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Programmable DC-DC Buck Converter

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Abstract: Design of the power electronics circuitry are now-a-days reducing the size, space and weight of converter and inverter circuits. This is possible because of the availability of new high switching frequency devices. This paper presents a generalized model of buck converters that is programmable. The converter used for stepping down the voltage is called buck converter. Buck converter is designed, analysed, simulated & developed. The proposed model of this Buck converter consists of two parts: (a) Main converter circuits with the components like switch, inductor, diode, capacitor, and a load, (b) A control circuit for controlling the operation of the switch using microcontroller through digital potentiometer. This model can accurately give the power output voltage up-to three decimals.

I. INTRODUCTION

The objective of this design is to design a programmable DC-DC buck converter for the embedded users and for industrial purpose. This is the second version of non-programmable DC-DC step down converter (Buck converter) in this board there are two inputs which is used for provide input power supply to the board one is Micro USB socket and another is two pin male header and in the output side there are three two pin headers out of which two headers having variable supply 1.23 to 11V and one is fixed 3.3V.

The variable output voltage is programmable in this version we used a atmega328p microcontroller and a 10K digital potentiometer AD5175 1024 Tap by varying the potentiometer value through program you can vary the output voltage

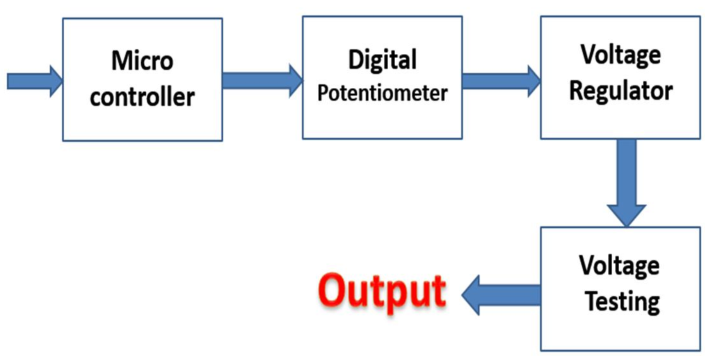
Atmega328p microcontroller is directly connected to a USB to serial driver IC CH340G so it is easy to program. Atmega328 microcontroller used in Arduino's board here we can use Arduino IDE software to program this board

Use a Micro USB B 2.0 to USB Male cable to program this board.

A blue LED is connected to D13 pin same as Arduino Nano/UNO to test the board and program and another blue LED is connected to output 3.3v to test the output voltage.

Input voltage can be 5V to 24V and maximum up-to 40V.

II. BLOCK DIAGRAM



III. INDENTATIONS AND EQUATIONS

In this project I used LM2576 voltage regulator IC to get the adjustable output voltage, this is an industrial use voltage regulator IC which is widely used. The range of the output voltage vary from 1.23v to 37v with 4% tolerance. It is a monolithic integrated circuits ideally suited for easy and convenient design of a step-down switching regulator or buck converter. This ICs are available in fixed and variable output version. These regulator ICs is designed to reduce the number of components and minimize the size of buck converter and simplify the design.

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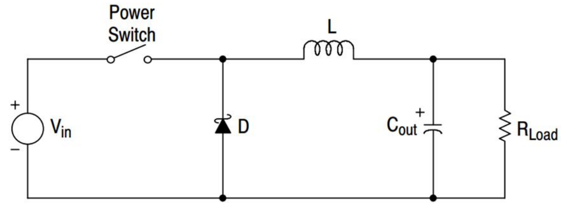
IV. BASICS OF BUCK CONVERTER

The LM2576 is a “Buck” or Step−Down Converter which is the most elementary forward−mode converter. Its basic schematic can be seen in Figure 16. The operation of this regulator topology has two distinct time periods. The first one occurs when the series switch is on, the input voltage is connected to the input of the inductor. The output of the inductor is the output voltage, and the rectifier (or catch diode) is reverse biased. During this period, since there is a constant voltage source connected across the inductor, the inductor current begins to linearly ramp upwards, as described by the following equation.

