Lab 10: Practical Experimentation with Boost Converters

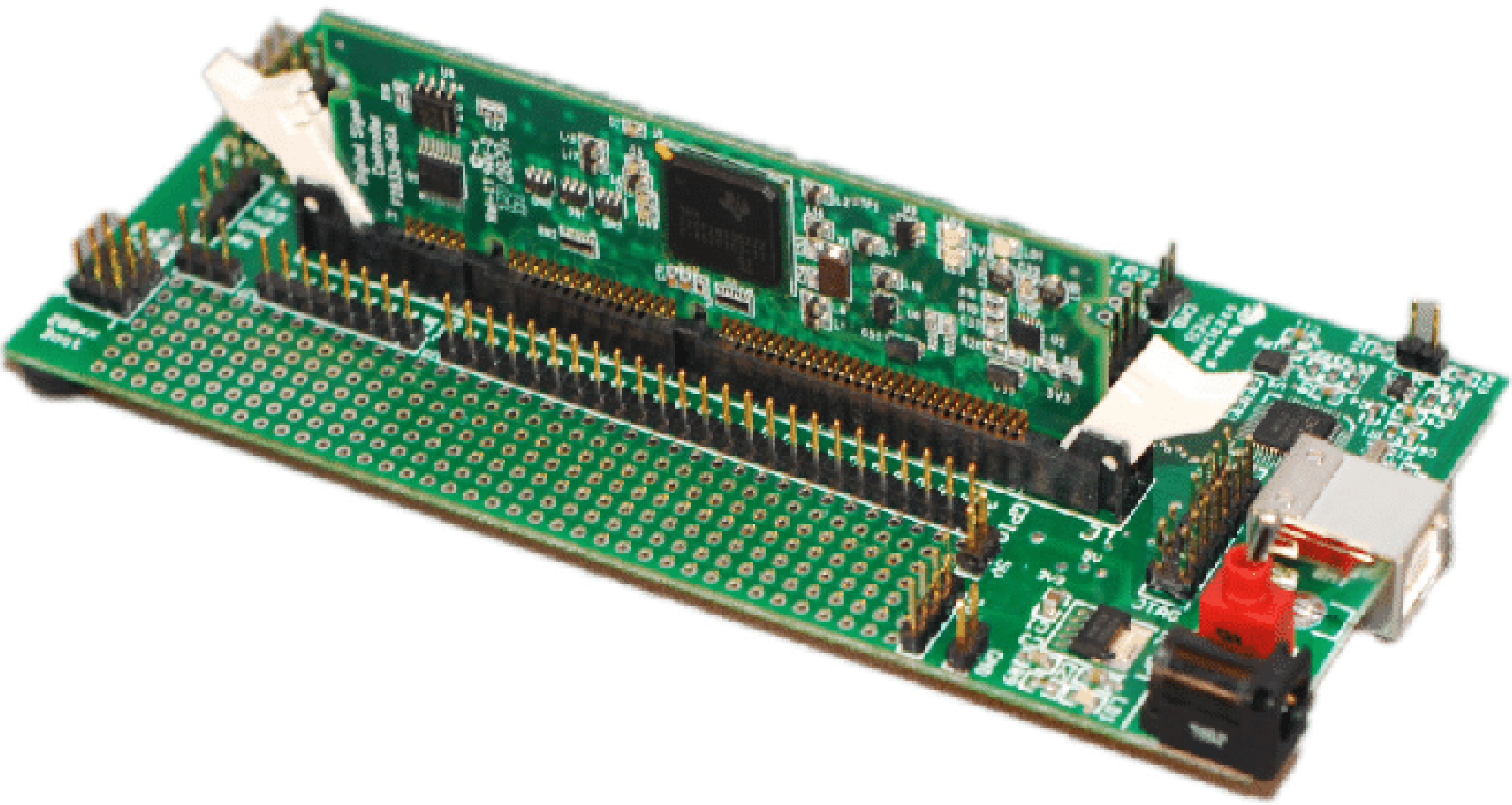
Mastery of PWM Modulation Techniques and Application of DC-DC Converters

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

1.1.1 Context and Review of Previous TPs

In previous practical sessions, 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 us understand how variations in duty cycle influence output voltage, which is essential for applications requiring precise power regulation.

1.1.2 Transition from Using a Function Generator to the TI Card

This practical session marks a significant evolution in our experimental approach: we are replacing the function generator with the Texas Instruments TF28335 board. This transition is driven 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 adjustment of these parameters based on circuit needs. This skill is crucial for the development of integrated solutions in the fields of power electronics and embedded systems, where customization and quick response to changing conditions are essential.

