cycle above, and so on and so forth to obtain a more stable and steady voltage output. As shown in figure 2.

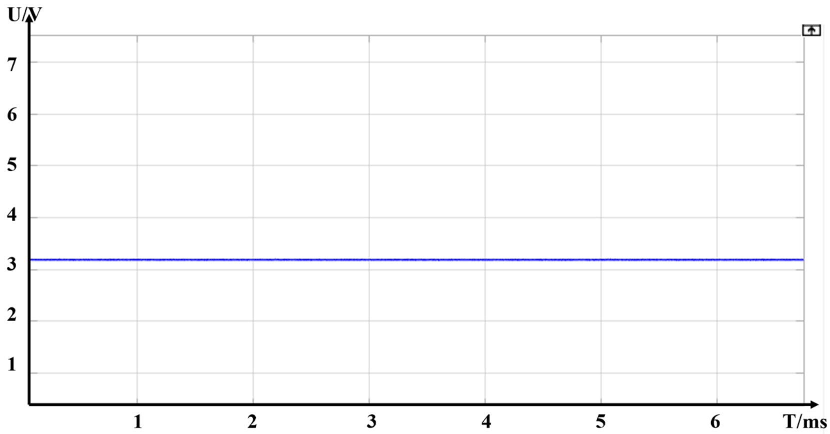

Figure 2. Simulation results

The waveform of the load voltage is depicted in the figure that can be found above. The average value of the load voltage is:

$$U_o = \frac{t_{on}}{t_{on}+t_{off}} E = \frac{t_{on}}{T} E = \alpha E \, (1)$$

t_{on} is the time when M is in the on-state, t_{off} is the time when M is in the off-state, T is the switching period, and α is the on-off duty ratio, referred to as duty ratio or on-off ratio.

From the equation, the average value of the output voltage to the load U0 is maximum E. Decreasing the duty cycle α, U0 decreases. Therefore, the circuit is called a step-down chopper circuit.

2.2 DC Boost Circuit

The following diagram figure 3 shows the schematic of the boost chopper circuit.

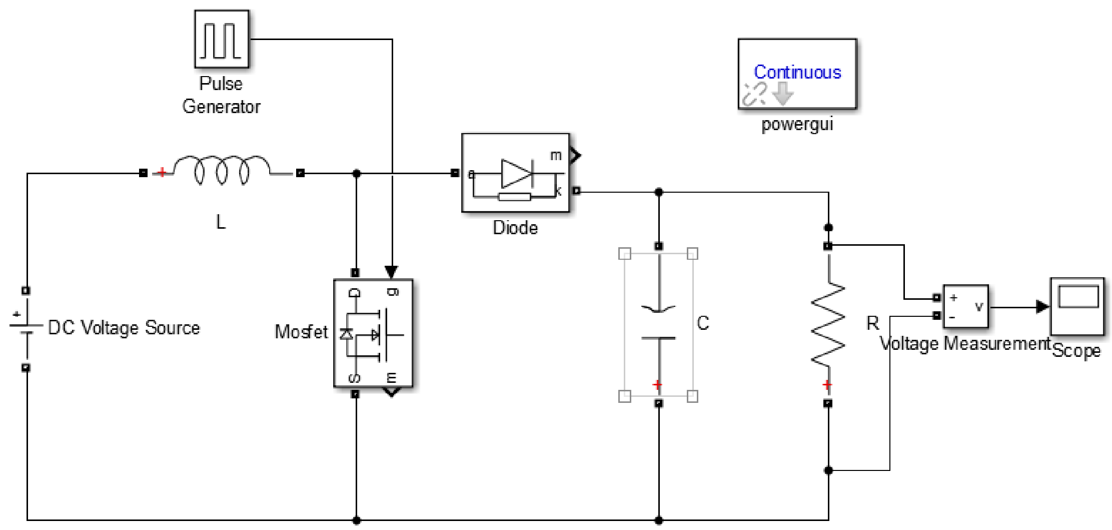

Figure 3. Boost chopper circuit

A large inductor value L and a large capacitor value C are present in this circuit. When the switch M is turned on, the power supply E charges the inductor L with a constant current output. The capacitor C also supplies power to the load R at the same time. Because the value of C is large, it makes the output voltage U0 basically constant. Set the length of time that M is on as ton, the inductor L accumulates energy during this phase. When M is disconnected, E and L together supply energy to capacitor C and load R. Set the duration of M disconnection as toff, inductor L releases energy during this phase [5]. When the circuit works in steady state, the energy accumulated and released by inductor L in one cycle T is equal, which gives:

