Lab 11: Expérimentation Pratique avec Convertisseurs Buck

Maîtrise des Techniques de Modulation PWM et Application des Convertisseurs DC-DC

Work done by :

CHERIF Enzo

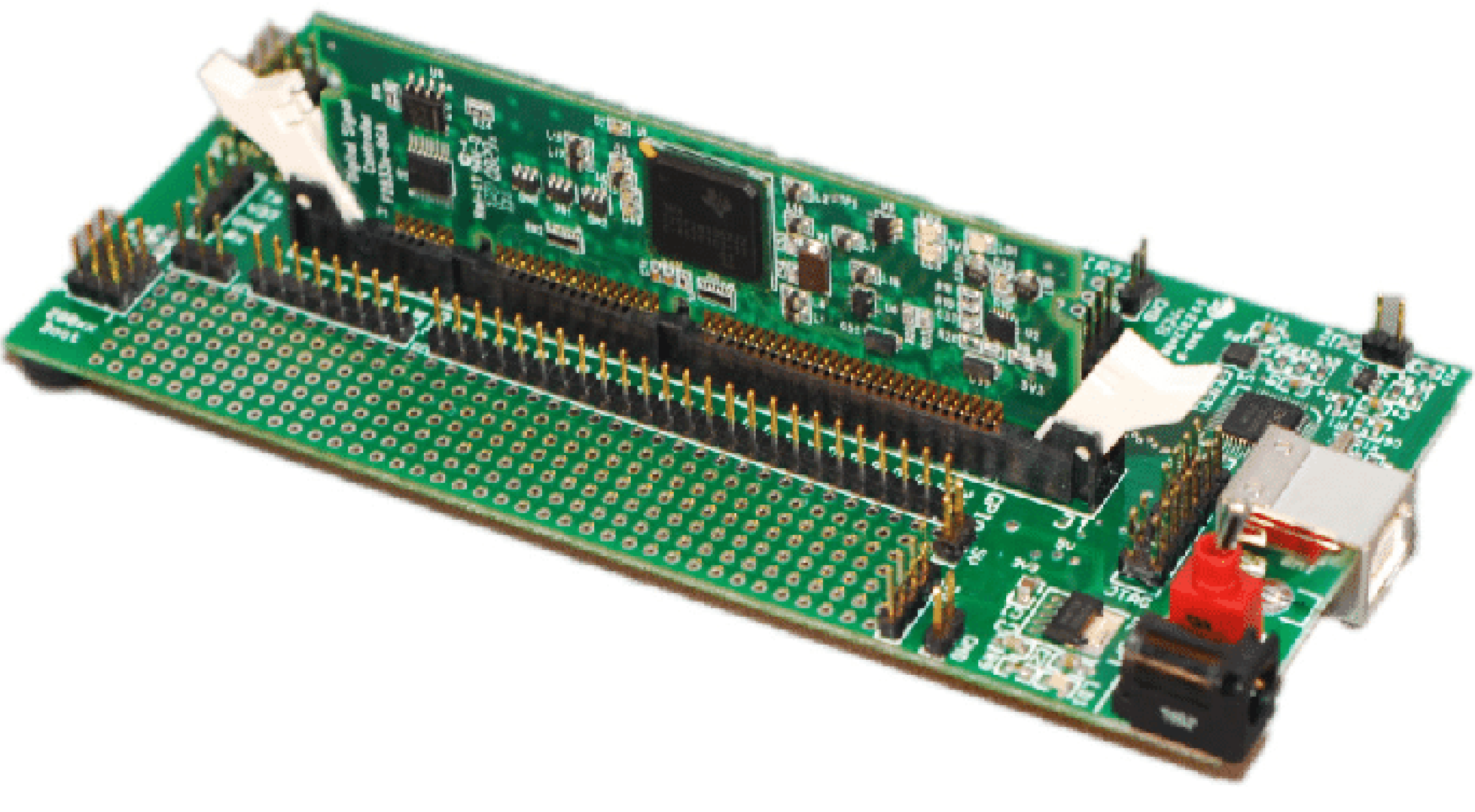
Students at Seatech in Class of 2025

2A, SYSMER track

As part of the course :

Programming on electronic card

August 2024



Contents

1 Introduction

1.1 General Presentation

Background and Review of Previous Practical Works

In previous practical works, we explored the fundamental principles of voltage converters, particularly Boost and Buck converters, using a function generator to modulate the PWM signal. These experiments helped understand how variations in the duty cycle influence the output voltage, essential for applications requiring precise power regulation.