$$I_{L(on)} = \frac{(V_{in} - V_{out})\, t_{on}}{L}$$

During this “on” period, energy is stored within the core material in the form of magnetic flux. If the inductor is properly designed, there is sufficient energy stored to carry the requirements of the load during the “off” period



The next period is the “off” period of the power switch. When the power switch turns off, the voltage across the inductor reverses its polarity and is clamped at one diode voltage drop below ground by the catch diode. The current now flows through the catch diode thus maintaining the load current loop. This removes the stored energy from the inductor. The inductor current during this time is.

$$I_{L(off)} = \frac{(V_{out} - V_D)\, t_{off}}{L}$$

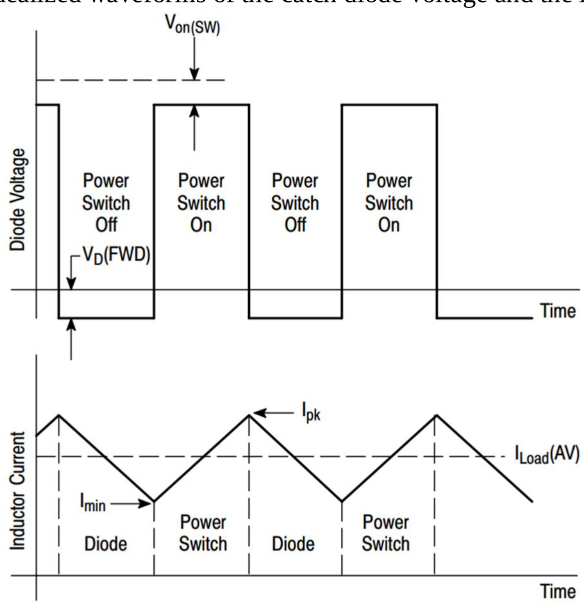
This period ends when the power switch is once again turned on. Regulation of the converter is accomplished by varying the duty cycle of the power switch. It is possible to describe the duty cycle as follows:

$$d = \frac{t_{on}}{T}$$ where T is the period of switching.

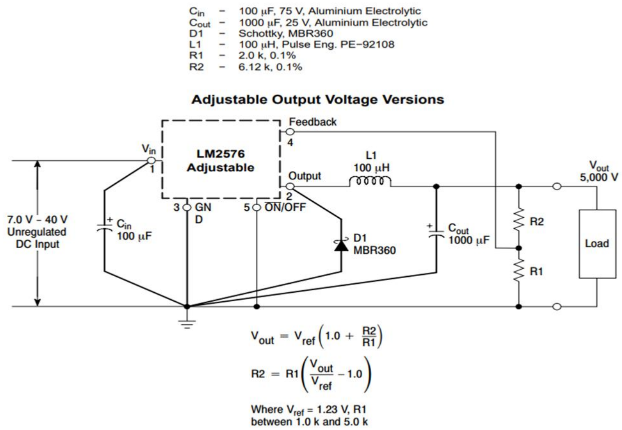
For the buck converter with ideal components, the duty cycle can also be described as:

$$d = \frac{V_{out}}{V_{in}}$$

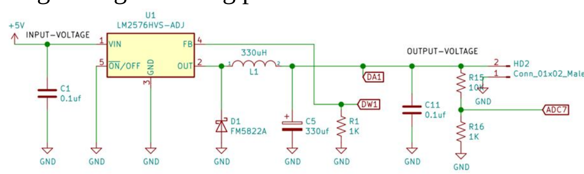
Figure 17 shows the buck converter, idealized waveforms of the catch diode voltage and the inductor current.