$$U_o = \frac{t_{on}+t_{off}}{t_{off}}E = \frac{T}{t_{off}}E \quad (2)$$

In the equation T/ toff >= 1, the voltage output is greater than the supply voltage, and thus the circuit is a boost chopper circuit. The figure 4 below shows the waveform of the load voltage.

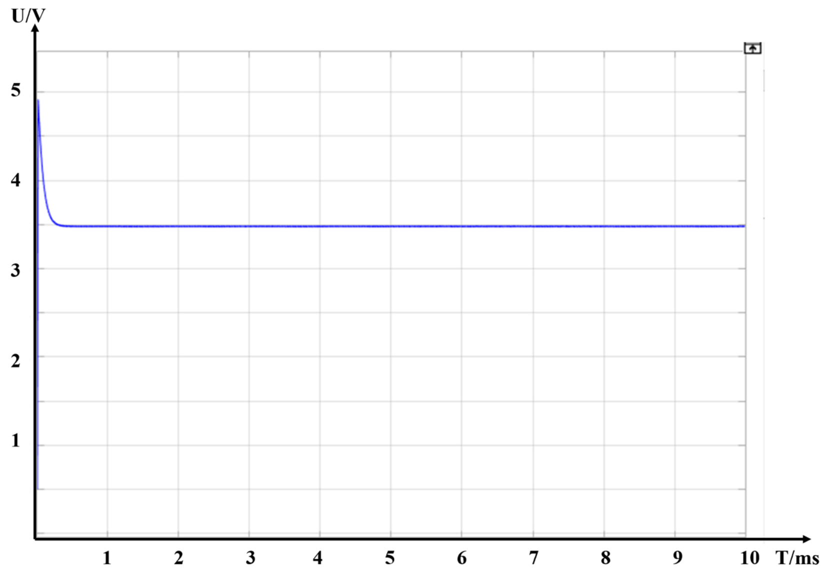

Figure 4. Simulation results

To adjust the output voltage, adjust the boost ratio T/toff size.

Inductor L has the effect of pumping up the voltage after storing energy. Capacitor C has the effect of maintaining the output voltage. In the boost chopper circuit, the effect that the output voltage can be higher than the supply voltage is made possible by these two points, which are the key to the effect. Because the value of C cannot be infinite in practice, U0 is always going to decrease; thus, the true output voltage will be only a little bit less than what is predicted by the above calculation [6].

3. Arduino-based DC Voltage Converter Circuit Implementation

Based on the Arduino UNO development board with Atmel's ATmega328P as the MCU, we used one PWM output of ATmega328P to make an open-loop Buck DC step-down circuit that uses PWM as the gate control method for Mosfet.

According to the block diagram provided in 3.2 in this article, we use the Arduino as the 'Pulse Generator' in the block diagram, using the 5V voltage drawn from the Arduino pins as the DC input supply voltage. In this way, we can use the self-recovery fuse of Arduino itself and the protection circuit of the USB power supply powered by Arduino to avoid circuit burnout and personal injury accidents caused by operation errors, and effectively improve the safety of experiments and circuits. Since the Arduino board comes with a linear voltage regulator (LDO) and a solid capacitor with a large capacity, which can ensure the stability of the power supply voltage, therefore, the voltage fluctuation caused by our operation on the 5V DC voltage power rail will not affect the normal operation of the Arduino.

3.1 Related Hardware Options

Since the ArduinoUNO development board is easy to purchase and its PWM performance meets the needs of the Buck buck circuit for this project, and its built-in Flash storage and built-in SRAM space are sufficient to run the code for this project, this development board is chosen as the main control for the circuit.