Transition from Using a Function Generator to the TI Board

This practical work marks a significant evolution in our experimental approach: we are replacing the function generator with the Texas Instruments TF28335 board. This transition is motivated by the desire to practice more advanced skills in programming and microcontroller manipulation, offering increased flexibility and precision in PWM generation. The TI board, programmed via MATLAB, will not only allow precise control of PWM parameters but also enable dynamic adaptation of these parameters according to the circuit's needs. This skill is crucial for the development of integrated solutions in the fields of power electronics and embedded systems, where customization and rapid response to changing conditions are essential.

1.2 Objectives of the Practical Work

Using the TI Board to Generate PWM

One of the primary objectives of this practical work is to master the use of the Texas Instruments TF28335 board to generate PWM signals. Using MATLAB as the programming interface, students will learn how to configure and manipulate the microcontroller to produce precise Pulse Width Modulation (PWM) signals. This skill is essential for effectively controlling various electronic devices and for integrating TI technology into more complex power electronics applications.

Application on the Buck Circuit for Voltage Modulation

The secondary, yet equally important, objective is to apply the PWM signal generated by the TI board to the Buck circuit to observe and analyze the effects of modulation on the output voltage. Students will verify the capability of the Buck circuit to lower the voltage according to variations in the PWM duty cycle. This process includes not only checking the performance of the circuit in terms of output voltage but also evaluating the efficiency and accuracy of PWM control under real conditions. This experience aims to reinforce the understanding of the links between electronic theory and its practical application, highlighting the challenges and considerations necessary when designing efficient electronic systems.

2 Initial Setup

2.1 Review of Previous Configurations

This section refers to the skills and knowledge already developed in previous modules regarding the programming of the Texas Instruments TF28335 board. For those wishing to deepen their understanding or to review the board settings in detail, it is recommended to consult the practical works of Labs 3 and 4. These labs provide a comprehensive introduction to the board, explaining its operation and how to manage it effectively. For the current practical work, it is assumed that participants already master these aspects and are ready to apply this knowledge to controlling the Buck circuit.

2.2 Installation and Configuration

This section guides participants through the steps required to set up and configure the Texas Instruments TF28335 board for integration into the existing Buck circuit. Previous configurations, explained in Lab 9, will serve as the foundation for this transition from the function generator to the TI board.

2.2.1 Review of the Buck Circuit Assembly

Participants should refer to Lab 9 to review the details of the assembly and connections of the Buck circuit components. This review ensures that all necessary elements are correctly aligned for this experimentation.

2.2.2 Replacement of the Function Generator with the TI Board

- **PWM Connection:** Connect pin 01 of the Texas Instruments board to pin number 3 of the Gate Drive TPL250 for transmitting PWM signals.
- **Grounding:** Connect the GND of the Texas Instruments board to pin number 2 of the Gate Drive TPL250 to ensure a common ground reference.