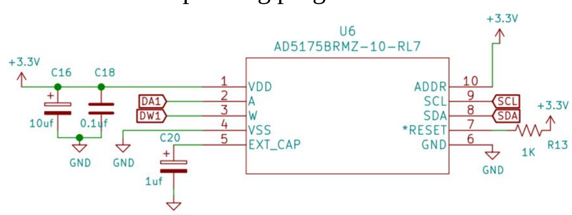
V. MATHMATICA ANALYSIS



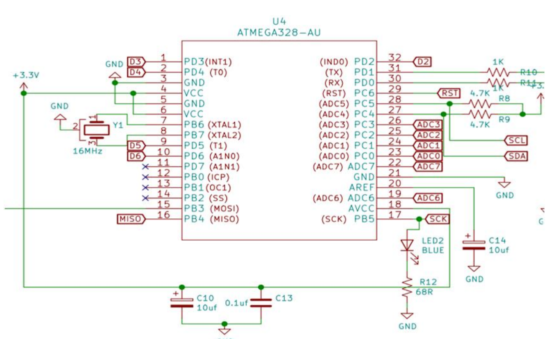
Where the R2 is Digital Potentiometer AD5175 1024 tap which is controlled by microcontroller, by varying the R2 value we can adjust the output voltage from 1.23 to 37V when R1 need to be fixed as per calculation.
Below is the circuit diagram of the final circuit.
This diagram represents the basic circuit of a voltage regulator, her HD2 connector provides the output voltage and which you can adjust through the DA1 and DW1 (Digital potentiometer) while the value of R1 will be fix.
ADC7 is used to measure the output voltage using an analog pin of microcontroller and LCD Display.



This is the schematic of digital potentiometer AD5175 which is directly connected to the I2C bus of microcontroller serial data and serial clock. We can set the tap value from 0 to 1023 steps using program.



Now let's come to the main part of this project which is microcontroller. This is the AVR category controller which is low power CMOS 8-bit microcontroller. To program this controller we can use any IDE tools, here I used Arduino IDE which is open source software.



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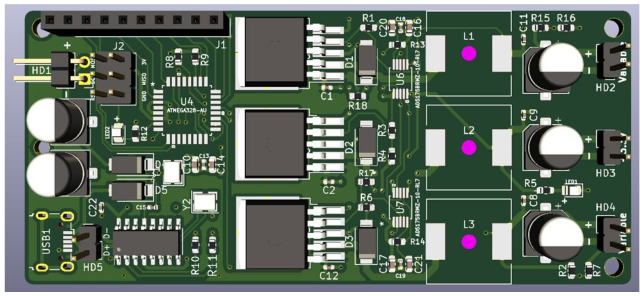
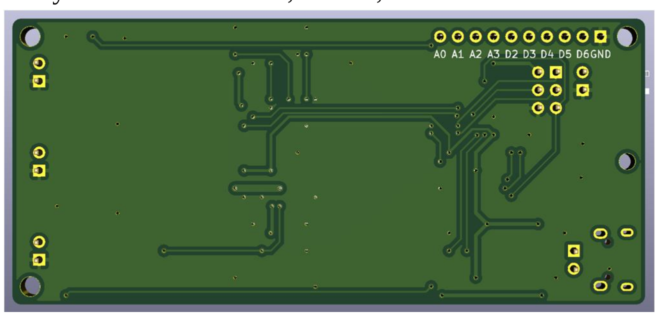
VI. DESIGNING PART

This is the final design that I had done on PCB designing tools. I used to prefer KiCAD for my work but there are many tools to design a PCB. The final design has come up with very minimum size and in good look.

