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Design of a Micro-controller based programmable voltage source for process automation

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ABSTRACT

Automated control of processes is emerging in all spheres as it saves time and energy by providing a significant improvement in productivity and accuracy when compared to the manual methods of controlling processes which require constant human intervention. This paper presents a design of a voltage source that can be programmed using a micro-controller board to control the voltage that needs to be generated. The design is achieved by interfacing the electronic components required along with necessary software tools as a part of an embedded system consisting of the input/output peripherals and a microcontroller. There are two approaches of design, the first approach is based on a Digital to Analog converter and an Operational amplifier, the second approach is based on a MOSFET driver circuit. The circuits are constructed based on the design methodology which is developed with all the components chosen according to desired requirements. The circuits are simulated in Proteus in order to evaluate their performance and the readings are tabulated. The accuracy of both the approaches are computed and it is found that both the approaches have high levels of accuracy.

Keywords: *Arduino Microcontroller, Digital to Analog converter (DAC), Duty cycle, Inter Integrated Circuit (I2C) protocol, MOSFET, Programmable Voltage Source, Pulse Width Modulation (PWM)*

1. INTRODUCTION

Voltage is one of the most important parameters as it is required to determine the power that is supplied to a load. An electrical component would work as desired only in the voltage range it is specified to work. If the voltage supplied is above the rated voltage, then there is a possibility of the component undergoing permanent damage. In case the voltage that is supplied to the device is below the rated voltage, then the device would underperform. Hence it is necessary to supply the right voltage to a device. Since different devices have different levels of rated value of voltage for safe and optimized operation, it is necessary to have a variable voltage supply that has the capability to generate voltages over a wide range of operation to ensure that the variable voltage supply module can handle a large number of components in order to expand the applications of the module.

There is a globally emerging trend to minimize human intervention in all spheres of technology. The field of electronics is no exception to this growing trend. There is need for an automated low-cost variable voltage supply that can supply the required voltage based on the user's requirement without the need to physically turn the knobs of the DC power supply. This type of variable voltage source would be of great use in DIY (Do it yourself) projects, academic and industrial purposes. The aim of the paper is to present a design of a programmable variable voltage source that would generate a voltage based on the value entered by the user in a computer or based on reading a file that contains the value of voltages to be generated stored in a PC or in a removable storage device. The safety aspects are also taken into consideration and modules to ensure safety of the device under test from sudden voltage or current spikes are included. The design that is presented in this paper is based on having a microcontroller as the key governing element. The design proposed is user friendly and has a high ease of usage as the end user does not need to possess in depth knowledge regarding the working of the tool.

2. DESIGN METHODOLOGY

This Paper aims to develop a Programmable voltage source based on the Arduino Microcontroller to generate variable voltage signals between 0 to 24 V in order to drive the components. Safety module is also provided to protect the circuit from high voltage and current surges. The approach to address the issue is by interfacing the hardware and software in an embedded system with the

Arduino microcontroller serving as the heart of the designed module which controls and regulates the working of the embedded system according to the desired expectation. The block diagram of the design is described in figure 1.

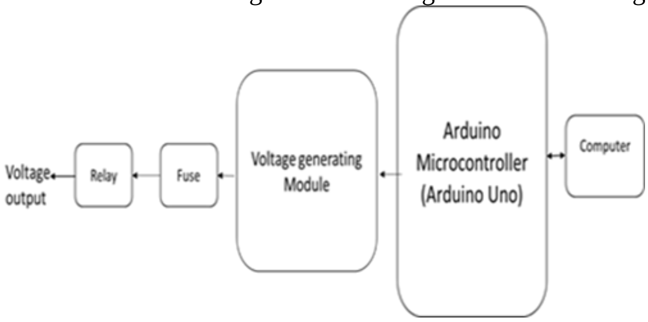


Fig 1 : Block Diagram of programmable voltage source

The block diagram is designed for generating variable voltage signals which is controlled by the Arduino microcontroller board. The functions of the different blocks are enumerated below:

1. **Computer:** The computer is used to enable the user to decide the voltage level that is required in the form of a code that is written in embedded C using the Arduino IDE (Integrated development environment) which is an open-source tool for embedded system development
2. **Arduino Microcontroller Board:** The Arduino microcontroller board is a low-cost multipurpose micro controller board based on ATmega328P. Codes written in Arduino IDE for defining the inputs and outputs can be uploaded on to this microcontroller board for performing the desired tasks. The microcontroller board controls the working of the entire setup and performs the role of a bridge by acting as an interface between the software and the hardware.
3. **Voltage generating module:** It is the most important block in the entire system as it performs the tasks of generating voltage signals from 0 to 24 V based on the requirement. This task is completed by using a couple of approaches. One using a DAC (Digital to Analog converter) and an Operational amplifier and the other approach being using a MOSFET driver IC.
4. **Fuse**: A Fuse is a sacrificial device that is added in the circuit to provide protection for the equipment from current surges. The fuse would melt if the current flowing in the circuit is above a rated value and the circuit would break.
5. **Relay**: The relay is a programmable electromechanical device which is included to protect the equipment from high voltages above the rated value. The relay can be controlled by the Arduino and depending on the voltage at the output the relay can be either switched on or switched off. Thus, isolating the components from high voltages.

Based on the block diagram discussed earlier, there are two approaches that are followed and two circuits are designed in order to develop a programmable voltage source, with the only change being made to the voltage generating module. The following are the circuits that are designed and simulated.

2.1 Using DAC and Op amp

In the first approach that is carried out, the operation of the voltage generating module is fulfilled by a combination of a Digital to Analog converter module and an operational amplifier. Here the digital signals are converted to analog signals and their amplitudes are amplified in order to generate voltage signals in the range of 0-24 V. The block diagram of this design is shown in figure 2.

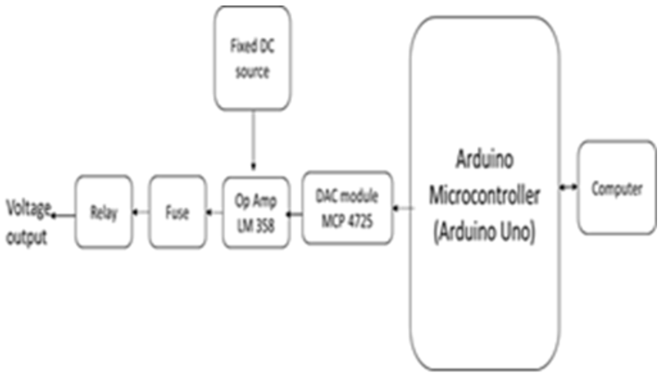


Fig 2: Block diagram of design using DAC and op amp

The following are the functions of the circuit designed using DAC and an Op amp which are different from the one covered in the basic block:

1. **Arduino Microcontroller** is used to communicate with the Digital to Analog converter through I2C (Inter integrated circuit) communication protocol and to transfer the values for digital to analog conversion.
2. **MCP 4725 DAC Module:** The Arduino microcontroller board can generate only voltage signals of 5 V and 3.3V**.** It does not have the capability to generate variable voltages. Hence additional circuitry is required to produce variable analog voltages. It is for this purpose that a digital to analog converter module is incorporated in the design. MCP 4725 is the DAC module used for digital to analog conversion. It has the capability to generate variable voltage levels between 0 – 5 V with a step size of 1.22 mV. It is a 12-bit device and voltages between 0 to 5 V can be generated by writing numerical values ranging between 0 to 4096 to the DAC module using I2C communication. A Master slave relationship is created between the Arduino Uno board and the

MCP 4725 DAC module through I2C communication. In order to enable I2C communication the Serial Dataline and the Serial clock of the DAC module are connected to analog pins A4 and A5 respectively of the Arduino board.

3. **LM 358 Op Amp:** The voltage levels that are produced by the DAC is between 0 to 5V. But this range of voltages is narrow and devices with higher voltage rating cannot be connected to this supply as voltages lower than the rated values would cause the devices to underperform and stall. In order to obtain higher value of voltages in the desired range from 0 to 24 V, an Operational amplifier is used. The Op Amp LM 358 IC is used to amplify the level of signals coming from the DAC. The Op amp steps up the value of input voltage to a higher value which is a multiple of the input voltage. The output voltage is determined by the ratio of the external resistances. The Op amp is operated in non-inverting mode. Figure 3 shows the implementation of the programmable voltage supply using DAC and Op Amp.