1.2 Objectives of the Practical Work

1.2.1 Using the TI Board to Generate PWM

One of the main 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 integrating TI technology into more complex power electronics applications.

1.2.2 Application on the Boost Circuit for Voltage Modulation

A secondary but equally important objective is to apply the PWM signal generated by the TI board to the Boost circuit to observe and analyze the effects of modulation on the output voltage. Students will verify the ability of the Boost circuit to lower the voltage based on variations in the duty cycle of the PWM. This process includes not only verifying 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 enhance understanding of the links between electronic theory and its practical application, highlighting the challenges and considerations necessary when designing effective electronic systems.

2 Initial Setup

2.1 Review of Previous Configurations

This section refers to the skills and knowledge already developed in previous modules concerning the programming of the Texas Instruments TF28335 board. For those wishing to deepen their understanding or review the board configurations in detail, it is recommended to consult the practical work 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 lab, we assume that participants already master these aspects and are ready to apply this knowledge to the control of the Boost circuit.

2.2 Installation and Configuration

This section guides participants through the steps of setting up and configuring necessary to integrate the Texas Instruments TF28335 board into the existing Boost circuit. Previous configurations, explained in Lab 8, will serve as a foundation for this transition from the function generator to the TI board.

2.2.1 Review of the Boost Circuit Assembly

Participants should refer to Lab 8 to review the details of the assembly and connections of the Boost circuit components. This review ensures that all necessary elements are correctly aligned for this experiment.

2.2.2 Replacing the Function Generator with the TI Board

- **PWM Connection**: Connect pin 01 of the Texas Instruments board to pin number 3 of the TPL250 Gate Drive for the transmission of 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.

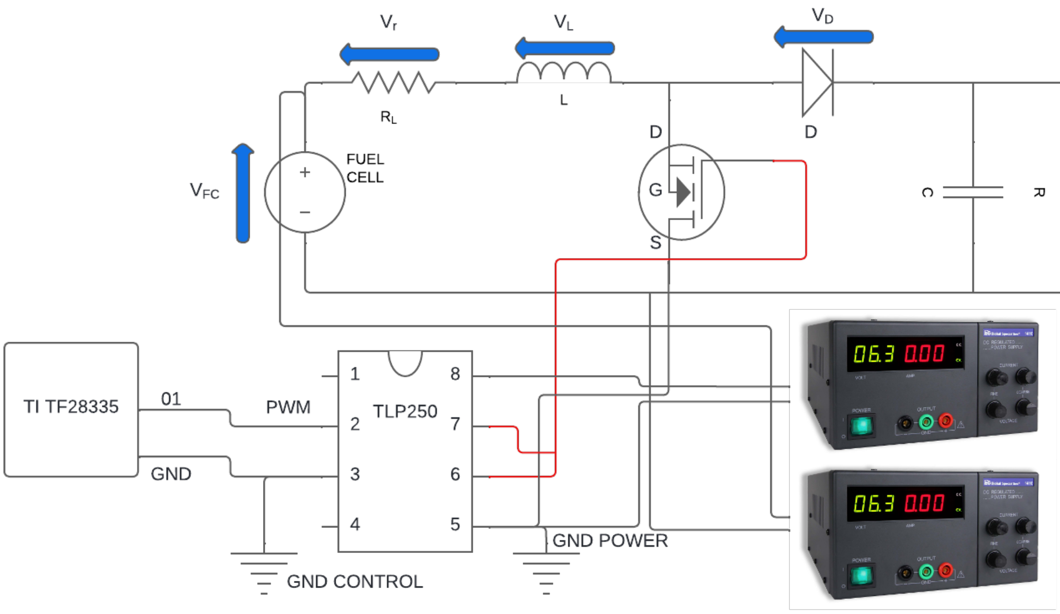


Figure 1: Connecting the TI TF28335 board with the TPL250

2.2.3 Confirmation of Existing Connections

- **Power Supply Verification**: Ensure that the power supplies (Power Supply) are still connected at the same points as in previous configurations (see LAB 8). One of the power supplies is connected to the Gate Drive TPL250 at 15V, the other is connected to the Boost circuit at 10V.
- **Multimeter Positioning**: Confirm that the multimeters are connected at the same measurement points to monitor the output voltage of the Boost circuit, as in previous experiments (see LAB 8). 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 Verification**: Before starting the tests, make sure that replacing the function generator with the TI board has not affected the overall functionality of the circuit. Perform preliminary tests to verify that the PWM signals are correctly generated and that the Boost circuit reacts as expected.