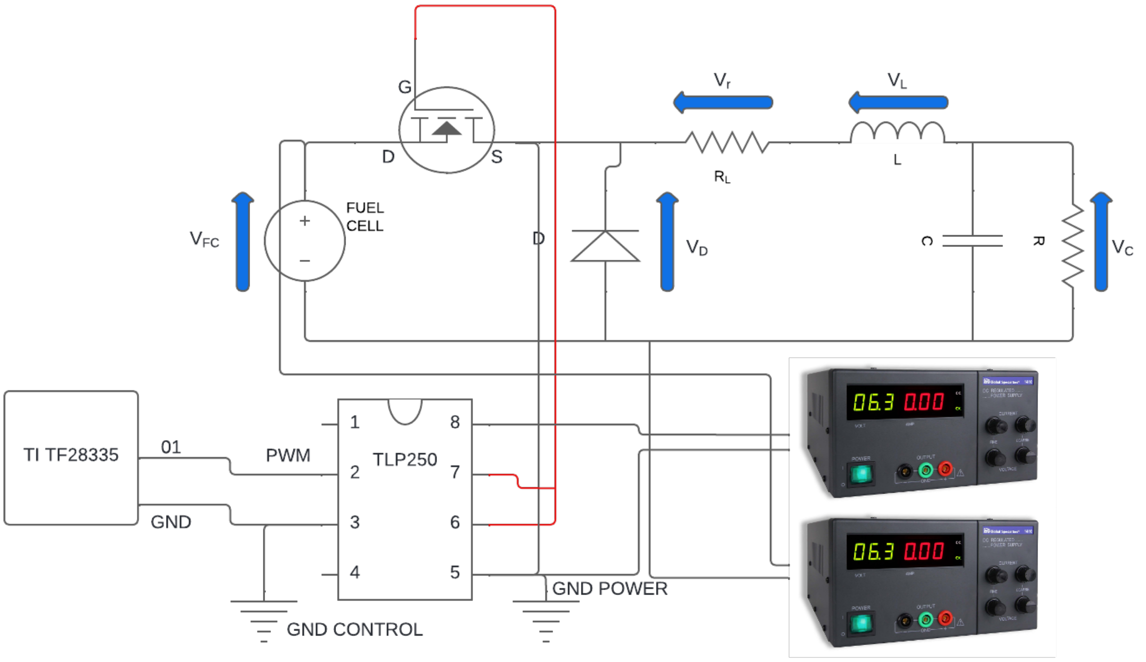


Figure 1: Connection of the TI TF28335 board with the TPL250

2.2.3 Confirmation of Existing Connections

- **Verification of Power Supplies:** Ensure that the power supplies (Power Supply) are still connected to the same points as in previous configurations (see LAB 9). One of the power supplies is connected to the Gate Drive TPL250 with a voltage of 15V, the other is connected to the Buck circuit with a voltage of 10V.
- **Positioning of the Multimeter:** Confirm that the multimeters are connected at the same measurement points to monitor the output voltage of the Buck circuit, as in previous experiments (see LAB 9). One multimeter is connected to the input voltage and the other to the output voltage, i.e., at the terminals of the load resistance.

2.2.4 Configuration Testing

- **Functionality Check:** Before starting the tests, ensure that replacing the function generator with the TI board has not affected the overall functionality of the circuit. Perform preliminary tests to verify that PWM signals are correctly generated and that the Buck circuit reacts as expected.

2.2.5 Tips for Configuration

- **Double Checking:** Recheck all connections to avoid potential errors that could occur due to the change in the PWM control device.
- **Documentation of Configuration:** Document all changes made during this phase to facilitate troubleshooting and future adjustments.

By following these guidelines for transition and configuration, participants will be prepared to experiment with the Texas Instruments board to control the Buck circuit, ensuring a smooth and effective transition of PWM control methods.

3 Tests with Fixed PWM

3.1 Generation of PWM Signals

This part of the practical work involves using MATLAB and Simulink to program and generate PWM signals from the Texas Instruments TF28335 board. Here are the detailed steps for setting up and executing the process.

3.1.1 Opening and Configuring Simulink

- **Gain Block**: Add a Gain block to adjust the amplitude of the PWM signal according to the needs of the Buck circuit, setting the value to "*0.5*".
- **Function Generator Block**: Integrate a Function Generator block to create a timing base for the PWM.
- **PWM Block**: Use a PWM block to generate the actual signal. Ensure that the block's settings are adjusted accordingly (refer to LAB 3).

You can refer to the provided image to confirm the settings and arrangement of the blocks.

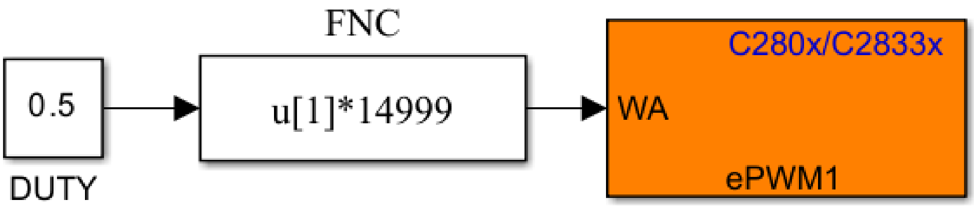


Figure 2: Block diagram of configurations for generating the PWM signal.

3.1.2 Downloading and Running on the TI Board

- **Loading the Program**: Connect the board to the computer via USB. Build, Deploy & Start your Simulink configuration on the Texas Instruments TF28335 board. This step is crucial to ensure that the microcontroller correctly executes the configured PWM signal.