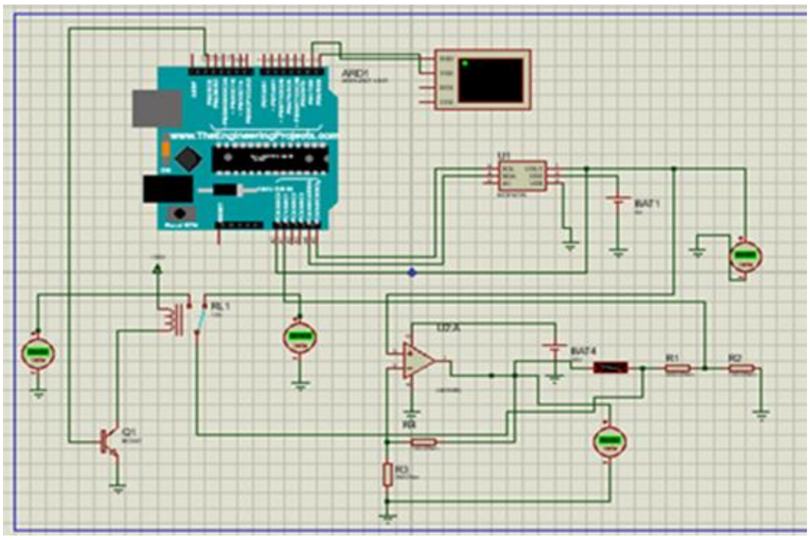


Fig 3: Implementation of programmable voltage supply using DAC and op amp

2.2 Using MOSFET driver circuit

In the second approach that is carried out, the operation of the voltage generating module is fulfilled by a combination of a MOSFET driver IC and a RC low pass filter. Here the PWM (Pulse width modulation) signals are generated from the Arduino microcontroller. These PWM signals are used to control the output of the MOSFET driver in order to generate variable voltage signals from 0 to 24 V. A Low pass filter is used to obtain a pure DC analog output. The block diagram of this design is shown in figure 4.

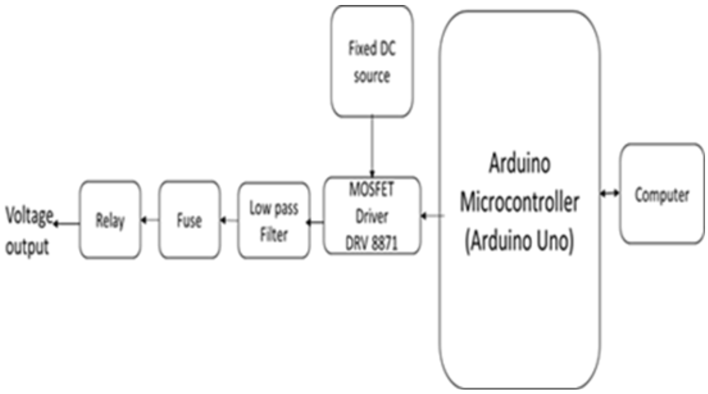


Fig 4: Block diagram of design using MOSFET driver

The following are the functions of the blocks in the circuit designed using MOSFET driver which are different from the one covered in the basic block-

