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Embedded Buck-Boost Converter Design and Implementation Using Nucleo Board STM32F446RE

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1. Introduction

In this report, you will find the progress that the team made in the development of the assigned project. In this case, it is about the DC-DC Buck-Boost converter, and this progress report will cover the physical implementation of the process to be controlled and the independent evaluation of each of the physical components.

2. Theoretical Framework

DC-DC converters are dynamic control systems. There are two types of models applicable to power electronics: *single-variable* and *multi-variable*. The first class refers to those that have a single input variable represented by the position of a switch. The ”Buck-Boost”DC to DC converters generally fall into this category. The second class includes those that have multiple switches as inputs. [1]

2.1. Buck-Boost Converter

The purpose of the buck-boost converter is to receive an input DC voltage and obtain a different DC voltage level as output, either increasing or decreasing the voltage as needed. This converter is obtained by exchanging the diode and the inductor of the Buck converter.
One of the main differences between this type of converter and the Buck or Boost is that the output voltage is of opposite sign to that of the power supply. In **Figure 7**, we can observe the circuit of the Buck-Boost converter with switching via semiconductors, while in **Figure 8**, we can observe the circuit with an ideal representation of the switch within the circuit. [1]

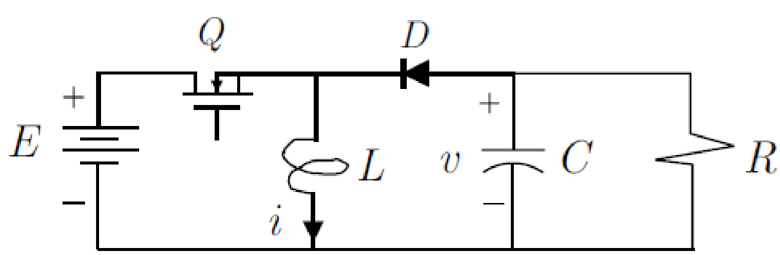

Figura 1: Buck Boost converter circuit with switch via semiconductors.

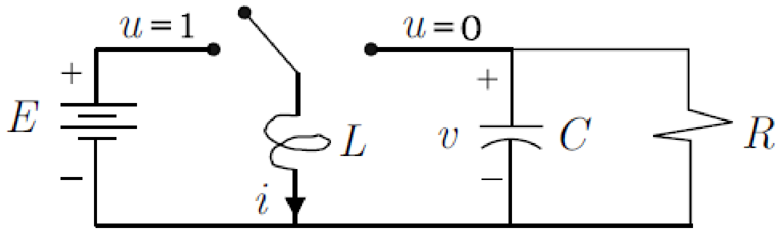

Figura 2: Buck Boost converter circuit with ideal switch representation.

When the transistor is in conduction state, the diode is reverse biased (**Figure 7**). During this period, the inductor current is generated from the voltage source E. When the diode remains reverse biased, it can be said that the circuit is operating in the çharging period".
While when the transistor is in the off state, the diode is polarized, generating the circuit that we can observe in **Figure 8**. This period is known as the "discharge period"since the energy in the inductor L is transferred to the load system L. [1]

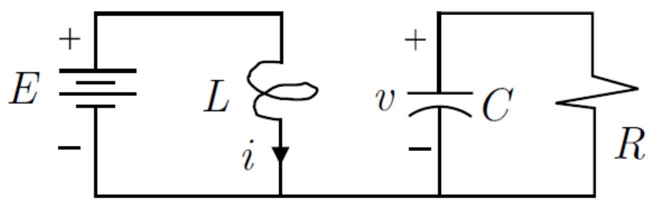

Figura 3: Boost converter circuit u = 1.

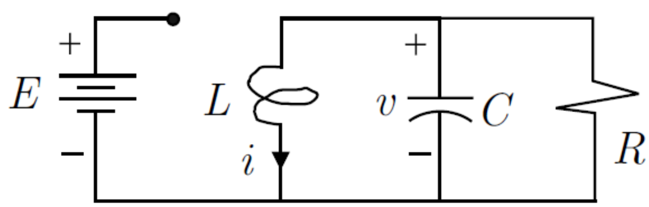

Figura 4: Boost converter circuit u = 0.