3.1.3 Verification and Testing

- **Powering the Gate Drive TPL250**: Activate the Power Supply connected to the Gate Drive TPL250. Check all connections to avoid any short circuit or wiring errors. Set a voltage of 15V.
- **Oscilloscope Observation**: Connect the oscilloscope to monitor the output signals. This allows you to verify that the PWM signal generated matches the specifications defined in Simulink. You should see two signals; the one from channel 1 in yellow is the one you are sending from the TI board, and the other on channel 3 in pink corresponds to your signal transformed by the Gate Drive TPL250.

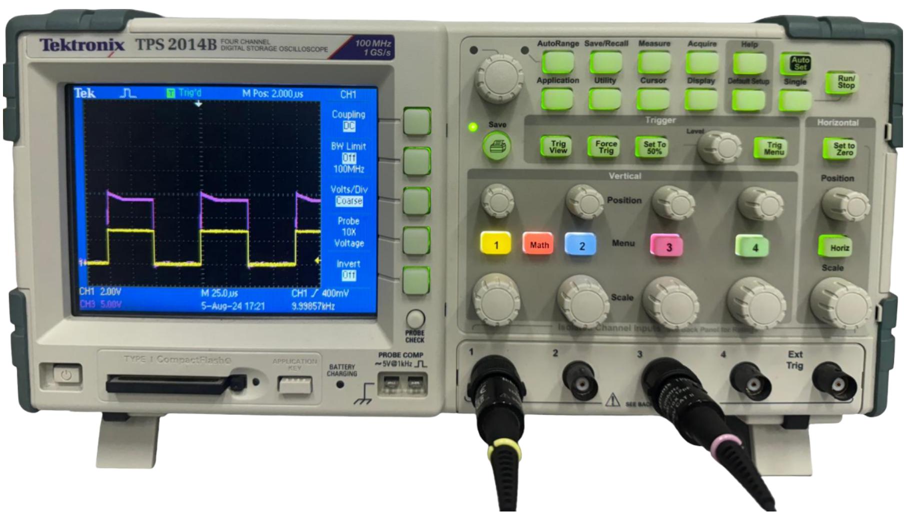


Figure 3: Signals observed on the oscilloscope.

- **Activating the Power Supply of the Buck Circuit**: After confirming the proper functioning of the PWM signal at the Gate Drive level, power up the Power Supply dedicated to the Buck circuit, with a voltage of 10V. This action is crucial to observe the efficiency of voltage modulation of the Buck circuit. For a Duty Cycle of 0.5, you should obtain the following values:

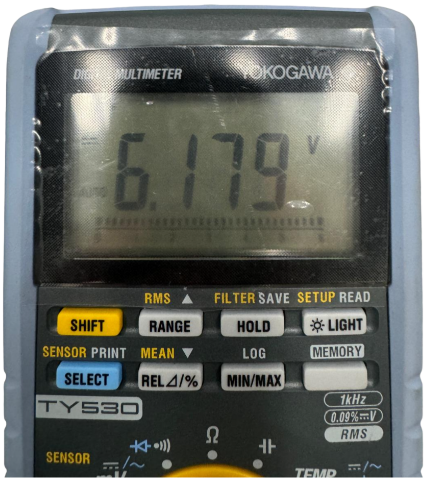


Figure 4: Measurement with a load resistance of 150 Ω

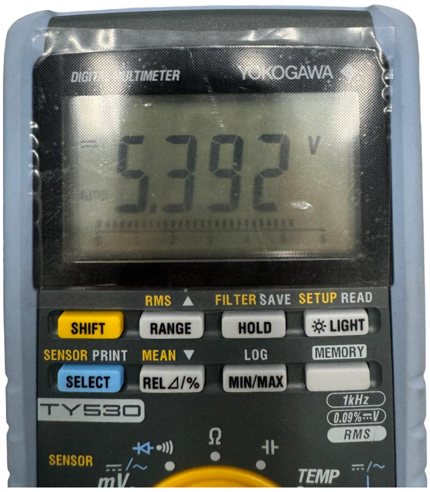


Figure 5: Measurement with a load resistance of 92 Ω

Figure 6: Output voltage measurements from the Boost circuit as displayed on the multimeter.

These detailed procedures guide you through the practical steps of configuration and verification of the functioning of key components, thus consolidating your theoretical knowledge into applied practice, especially in advanced PWM management with the Texas Instruments TF28335 board.