1. **Arduino Microcontroller** board does not have the capability to generate analog signals. But it has another property of generating PWM (Pulse width modulation) signals which can be utilized here. A PWM signal is a digital signal with varying ON and OFF times. The width of these ON and OFF times depend on the duty cycle. Duty cycle refers to the percentage of time during which the pulse is in ON state. Thus, by changing the duty cycle with the help of the Analog write function, the width of these ON and OFF times can be changed which results in change in average voltage. When this varying average voltage of the PWM signal is extracted properly, then it becomes equivalent to varying analog voltages. The PWM pins in Arduino are pins 5 and 6 with 980 Hz frequency and pins 3, 9, 10 and 11 with 490 Hz. The duty cycle can be varied from 0 to 100% by writing values between 0 and 255 into the PWM pins.
2. **MOSFET Driver DRV 8871:** The MOSFET driver DRV 8871 can be controlled by the PWM signals that are generated by the Arduino. The output of the MOSFET driver can be regulated by feeding these PWM control signals to the gate of the MOSFET. The MOSFET driver is a high-speed switching device and the input to the gate acts a switch. The switching in these devices takes place in accordance with the PWM signals. When the PWM pulse is in ON state the MOSFET is switched on and the signal flows from the 24 V supply to the output. When the PWM pulse is in OFF state the MOSFET is switched off and the signal flow from the 24 V supply to the output is stopped. The Output voltage obtained is the PWM signal varying between two levels which are 0 V and the supply voltage (24 V). The output resembles the input PWM signals in ON and OFF times, only

differing in magnitude where an amplified version of input is obtained. Input coupling capacitors are used at the input to remove any AC components from the signal and to obtain a pure DC input signal.

3. **Low pass filter:** The output from the MOSFET driver is a PWM signal with frequency equal to the input frequency of either 980 Hz or 490 Hz. In order to obtain a pure DC analog signal, a low pass filter is used to attenuate the high frequency components and to obtain a baseband DC output with voltage equal to the average value of PWM signal. The simplest low pass filter implementation is a series combination of a resistor and a capacitor.

Figure 5 shows the implementation of the programmable voltage supply using MOSFET driver.

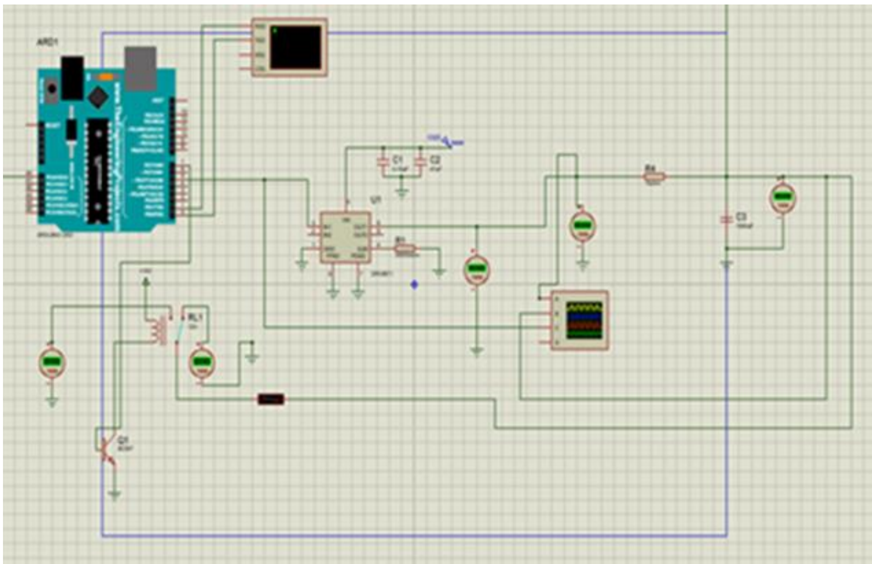


Fig 5: Implementation of programmable voltage supply using MOSFET driver

3. RESULTS

In this section, the performance of the two circuits that are designed are discussed and the various characteristics of circuits are analyzed.

3.1 Circuit Using DAC and Op amp

The code is written to generate voltage values according to the desired levels and commands for I2C communication are also included. The voltage levels are varied from 0 to 24 volts so as compute the performance of the circuit over the entire range of operation. The values are fed to the MCP 4725 DAC module through I2C communication for generating values between 0 and 5 V, this signal is then amplified with an Operational amplifier of gain 5. The voltages are measured at the output of the DAC and at the output of the Operational amplifier which must be equal to the desired voltage. A relay and fuse are added to protect the test setup. Figure 6 shows the voltage readings taken in the Virtual terminal.