When we apply Kirchhoff's law for voltage and current in the two circuits shown above and combine them into a single dynamic model, we have the following differential equations that describe this Buck-Boost converter. [**?**]

$$L\frac{di}{dt} = (1-u)v + uE \tag{1}$$

$$C\frac{dv}{dt} = -(1-u)i - \frac{v}{R} \tag{2}$$

The buck-boost converter can increase or decrease the input voltage, depending on the load conditions and the duty cycle ratio of the switch. The voltage generation ratio is expressed by the following equation:

$$V_{\text{out}} = \frac{D}{1-D} \cdot V_{\text{in}} \tag{3}$$

where:

V_{out} : Output voltage V_{in} : Input voltage D : Switch duty cycle

Operating a double switch buck-boost converter in buck or boost mode can reduce current stress and improve efficiency. These converters are useful in applications where a positive voltage output is required, and they offer an efficient alternative to conventional inverting buck-boost converters. [2]

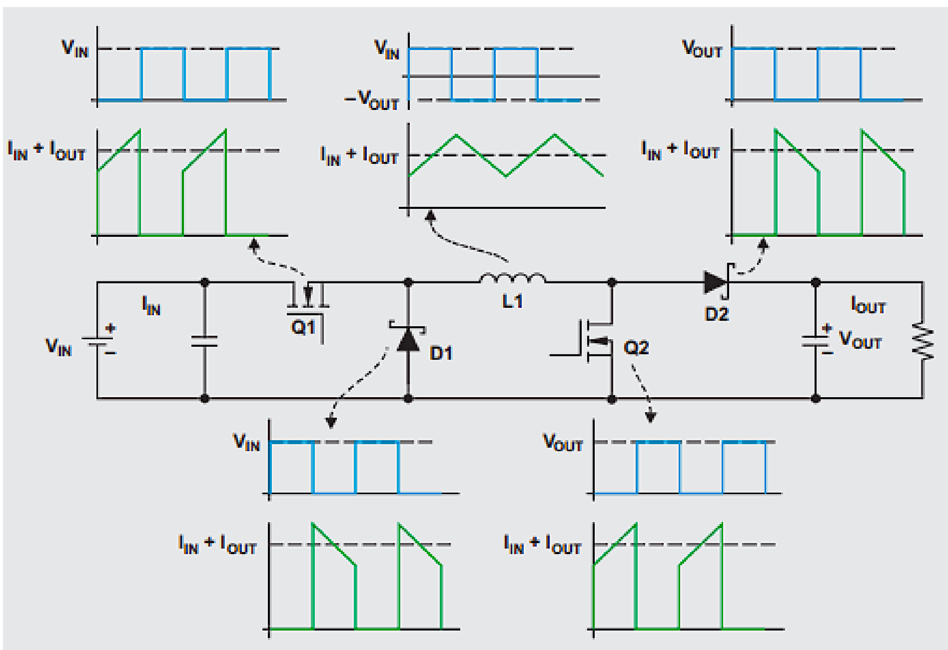

Figura 5: Non-inverting Buck-Boost converter circuit, double switching.

3. Experimental Conditions

To carry out the control of the Buck-Boost power converter as well as the voltage sensor, the following materials shown in **Table 1** were required:

Material	Quantity
MOSFET IRLR 2905	2
Inductor 1mH	1
Electrolytic Capacitors SMD 22 uF	1
Microcontroller STM32F446RE	1
Schottky Diodes MBR1045	2
Resistors $2k2\Omega$ 1/4 Watt	2
Zener Diodes	3
Resistor $10k\Omega$	1
Resistor $1k\Omega$	5
TL072	1
LM358D	1

Tabla 1: List of materials

The code that will be implemented to carry out the control of the PWM signal to regulate the desired voltage is found in the pseudo-code of **Algorithm 1**.