3.2 Measurements and Observations

3.2.1 Adjusting PWM Parameters

- **Modification via MATLAB**: Using the MATLAB script, gradually adjust the duty cycle of the PWM signal. Start at a low value of 0.1 and increase in increments up to 1.0, the maximum allowed.

- **Programming and Execution**: Load and execute the modifications in the MATLAB script for each new duty cycle value, ensuring to apply changes one by one to observe variations in the Buck circuit behavior and record the output value on the multimeter.

3.2.2 Data Compilation

- **Results Table**: Fill in the summary table with the adjusted duty cycle values and the corresponding output voltages measured with a multimeter connected to the load resistance of the Buck circuit.

- **Additional Experimentation**: Also vary the input voltage for each duty cycle and note the results. This second table will help to better understand the interaction between input voltage and duty cycle in regulating output voltage.

3.2.3 Theoretical vs Practical Analysis

- **Observation of Discrepancies**: Analyze the differences between the measured results and theoretical expectations. Discuss potential causes for discrepancies, such as inherent circuit losses, component limitations, or calibration errors of measurement instruments.

Discrepancy Observations and Explanations:

....
....
....

$V_{in}(V)$	**Duty Cycle (%)**	$V_{out}(V)$
10	10	...
10	20	...
10	30	...
10	40	...
10	50	...
10	60	...
10	70	...
10	80	...
10	90	...
10	100	...

Table 1: Table of values of Vin, Duty Cycle and V_{out}

$V_{in}(V)$	**Duty Cycle (%)**	$V_{out}(V)$
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...
...	...	...

Table 2: Table of values of Vin, Duty Cycle and V_{out}

- **Reflection on Results**: This analysis is crucial for assessing the efficiency of the Buck circuit and for identifying potential improvements in future configurations. Calculate the average of relative discrepancies, for this purpose.

  1. After taking several measurements of the output voltage, calculate the average of these values using the following formula:

  $$\text{Average of Voltages} = \frac{\sum_{i=1}^{n} \text{Voltage}_i}{n}$$

     Where:

     – Voltage_i is the i-th voltage measurement.
     – n is the total number of measurements taken.

  2. Once you have calculated the average of the voltages, use this value as the Measured Value in the formula for relative discrepancy:

  $$\text{Relative Discrepancy} = \left(\frac{\text{Average of Voltages} - \text{Theoretical Value}}{\text{Theoretical Value}}\right) \times 100\%$$

Enter your relative discrepancy with a minimum of detail:

....
....
....

Question: If the relative discrepancy between the measured voltage and the theoretical value is less than 10%, explain why this discrepancy can be considered normal and propose methods to decrease it. If the discrepancy exceeds 10%, identify and explain potential errors that could have caused this discrepancy. Use indicators such as component tolerance (e.g., capacitors at 10%) to support your response.

Response:

....

....

....

These measurements and analyses are fundamental for validating the capabilities of the TI board to effectively manage PWM in a real voltage conversion context, providing practical insights into the circuit behavior under different operating regimes.

4 Dynamic PWM Modulation

4.1 Integration of the Potentiometer

4.1.1 Modifying Code for Dynamic Control

- **Reference to Lab 4**: If you encounter any issues or are not familiar with the procedure, refer to the detailed instructions in Lab 4, where these steps have been thoroughly explored.
- **Configuration in Simulink**: In the Simulink environment, add an analog read block connected to a gain block. Link these blocks to the rest of your setup as shown in the figure below:

Figure 7: Simulink block diagram for dynamic PWM control via a potentiometer.

  - **ADC Block Settings**:

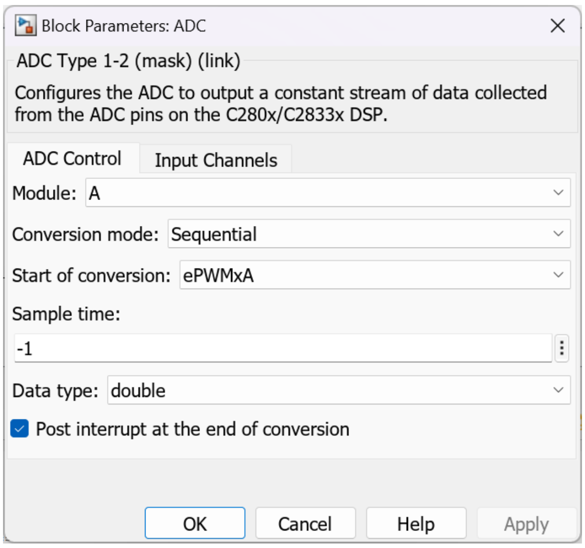


Figure 8: ADC control settings window.