2.2.5 Configuration Tips

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

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

3 Tests with Fixed PWM

3.1 Generation of PWM Signals

For this part of the lab, we will use MATLAB and Simulink to program and generate PWM signals from the Texas Instruments TF28335 board. Here are the detailed steps to set up and execute 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 Boost circuit, here we will set the value to "*0.5*".
- **Function Block**: Incorporate a Function Generator block to create a time base for the PWM.
- **PWM Block**: Use a PWM block to generate the actual signal. Ensure that the block's parameters are set accordingly (see LAB 3).

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

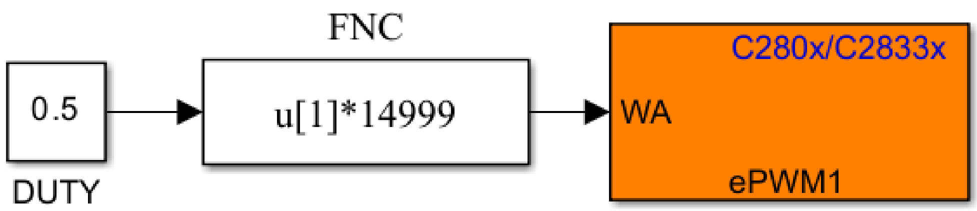


Figure 2: Block diagram of configurations for PWM signal generation.

3.1.2 Downloading and Executing on the TI Board

- **Program Loading**: 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 TPL250 Gate Drive**: Turn on the Power Supply connected to the TPL250 Gate Drive. Check all connections to avoid any short circuits or wiring errors. Set a voltage of 15V.
- **Oscilloscopic Observation**: Connect an 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 as shown in the image below, the one from channel 1 in yellow is the one you send from the TI board, and the other on channel 3 in pink corresponds to your signal transformed by the Gate Drive TPL250.

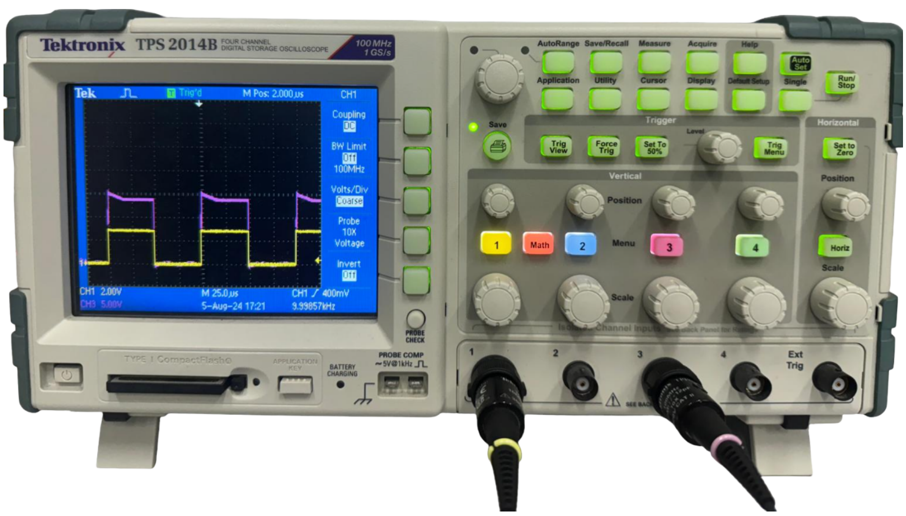


Figure 3: Signals observed on the oscilloscope.