Listing 1: Algorithm for the program that will be used in the system control.

```
// Initialize peripherals and global variables
while(1) {
/* USER CODE END WHILE */
Copy/* USER CODE BEGIN 3 */
long currT = micros();
   deltaT = ((float) (currT - prevT))/( 1.0e6 );
   prevT = currT;

        adc_values[2] = adc_values[1];
    adc_values[1] = adc_values[0];
    adc_values[0] = adc_value;

    variable = ((((float)(adc_values[0] +
       adc_values[1] + adc_values[2])) / 3.0)
       *3.3)/4095;

   voltaje=(variable*100)/3.3;

   error = referencia-voltaje;

   if(dutyCicle>maxDuty)
```

```
    {
        dutyCicle=maxDuty;
    }
    else if(dutyCicle<=0)
        {
            dutyCicle=0;
        }
  if(error<0)
  {
        dutyCicle--;
        __HAL_TIM_SET_COMPARE(&htim2,
            TIM_CHANNEL_1, dutyCicle);
  }
  else if(error>0)
  {
        dutyCicle++;
        __HAL_TIM_SET_COMPARE(&htim2,
            TIM_CHANNEL_1, dutyCicle);
  }
  else if(error==0)
  {
        __HAL_TIM_SET_COMPARE(&htim2,
            TIM_CHANNEL_1, dutyCicle);
  }
}
```

4. Results

At this point, the instrumentation generated throughout the semester is implemented and the results obtained are discussed.

4.1. Voltage Sensor Circuit

The voltage sensor is mainly based on a series of voltage dividers protected by Zener diodes, which will not allow values above their nominal voltage to pass. In this case, a first voltage divider was proposed that reduces the voltage 10 times and subsequently one that reduces it 3 times, to allow better isolation of the control circuit from the power circuit and prevent failures. The voltage dividers are configured with buffers or voltage followers, their function is to prevent the voltage from being reduced due to lack of current and to be exactly the division that is being sought.