3.1.1 ArduinoUNO

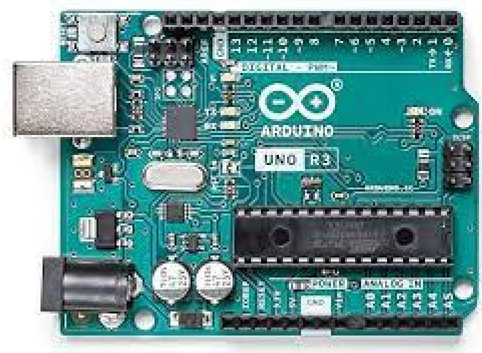

Figure 5. Arduino UNO

As shown in figure 5, this is the physical picture of Arduino UNO R3, we can see in this picture that it has a USB-B type interface, and a rich pinout. It has a USB to serial conversion chip, so we can easily and quickly use USB to debug Arduino without any external conversion device.

3.1.2 Mosfet

MOSFET are one of the field effect transistors (FETs), which are usually manufactured by controlling the oxidation of silicon. The voltage applied to the gate determines the conductivity of the MOSFET's insulated gate, and in this way, we can use the MOSFET to amplify or switch electronic signals by applying different gate voltages. In this section of the article, we use the characteristics of MOSFETs that can be switched.

The gate input current of MOSFETs is very small, and this advantage is outstanding compared to another type of transistor, the bipolar transistor (BJT). Like an ideal relay, MOSFETs require only voltage and almost no input current to control the load.

Nowadays, MOSFETs are used in a wide range of applications, and a large part of the digital circuits in our daily use of cell phones and computers is composed of MOSFETs. MOSFETs can be made into N-channel or P-channel, so that pairs of MOSFETs can be used to create low-loss switching circuits, and then CMOS logic chips are created. For the selection of MOSFET in this circuit, it should have the characteristics of low on-state resistance (R_{dson}), small gate capacitance (C_g), low gate driving voltage (V_{gs}), and large current. So, we chose FDD6635. By using this MOSFET with ultra-low gate voltage (V_{gs}), we can directly use the pin output voltage of Arduino to drive the MOSFET, to reducing external components, and reducing overall cost and difficulty.

FDD6635 is an N-channel MOSFET with 35V withstand voltage developed by Fairchild. Its typical V_{gs} value is 1.9V. According to its datasheet, at 25 degrees Celsius, when V_{gs} is 3.3V, its R_{dson} is only 0.013Ω, meanwhile, its C_{iss} is only 1400pF, which means that even an Arduino without any additional drivers can switch at higher frequencies.

3.1.3 Diode

In this Buck circuit, we use the rectifier diode as the rectification method. To improve the overall efficiency of the circuit, we should choose a diode with a small forward voltage drop V_f, and its maximum operating frequency should meet the PWM switching frequency of the Buck circuit The maximum reverse withstand voltage should exceed the maximum peak voltage that can be generated in the circuit. The maximum operating frequency of a diode is determined by an RC circuit consisting of its junction capacitance and forward series resistance. Therefore, the two most important factors that determine the diode selection are: the forward voltage drop V_f, and the maximum operating frequency. Therefore, we give priority to the diode with the best of these two characteristics: the Schottky diode.

This diode is formed at the junction of a semiconductor and a metal and is named after a German scientist. It has a very fast switching speed and a lower forward voltage drop than ordinary silicon diodes, so it is very suitable for use in the circuits mentioned in this article.

The forward voltage drop V_f of ordinary silicon diodes is 600-700 mV, while the forward voltage drop V_f of Schottky diodes is 150-450 mV. The lowered forward voltage can give this kind of diode higher switching speed, and if the Schottky diode is used, the efficiency of the system will be greatly improved compared to the use of ordinary silicon diodes. An obvious difference between silicon semiconductor diodes and Schottky diodes based on the principle of PN junction is the recovery time when switching from the forward conduction state to the cut-off state. In ordinary silicon diodes, the reverse recovery time of fast silicon diodes is several ms to 100 ns. But Schottky diodes are significantly faster than ordinary silicon diodes, and due to the special structure of these diodes, their switching speed is limited only by their own capacitance. For the switching of the PN junction, there will also be reverse recovery current. In higher power applications, reverse recovery current can cause noise, but if a Schottky diode is used, this process will be much faster, greatly reducing the reverse recovery current. To the magnitude of the recovery current, there is only a very small capacitance, so the EMI noise can be greatly reduced.