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

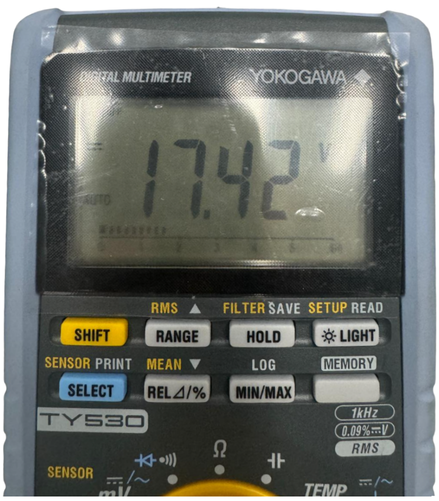


Figure 4: Measurement with a load resistance of 150 Ω

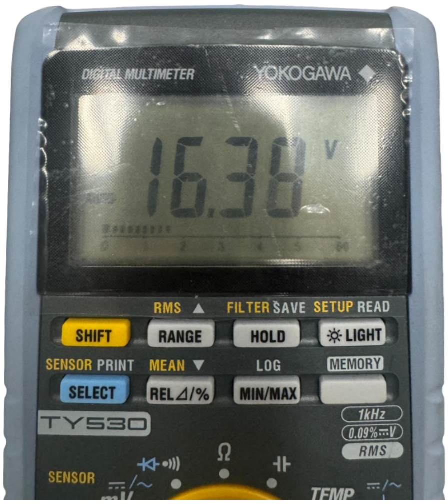


Figure 5: Measurement with a load resistance of 92 Ω

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

These detailed procedures guide you through the practical steps of setting up and verifying the operation 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**: Use the MATLAB script to gradually adjust the duty cycle of the PWM signal. Start with 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, making sure to apply the changes one at a time to observe variations in the behavior of the Buck circuit 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 corresponding output voltages measured with a multimeter connected to the load resistance of the Buck circuit.
- **Additional Experimentation**: Also modify 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.

Theoretical vs. Practical Analysis

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

Observations of Discrepancies 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 evaluating the effectiveness of the Buck circuit and identifying potential improvements for future setups. Calculate the average of relative discrepancies, to do this:
  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 voltages, use this value as the Measured Value in the formula for relative discrepancy:
  $$\text{Relative Discrepancy} = \left(\frac{\text{Average of Voltages} - \text{Theoretical Value}}{\text{Theoretical Value}}\right) \times 100\%$$

Write 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 reduce it. If the discrepancy exceeds 10%, identify and explain potential errors that could have caused this discrepancy. Use hints such as component tolerance (e.g., 10% capacitors) to support your answer.

Response:

....

....

....

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

4 Dynamic PWM Modulation

4.1 Integration of the Potentiometer

4.1.1 Code Modification for Dynamic Control

- **Reference to Lab 4**: If you encounter any issues or if the concept is not mastered, refer to the detailed instructions in Lab 4, where these steps were explored in depth.
- **Configuration in Simulink**: In the Simulink environment, add an Analog Read block connected to a Gain block. Connect these blocks to the rest. You should have this setup:

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

  - **ADC Block Parameters**:

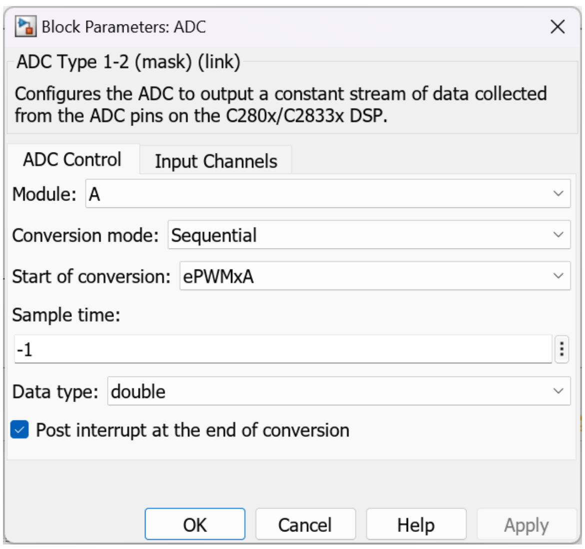


Figure 8: ADC control settings window.

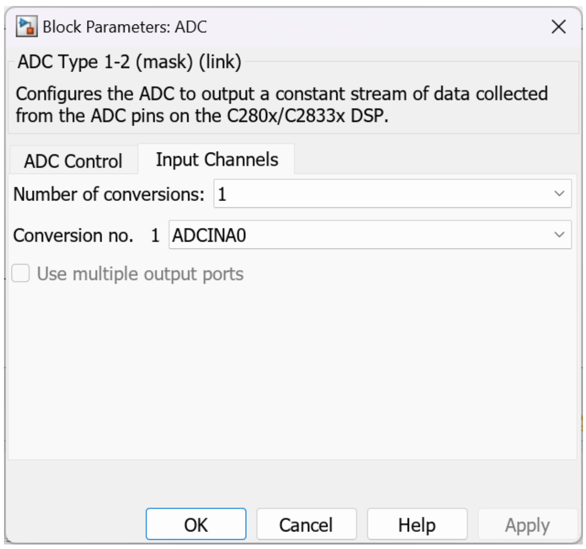


Figure 9: ADC input channels settings window.

  - **Gain Block Value**:

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

- **Calibration and Wiring of the Potentiometer**:
  - **Wiring**: Connect the leftmost wire of the potentiometer to the 3V3 pin of the board. Connect the middle wire to ADC0, and the right wire to the ground (GND) of the board.