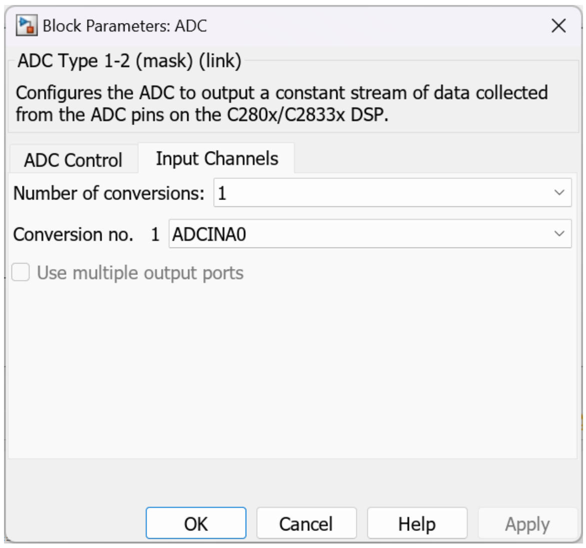


Figure 9: ADC input channels settings window.

  - **Gain Block Value**:

$$4095 \times \text{gain} = 1 \Rightarrow \text{gain} = \frac{1}{4095} \quad (1)$$

- **Calibration and Connection of the Potentiometer**:

   - **Connection**: Connect the leftmost wire of the potentiometer to the 3V3 pin of the board. Connect the middle wire to ADC0, and the rightmost wire to the board's ground (GND).

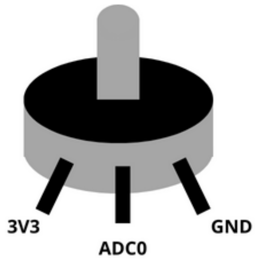


Figure 10: Potentiometer connection diagram.

   - **Calibration**: Ensure proper calibration of the potentiometer so that variations translate correctly into changes in the duty cycle. The output values from the potentiometer should be mapped to match the acceptable duty cycle limits from 0 to 1 (0% to 100%).

- **Test of Dynamic Control**:
   - **Test Initiation**: First, turn on the Power Supply of the Gate Drive TLP250 to 15V and observe on the oscilloscope if you are getting both signals: the one generated by the TI board and the one from the Gate Drive.
   - **Activation of the Buck Circuit**: Then turn on the second Power Supply for the Buck circuit, setting the voltage to 10V. Use a multimeter to verify if the observed voltages are consistent with theoretical expectations.
   - **Observations**: If the initial observations are consistent, you may proceed to more detailed measurements and analyze the effect of dynamic duty cycle adjustment on the performance of the Buck circuit.

These steps will not only validate the added functionality but also provide a rewarding practical experience by manipulating programmable aspects of the TI board in conjunction with user interface elements like the potentiometer.

4.2 Dynamic Tests

4.2.1 Using a Potentiometer for Duty Cycle Control

- **Role of the Potentiometer**: The potentiometer allows for analog adjustment of the PWM duty cycle, but does not provide a direct reading of the adjusted duty cycle.

4.2.2 Determining Duty Cycle via Oscilloscope

- **Oscilloscope Setup**:
   - **Channel Adjustment**: Use two channels on the oscilloscope, one to observe the PWM signal generated by the TI board and another to monitor the signal from the Gate Drive TLP250.
   - **Calibration**: Ensure the oscilloscope is calibrated to accurately measure the frequency and pulse width of the PWM signal.

- **Measuring the Duty Cycle**:
   - **Visualization**: Watch the waveform changes when the potentiometer is adjusted. Use the oscilloscope's measurement grid to determine the proportion of the signal that is high relative to the total cycle.
   - **Determining the Duty Cycle**: To calculate the duty cycle of a PWM signal from an oscilloscope capture, follow these steps:
      1. **Identify the Signal Period (T)**: This is the total time interval for a complete signal cycle.
      2. **Identify the High Time (T_{ON})**: This is the duration during which the signal is at its maximum level within a cycle.