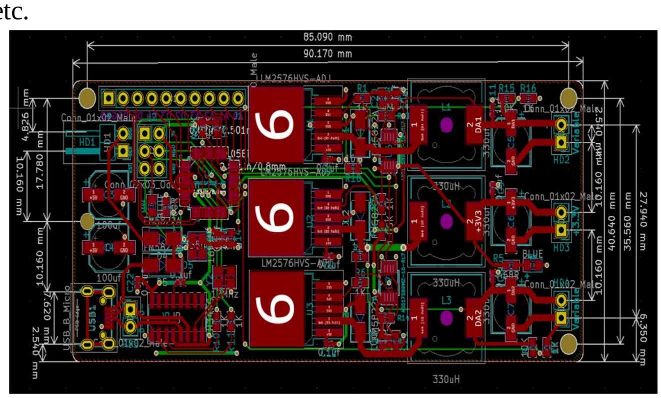
Here you can see the no. of components which is SMD and THT type. It is having two input connectors and three output connectors.

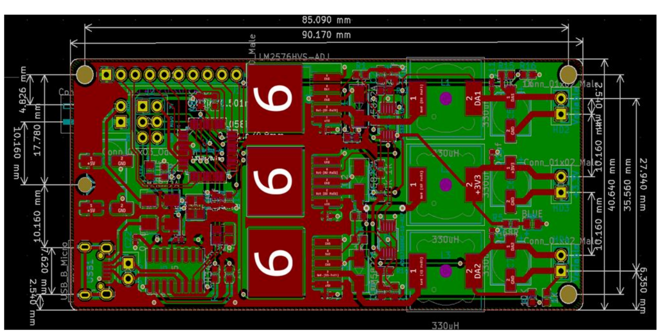


Back side of the board having silkscreen for additional pin of the microcontroller which is not using in this project and free for any external module and components which you can add like LCD, Buzzer, Bluetooth module etc.



Some areas of the designing parts looks like this which contains front copper layer F.Cu. back copper layer B.Cu. components footprint, silkscreen, Traces, Vias etc.





VII. FINAL OUTPUT

Below is the table for parallel resistor calculator. here I set the taping value of digital potentiometer by program in microcontroller and then fixed the value of R1 10KOhm. The output value came as expected which you can see in the below table. I have tested the value from 0 to 1023 Tap but here I attached limited values. The output voltage value is correctly matching with the theoretical calculations with 5% tolerance.

Tap	R1	R1 || 10k	Output voltage
1023	9.990234375	10	4.997557401
1000	9.765625	10	4.940711462
950	9.27734375	10	4.812563323
900	8.7890625	10	4.677754678
850	8.30078125	10	4.535752401
800	7.8125	10	4.385964912
750	7.32421875	10	4.227733935
700	6.8359375	10	4.060324826
650	6.34765625	10	3.882915173
600	5.859375	10	3.694581281
550	5.37109375	10	3.494282084
500	4.8828125	10	3.280839895
450	4.39453125	10	3.052917232
400	3.90625	10	2.808988764
350	3.41796875	10	2.547307132
250	2.44140625	10	1.962323391
200	1.953125	10	1.633986928
150	1.46484375	10	1.277683135
100	0.9765625	10	0.889679715
50	0.48828125	10	0.465549348
0	0	10	0

VIII. CONCLUSION

After all of these my research work. I have placed the designing file for PCB manufacturing and then bought all the required components after this I assembled all the components and tested it, it is working as expected up to two decimal digit of output voltage value (my expectations was for three decimal value) but after some time I found some errors that microcontroller was not able to program perfectly may be due to some hardware issue or I used this project as a bench power supply so.

The further research is going on continuously to get the perfect efficiency up to three decimal digits of output voltage value.