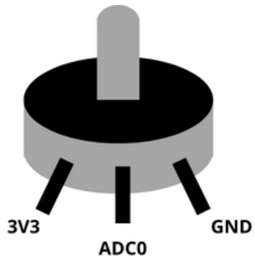


Figure 10: Potentiometer Connection

- **Calibration**: Ensure the potentiometer is properly calibrated so that variations are accurately translated into duty cycle adjustments. The output values from the potentiometer should be mapped to match acceptable duty cycle limits from 0 to 1 (0% to 100%).

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

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

4.2 Dynamic Tests

4.2.1 Using the Potentiometer for Duty Cycle Control

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

4.2.2 Determining the Duty Cycle via an Oscilloscope

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

- **Measuring the Duty Cycle**:
  - **Visualization**: Watch the waveform changes as 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.
  - **Duty Cycle Calculation**: To calculate the duty cycle of a PWM signal from an oscilloscope capture, follow these steps:
    1. **Identify the total period of the signal (T)**: This is the total time interval for one complete cycle of the signal.
    2. **Identify the high state time (T_{ON})**: This is the duration that the signal remains at its maximum level within one cycle.

    The duty cycle (D) formula is:

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

    Example from your oscilloscope capture:

    * **Horizontal scale (time per division)**: Each horizontal division appears to correspond to 25.0 microseconds (µs).

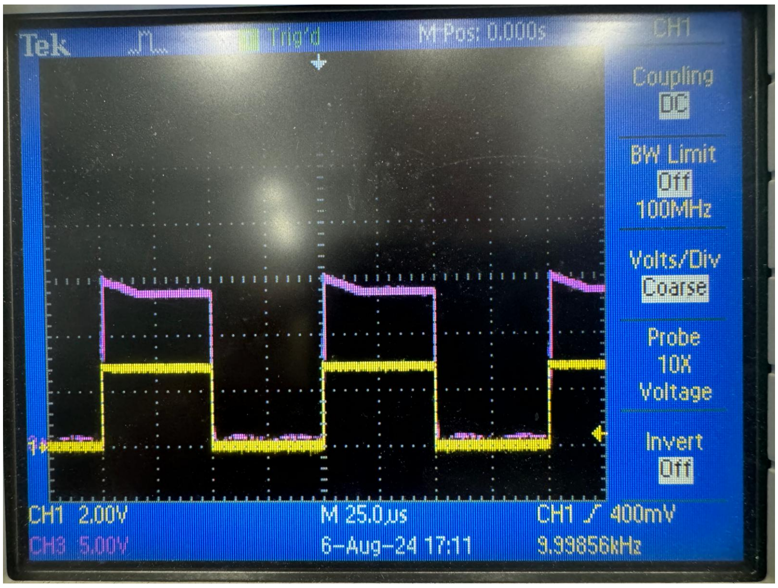


Figure 11: Oscilloscope capture showing the PWM signal. Channel 1 (yellow) represents the signal generated by the TI board, and channel 3 (pink) shows the signal processed by the Gate Drive TLP250.

∗ **Pulse width ($\mathbf{T}_{ON}$)** : $Fromthephoto, thesignalhighappearstolastabout2divisions.$**Total period (T)** : $Thesignalappearstorepeatevery4divisions.$
  Thus, calculate the duty cycle:

∗ $\mathbf{T}_{ON} = 50s(2divisions)\mathbf{T} = 100s(4divisions)$

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

  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 Relative to Duty Cycle

- **Using a Multimeter**:
  - **Connection**: Connect the multimeter to the terminals of the load resistor to measure the output voltage directly.
  - **Recording Results**: Record the voltages measured for different duty cycle values adjusted via the potentiometer.
- **Analysis and Correlation**:
  - **Data Table**: Create a table to compile the duty cycle values observed on the oscilloscope and the corresponding voltages measured by the multimeter.

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

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

– **Data Interpretation**: Analyze how changes in the duty cycle affect the output voltage, validating the functionality of the Boost circuit under different loads.

Response:

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

5 Conclusion

At the conclusion of this practical session, we have been able to assess the effectiveness of the Texas Instruments TF28335 board in controlling the Boost Converter through the generation of PWM signals. The integration of MATLAB programming enabled precise modulation of the duty cycle, crucial for adjusting the output voltage according to theoretical needs. Although discrepancies were observed between theoretical values and practical results, these differences underscore the importance of practical considerations such as internal resistances and inherent losses due to switching.

This work has enriched our understanding of pulse width modulation and its direct influence on the performance of energy conversion circuits. For the future, it would be beneficial to explore different board configurations and programs to further optimize performance and reduce energy losses. Further studies could also focus on the impact of circuit components on the reliability and efficiency of Boost Converters, paving the way for significant improvements in the design of robust and efficient power systems.