The formula for duty cycle (D) is:

$$D = \left(\frac{T_{\text{ON}}}{T}\right) \times 100\%$$

Example from your oscilloscope capture:

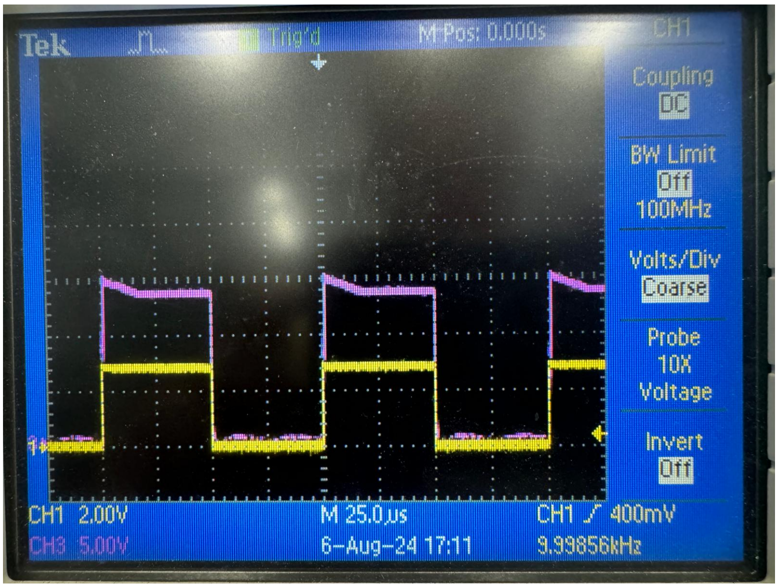


Figure 11: Oscilloscope capture showing the PWM signal. Channel 1 (yellow) represents the signal generated by the TI board, and Channel 3 (pink) shows the signal transformed by the Gate Drive TLP250.

* **Horizontal Scale (time per division)**: Each horizontal division appears to correspond to 25.0 microseconds (µs).
* **Pulse Width (T_{ON})**: From the photo, the signal appears high for about 2 divisions.
* **Total Period (T)**: The signal seems to repeat every 4 divisions.

Thus, calculate the duty cycle:

* T_{ON} = 50 µs (2 divisions)
* **T** = 100 µs (4 divisions)

$$D = \left(\frac{50\,\mu s}{100\,\mu s}\right) \times 100\% = 50\%$$

The duty cycle of this PWM signal is therefore 50%.

– **Documentation**: Record the potentiometer settings and the corresponding duty cycle measurements for future reference.

4.2.3 Measuring Output Voltage Based on Duty Cycle

- **Using a Multimeter**:
  – **Connection**: Connect the multimeter to the load resistance terminals to directly measure the output voltage.
  – **Documenting Results**: Record the measured voltages for different duty cycle values adjusted via the potentiometer.
- **Analysis and Correlation**:
  – **Data Table**: Create a table to compile the observed duty cycle values from the oscilloscope and the corresponding voltages measured on the multimeter.
  – **Interpretation of Data**: Analyze how changes in the duty cycle affect the output voltage, verifying the functionality of the Buck circuit under different loads.

Response:

....
....
....

$V_{in}(V)$	**Duty Cycle (%)**	$V_{out}(V)$
10	...	...
10	...	...
10	...	...
10	...	...
10	...	...
10	...	...
10	...	...
10	...	...
10	...	...

Table 3: Table of values of Vin, Duty Cycle and V_{out}

5 Conclusion

Au terme de ce travail pratique, nous avons évalué l'efficacité de la carte Texas Instruments TF28335 dans le contrôle du convertisseur Buck via la génération de signaux PWM. L'utilisation de la programmation MATLAB a permis une modulation précise du duty cycle, cruciale pour ajuster la tension de sortie en fonction des besoins théoriques. Bien que des écarts entre les valeurs théoriques et les résultats pratiques aient été observés, ces différences mettent en lumière l'importance des considérations pratiques telles que les résistances internes et les pertes inhérentes aux commutations.

Ce travail pratique a enrichi notre compréhension de la modulation de largeur d'impulsion (PWM) et de son influence directe sur les performances des circuits de conversion d'énergie. Pour l'avenir, il serait bénéfique d'explorer différentes configurations de cartes et de programmes pour optimiser davantage les performances et minimiser les pertes énergétiques. Des études plus approfondies pourraient également examiner l'impact des composants du circuit sur la fiabilité et l'efficacité des convertisseurs Buck, ouvrant ainsi la voie à des améliorations significatives dans la conception de systèmes d'alimentation robustes et efficaces.