3.1.4 Breadboard

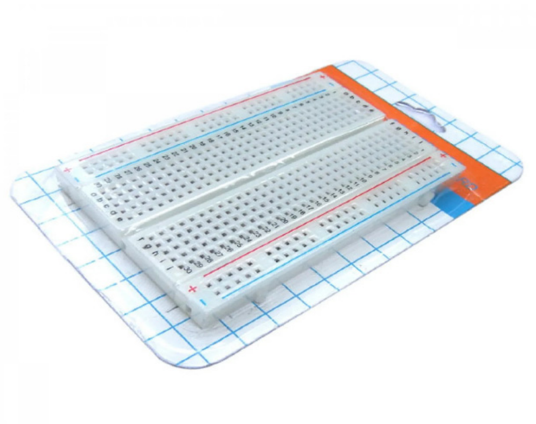

Figure 6. Bread board

Modern circuits are built on a board called PCB, as shown in figure 6. The PCB is printed with lines and soldering positions, and has excellent insulation properties. The Arduino motherboard is installed on the PCB board, but the production of the PCB requires A complete set of complex production process, we do not have this ability, we also need to modify the circuit and structure of the circuit frequently, which is unfavorable for the circuit construction method of PCB. Mounting components on a PCB requires soldering. Soldering is a time-consuming task. Before soldering, ventilation and protection must be done, so we use a breadboard. Most breadboard shells are made of plastic, which has good insulating properties and structural strength. The conductive structure in the breadboard is a nickel-plated iron sheet. This material is corrosion-resistant, has low contact resistance, and has good elasticity, so it can be stably contacted with components. Building a circuit on a breadboard does not require soldering, so it is more convenient to modify the circuit. The main purpose of the breadboard is to facilitate students' learning and engineers to build samples. Using a breadboard greatly speeds up our experiments.

3.2 Hardware Build

To install this circuit, we firstly insert the components from the circuit design into the breadboard in the proper order and direction. During this process, we need to pay attention to the polarity of the components, so that the pins of the components are in full contact with the springs in the breadboard to reduce the contact resistance. It is also necessary to minimize the length of the wires to minimize the parasitic capacitance and parasitic resistance in the line, so as not to cause unnecessary problems.

After installing the originals, we need wires of the right length and diameter to connect to the springs inside the breadboard. A better choice is single-core copper wire, which has good hardness and conductivity, and is more convenient in our next step of stripping the wire. Once you find the wire, cut it to the right length, strip about 5mm of insulation on both ends, bend it into a 'U' shape, and insert it into the breadboard. For now, we should pay attention that the stripped length should not be too long, otherwise it will cause unnecessary contact, which will cause the circuit to not work properly or damage the components and breadboard [7].

In this article, Arduino is used as its DC output power supply in the design process of realizing the DC step-down circuit. Connect the rest of the various components via a breadboard. First, the current passes through the FDD6635, and its turn-on and turn-off depends on its gate voltage, and the gate voltage signal is provided by the Arduino. The current reaches the inductor L after passing through the FDD6635. At this time, the diode D is subjected to reverse voltage and does not conduct. The power supply is subjected to the choke effect of the inductor, and charges the capacitor with a gradually increasing current. Due to the large capacity of the capacitor, the voltage across the capacitor is relatively flat, and the capacitor begins to supply power to the load R at this time. When the FDD6635 loses its gate voltage, its resistance rises to almost no current, and the inductor stores energy. Since the current flowing through the inductor cannot be abruptly changed, the inductor will provide a gradually decreasing current, which flows through the load R and charges the capacitor C at the same time, and the capacitor stabilizes the voltage. After that, the circuit repeatedly switches between these two states, and the output voltage of this circuit will stabilize within hundreds of milliseconds. The time and frequency of each state appear depends on the duty cycle and the PWM output set in the Arduino program [8].