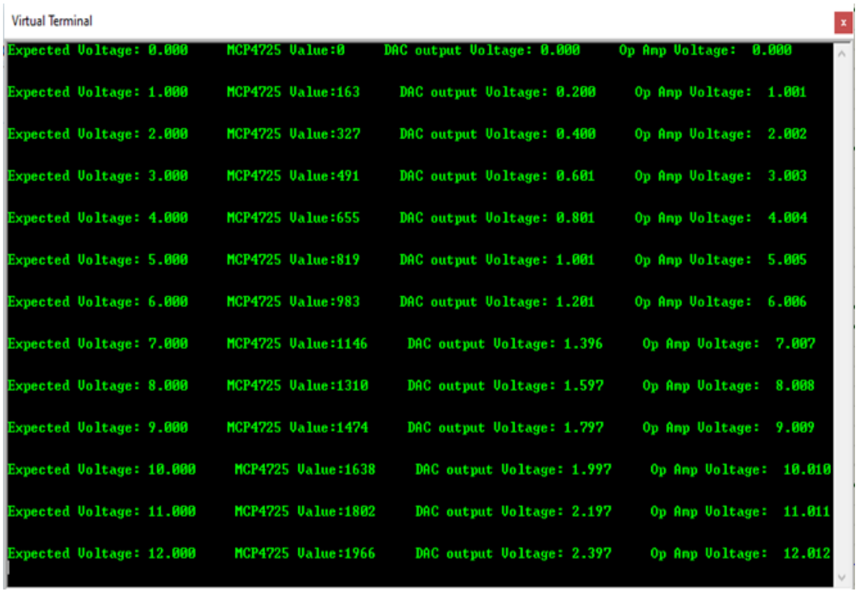


Fig 6: Voltage readings in the Virtual terminal

The relay used is a programmable relay and can be programmed to switch at any voltage level depending on the requirements. Based on the voltage sensed the relay is activated or deactivated. It is observed that the relay works as expected in the circuit and the relay is programmed to activate at 12 V. When the voltage is below 12 V as shown in figure 7(a), the relay is in OFF condition and when the voltage is greater than 12 V as shown in figure 7(b), the relay switches to ON condition.

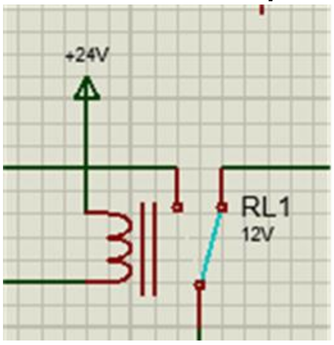


Fig 7(a): Relay deactivated when V<12

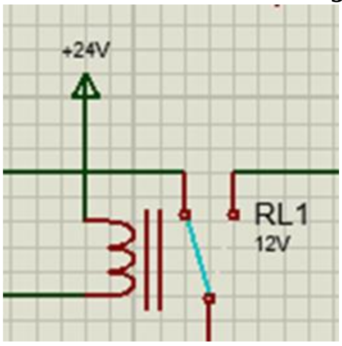


Fig 7(b): Relay activated when V>12

Table 1 shows the behavior of the circuit when the desired output voltage is varied from 0 to 24 V. It is seen that highly accurate voltages are obtained with the average accuracy being 99.92 percent and the difference between the required voltage and the measured voltage is minimal. The circuit works as desired and voltages are generated from 0 to 24 V. The values generated by the DAC is verified and this signal is amplified at the Op amp and the voltages are measured. The step size of output voltage that can be generated is 6.1 mV.

Table-1: Results of DAC and Op Amp circuit

Desired Output (V)	MCP 4725 value	DAC Voltage (V)	Measured Output (V)	Accuracy (%)
0	0	0	0	-
1	163	0.2	1.001	99.9
2	327	0.4	2.002	99.9
3	491	0.601	3.003	99.9
4	655	0.801	4.004	99.9
5	819	1.001	5.005	99.9
6	983	1.201	6.006	99.9
7	1146	1.396	7.007	99.9
8	1310	1.597	8.008	99.9
9	1474	1.797	9.009	99.9
10	1638	1.997	10.01	99.9
11	1802	2.197	11.011	99.9
12	1966	2.397	12.012	99.9
13	2129	2.598	12.988	99.907
14	2293	2.798	13.989	99.921
15	2457	2.998	14.99	99.933
16	2621	3.198	15.991	99.943
17	2785	3.398	16.992	99.952
18	2949	3.599	17.993	99.961
19	3112	3.799	18.994	99.968
20	3276	3.999	19.995	99.975
21	3440	4.199	20.996	99.980
22	3604	4.399	21.997	99.986
23	3768	4.6	22.998	99.991
24	3932	4.8	23.999	99.995