4.1.1. PCB Design

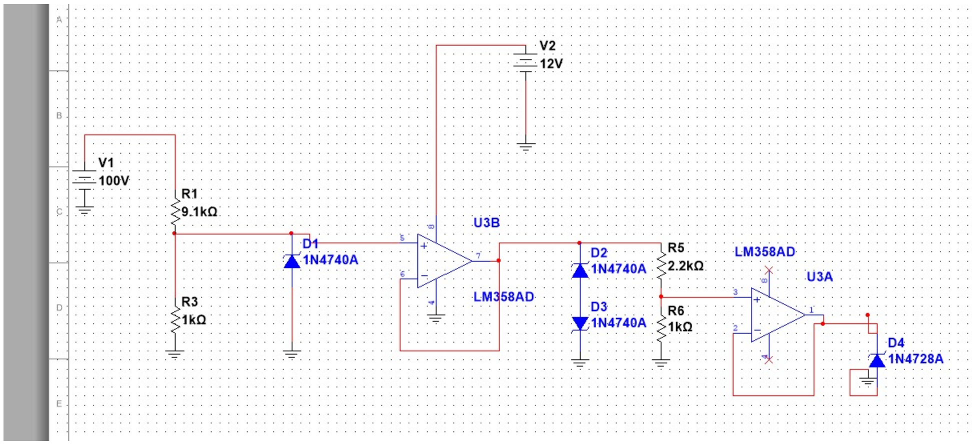

Figura 6: Voltage Sensor Circuit, Input 0-100V, Output 0-3.3V

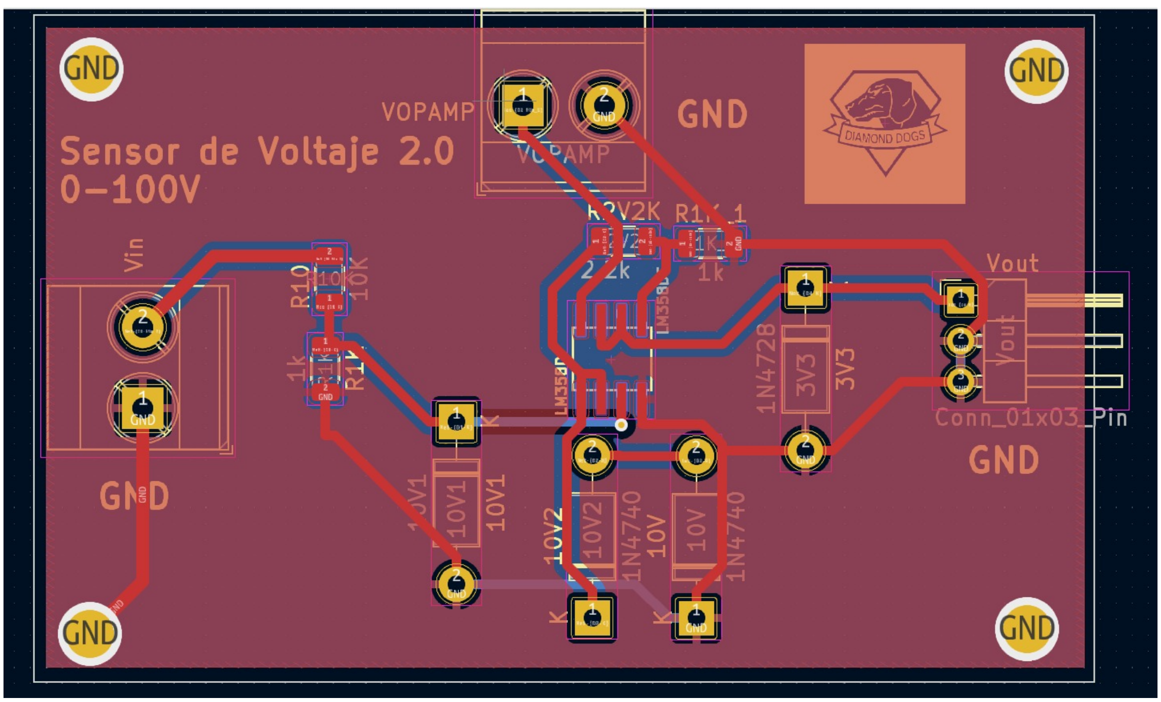

Figura 7: PCB Voltage Sensor, Input 0-100V, Output 0-3.3V

4.1.2. Implementation

The following figures show the physical implementation of the PCB board for the voltage sensor:

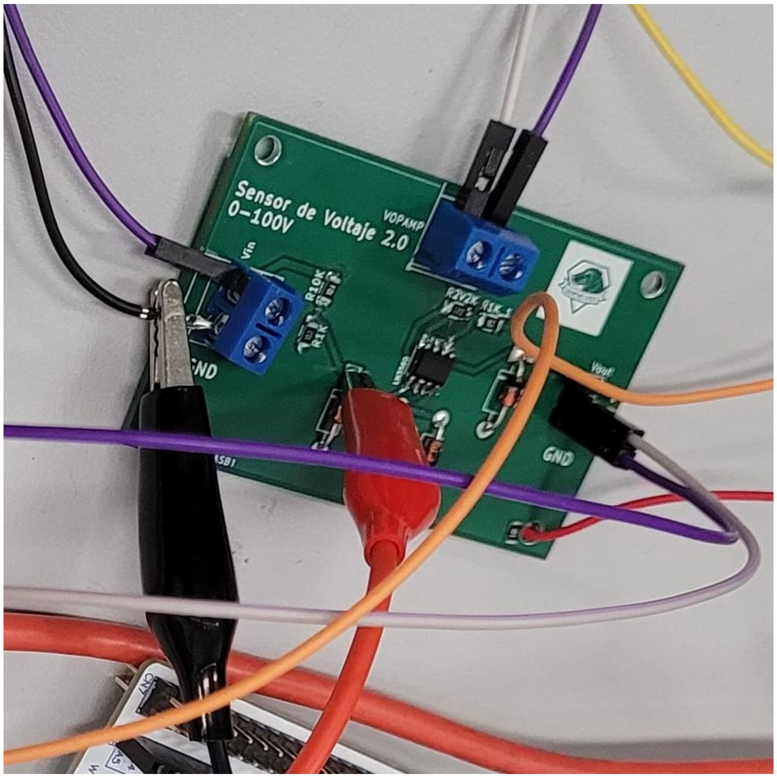

Figura 8: Physical implementation PCB Voltage Sensor, Input 0-100V, Output 0-3.3V

4.2. Buck-Boost Converter Circuit

The proposed buck-boost converter is a double switching one, which is used when a positive voltage is required 100