The final built circuit is shown in the figure 7 below:

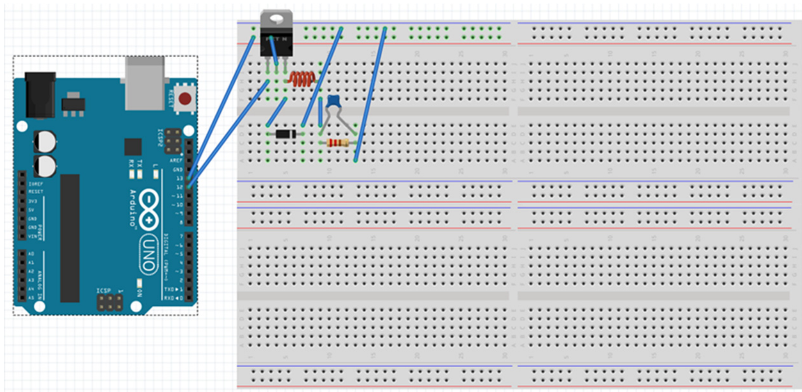

Figure 7. Final built circuit

3.3 DC Power Supply Programming Implementation

Due to the limitation of the output signal hardware of Arduino platform, the output signal peak can only be 5V. so set the DC power output as 5V. set the DC power as source, and use the pin 13 of Arduino platform as DC power output high signal. Use the following program to realize the output of DC 5V power supply [9].

The gate voltage in the fully controlled device Mosfet is a pulse wave with a period of T. ton is the on time, at which time the power supply E is supplied to the load. toff is the off time, at which time the control M is turned off. When a cycle T is over, then drive M on, repeat the process of the last cycle. And the average value of the load output voltage is controlled by adjusting the pulse signal conduction time [10].

3.4 Physical Testing

We tested the real thing, and the screenshot of the oscilloscope is shown in the figure below. The red line in the figure represents the voltage of the DC output (both ends of the inductor L and the load

R), which is a relatively stable 2.5V, and the blue line represents the voltage across the inductor L. We can see the oscillation of the inductor and the conducting PWM square wave in figure 8.

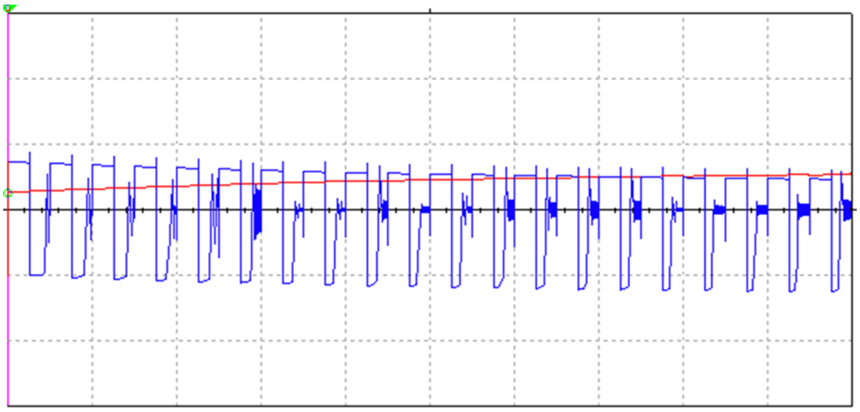

Figure 8. Testing result

Through the physical test, we can find that in the Arduino design, the above required process has been realized, and the output effect has reached the expectation.

4. Conclusion

In summary, the device was built using the Arduino platform to develop and run software to control the boosting and bucking circuits. It is expected to achieve a range of current boost and buck. In addition, as a result of the experiment presented in this paper, we have been able to demonstrate that the step-down circuit described in this paper can be fully implemented based on the waveform shown on the oscilloscope. This article will provide beginners with an introduction to Arduino, along with concepts of circuit building and software programming, and explain the specific principles of this circuit.

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