3.2 Circuit Using MOSFET driver

The code is written to generate voltage values according to the desired levels which depend on the PWM signals that are fed to the MOSFET driver. The voltage levels are varied from 0 to 24 volts so as to compute the performance of the circuit over the entire range of operation. The PWM values are fed to the MOSFET driver from the PWM pins of the Arduino micro controller corresponding to the voltages that are required to be generated between 0 and 24 V. The output signal from the MOSFET driver is then filtered with a low pass RC filter in order to attenuate the high frequency signals and obtain a clean DC output. A relay and fuse are added to protect the test setup. The working of the relay in the setup is same as described in the previous circuit. The duty cycle is varied in order to generate the corresponding voltages.

Figures 8(a) to 8(e) show the readings from the oscilloscope where the output voltages from the MOSFET driver of 0, 6, 12, 18 and 24 Volts are obtained corresponding to a duty cycle of 0, 25, 50, 75 and 100 percent respectively. It is evident from the figures that as the duty cycle increases there is an increase in ON time of the pulse and reduction in OFF time of the pulse, thereby increasing the average value of voltage. At the MOSFET output a PWM signal is obtained which switches between two levels: 0V and 24V, with the ON and OFF times of the output similar to the input PWM signal. After the signal is passed through a low pass RC filter, it is seen that the high frequency components are attenuated and a pure DC analog output voltage is obtained with its value equal to average voltage of the PWM signal