4.2.1. PCB Design

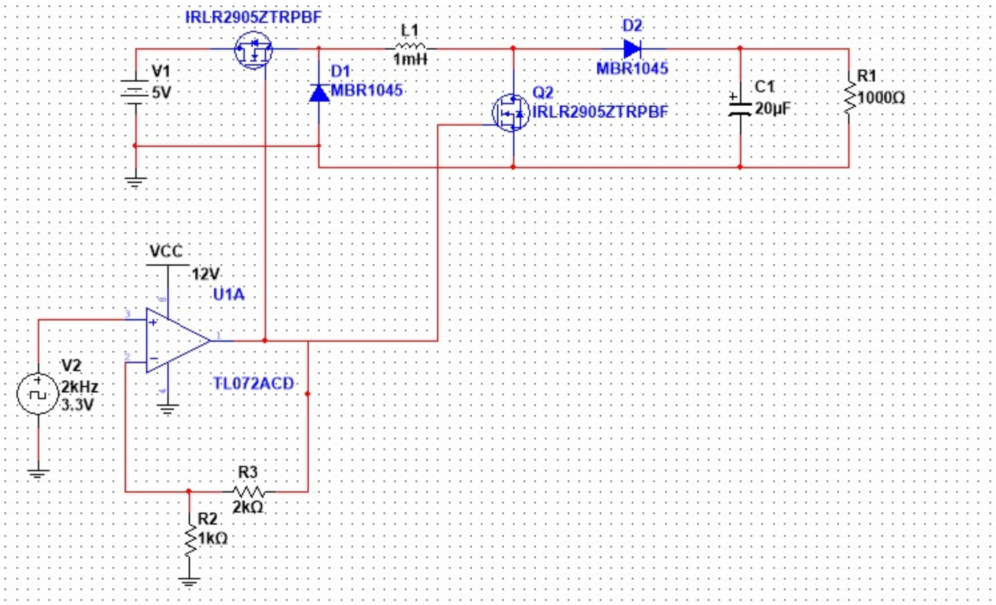

Figura 9: Proposed double switching DC-DC voltage converter circuit.

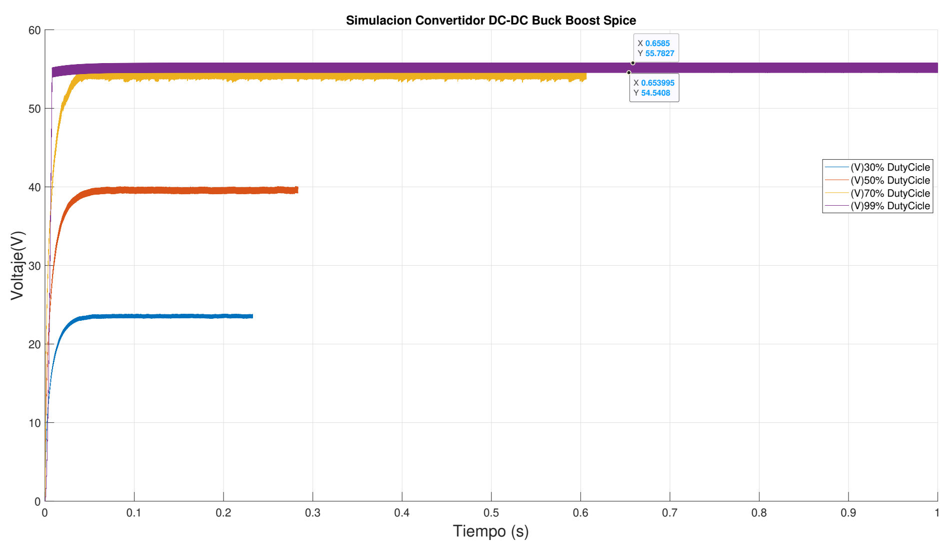

Figura 10: Operating voltage of the DC-DC buck boost double switching converter depending on the Duty Cycle of the PWM signal at 2kHz