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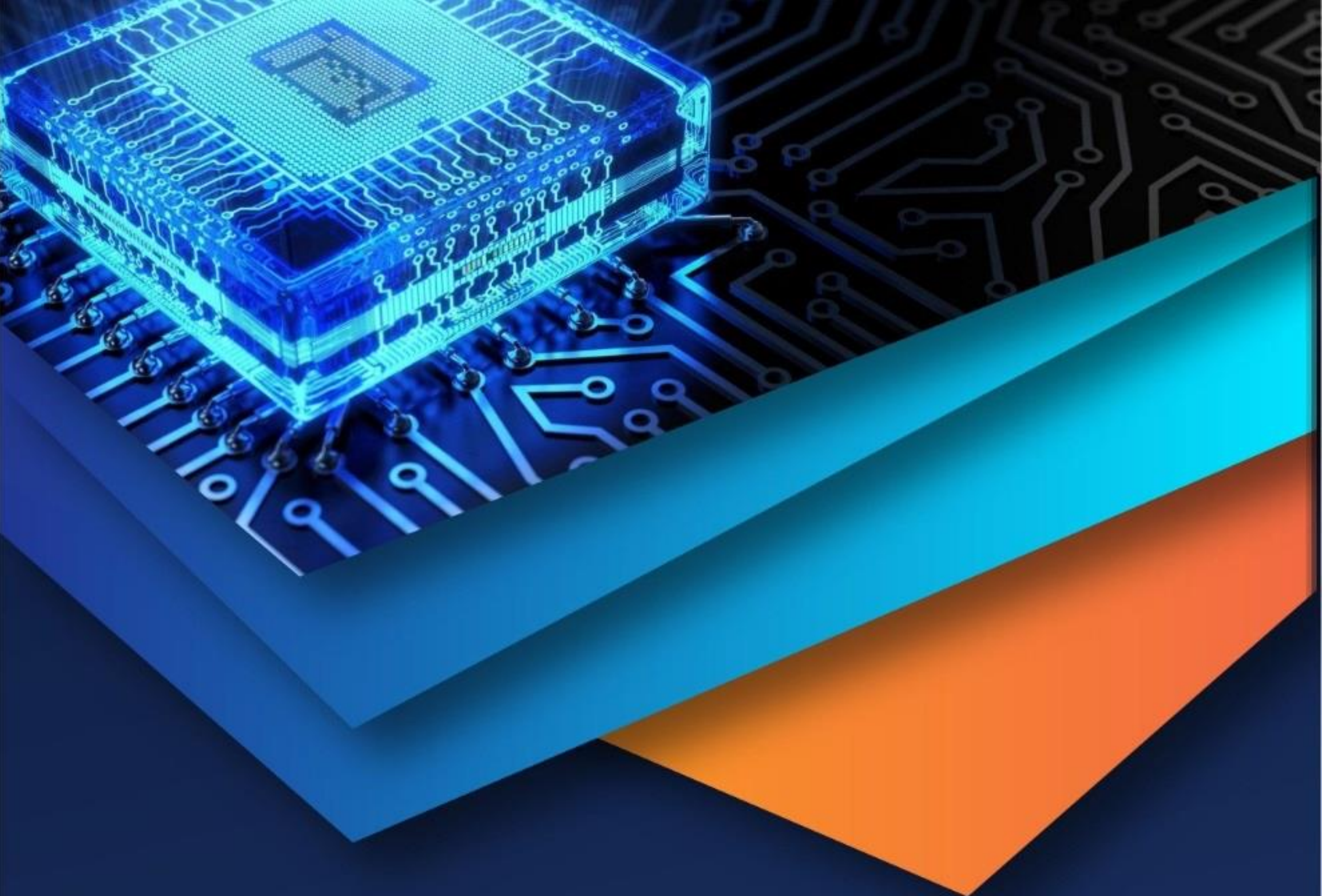
BIOGRAPHY

Vipin verma is an experienced engineer with a professional in Embedded R&D. He is a former BEL Engineer.
He has done graduation in Electrical Engineering and Masters in Power Electronics.
He is an electronics enthusiast from childhood and has done so many successful projects which are selling in the US, UK and Indian market. He has won many awards from IITs, NITs and other universities.
He has published multiple articles and research papers. One of them you can find on Google IJSTEV3I6131
He has a good experience in electronics fields like circuit design, schematics design, components selection, innovation, product development etc.



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