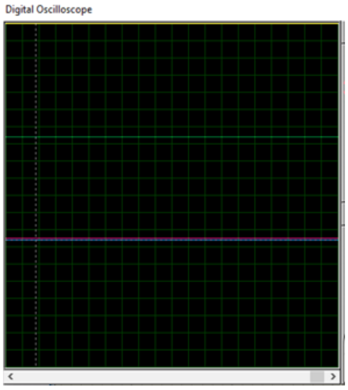


Fig - 8(a): Duty cycle = 0 %
Vout = 0 V

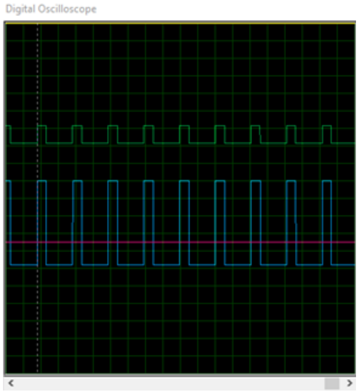


Fig - 8(b): Duty cycle = 25 %
Vout = 6 V

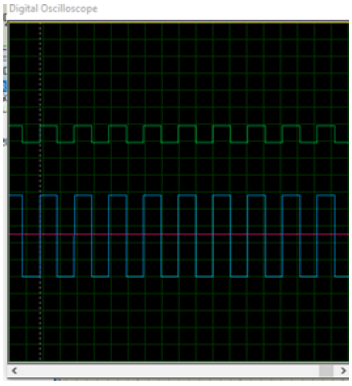


Fig - 8(b): Duty cycle = 50 %
Vout = 12 V

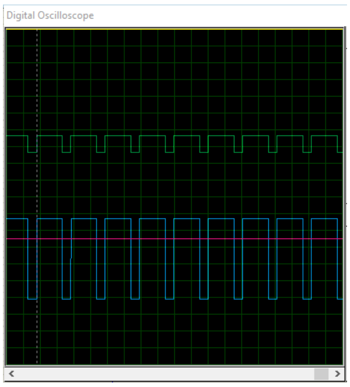


Fig - 8(d): Duty cycle = 75 %
Vout = 18 V

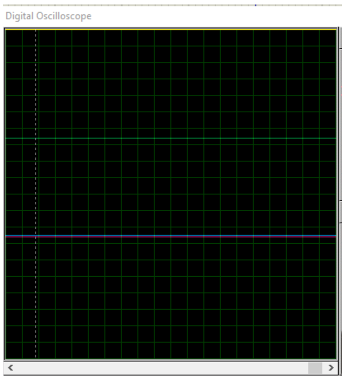
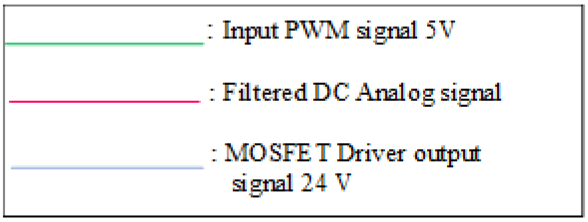


Fig - 8(e): Duty cycle = 100 %
Vout = 24 V

Legend



The results obtained by adding a filter is according to the expectation. In the absence of the filter, the output voltage just switches between the two levels: 0 V and the supply voltage (24 V). Whereas with filter the DC voltages are obtained in proportion to the duty cycle.

Table 2 shows the behavior of the circuit when the desired output voltage is varied from 0 to 24 V. It is seen that highly accurate voltages are obtained with the average accuracy being 99.54 percent and the difference between the required voltage and the measured voltage is minimal. The circuit works as desired and voltages are generated from 0 to 24 V. The values generated by the PWM is verified and this signal is used to switch the MOSFET and the output voltages are measured. The step size of output voltage that can be generated is 98 mV.

Table-2: Results of MOSFET driver circuit

Desired Output (V)	PWM values	Duty cycle (%)	Measured Output (V)	Accuracy (%)
0	0	0	0	-
1	10	3.921569	1.025	97.5
2	21	8.235294	2.051	97.45
3	31	12.15686	3.003	99.9
4	42	16.47059	4.028	99.3
5	53	20.78431	5.054	98.92
6	63	24.70588	6.006	99.9
7	74	29.01961	7.031	99.55714
8	85	33.33333	8.057	99.2875
9	95	37.2549	8.984	99.82222
10	106	41.56863	10.01	99.9
11	116	45.4902	10.962	99.65455
12	127	49.80392	11.987	99.89167
13	138	54.11765	13.013	99.9

14	148	58.03922	13.965	99.75
15	159	62.35294	14.99	99.93333
16	170	66.66667	16.016	99.9
17	180	70.58824	16.968	99.81176
18	191	74.90196	17.993	99.96111
19	201	78.82353	18.921	99.58421
20	212	83.13725	19.971	99.855
21	223	87.45098	20.996	99.98095
22	233	91.37255	21.924	99.65455
23	244	95.68627	22.949	99.77826
24	255	100	23.999	99.99583

3.3 Comparison of the circuits

The similarities and the contrasts between the characteristics of the two circuits are discussed here. Table 3 shows the Comparative analysis of the designed circuits.

Table-3: Comparative analysis of the designed circuits

Property	DAC and Op Amp	MOSFET Driver
Principle	Uses I2C protocol for generation of voltages	Uses PWM for generation of voltages
Power	Signal conditioning in low power side	Signal conditioning in high power side
Nature of output	Steady output observed.	Minor variations are observed in the output due to the use of capacitors till steady state is reached.
Step size	Step size of output voltage is 6.1 mV	Step size of output voltage is 98 mV
Accuracy	High accuracy	High accuracy
Range	Wide range of operation from 0 – 24 V	Wide range of operation from 0 – 24 V

4. CONCLUSION

The design of an Arduino microcontroller based programmable voltage source was developed and implemented incorporating two novel approaches. The first circuit was developed using a DAC and an Operational amplifier as the governing element and the subsequent circuit with a MOSFET driver as the governing element was developed. These developed circuits are simulated in order to validate and verify the design. In the simulations, it is observed that the voltages are generated with high levels of accuracy using both the approaches. The accuracy of voltage generated using a digital to analog converter and an operational amplifier circuit is 99.92 percent and accuracy of voltage generated using a MOSFET driver circuit is 99.54 percent**.**

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