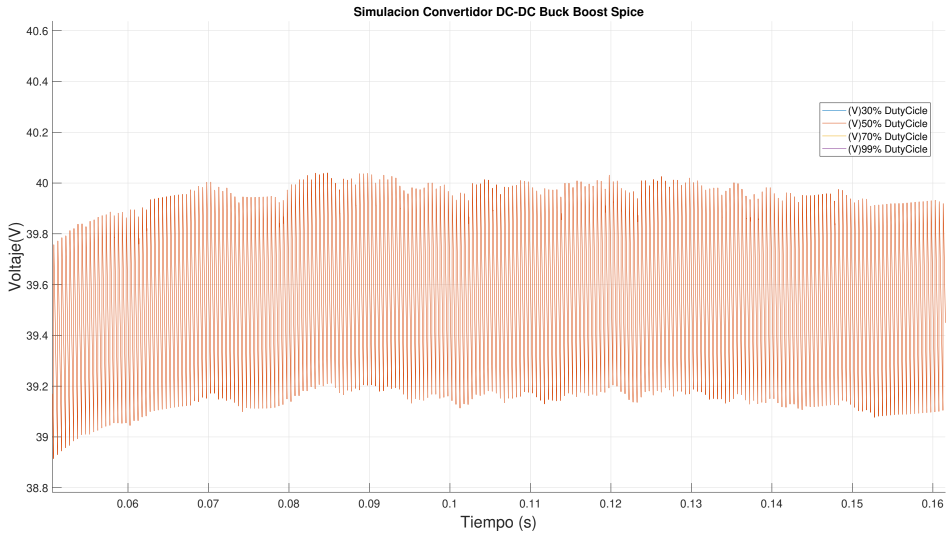

Figura 11: Converter ripple voltage at $70\,\%$ Duty Cycle

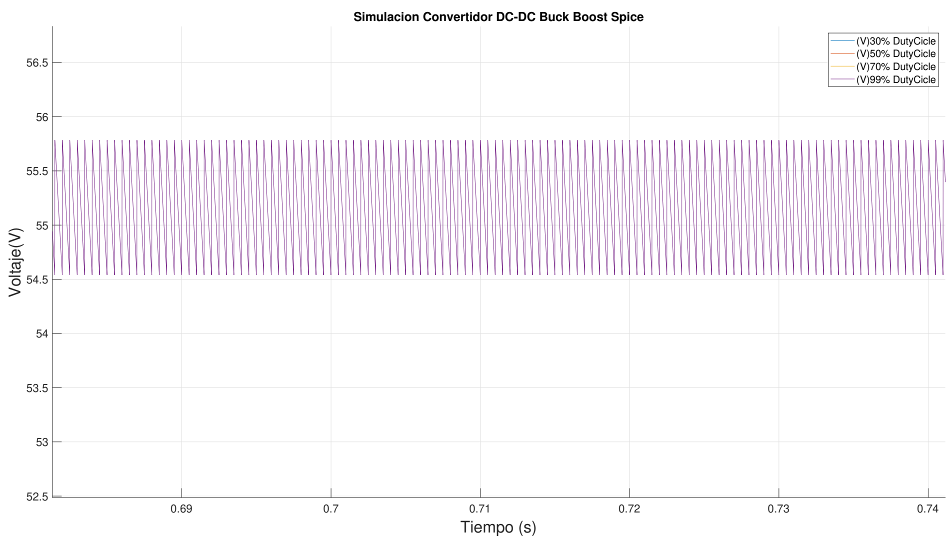

Figura 12: Converter ripple voltage at $99\,\%$ Duty Cycle

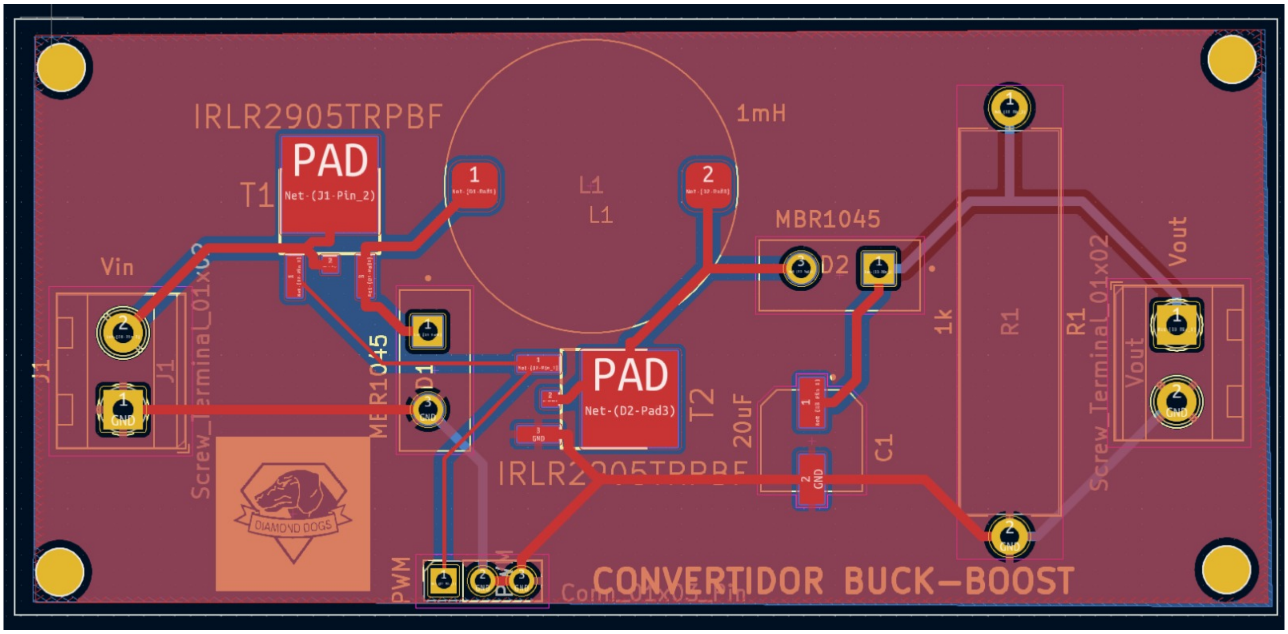

Figura 13: PCB non-inverting Buck-Boost converter, double switching.

4.2.2. Implementation

The following figures show the physical implementation of the PCB board for the non-inverting double switching Buck - Boost converter:

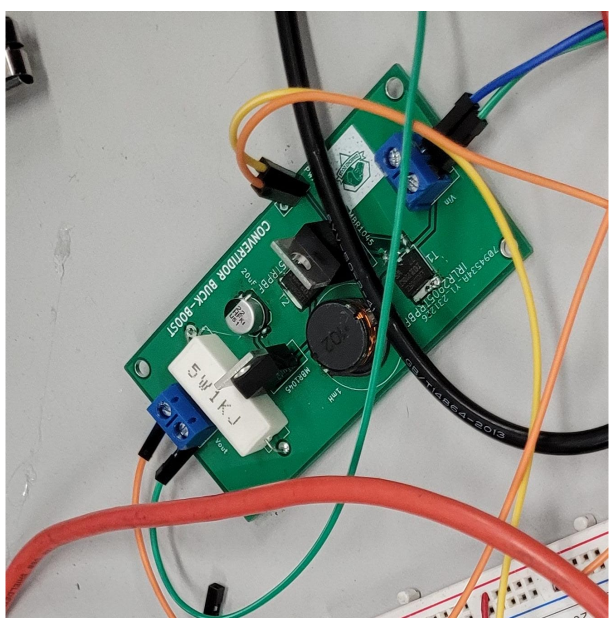

Figura 14: Physical implementation PCB non-inverting Buck-Boost converter, double switching.

5. Conclusions

5.1. Archundia Bazán Aarón Antonio

It is concluded from the project that controllable voltages were obtained through pulse width or duty cycle. In this case, the maximum voltages obtained were between 30 and 40 volts, depending on the experimental conditions, such as the input source. While it serves its function, there were some problems in achieving complete precision in the voltage sensor measurement with respect to the multimeter measurement. This is because the ADC resolution only allows 4095 different values, so information is lost in the conversion. The error can sometimes be 1V. This can also be due to the ripple voltage, which is around 0.8V based on the data obtained from the Spice simulation.

5.2. Hernández Vázquez César Arturo

To conclude the course project, we implemented the pulse width control to obtain the desired voltage at the output of the proposed Buck-Boost converter. For this, it was necessary to implement a voltage sensor circuit for the microcontroller's ADC input. During the development of this project, various problems were encountered, for example, the precision of the voltage sensor due to certain inaccuracy caused by the error obtained. Apart from this, once the PCBs and correct connections were obtained, it was possible to control the pulse width of the PWM signal to carry out correct voltage control of the Buck-Boost converter.

Referencias

[1] R. Silva-Ortigoza H. Sira-Ramirez. *Control Design Techniques in Power Electronics Devices*. Springer, 2006.

[2] Haifeng Fan. Design tips for an efficient non-inverting buck-boost converter. *Analog Applications Journal*, 2015. Industrial Analog Applications Journal, Volume 3, 2014, Pages 20-23.