

From Duty Cycle to Glow: Understanding PWM Brightness Control

Case Study

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1. Overview

Short description: This **Case Study** introduces the fundamental principles of Pulse Width Modulation (PWM) and its application in LED brightness control. Step-by-step instructions explain how to generate a PWM signal using the Analog Discovery Product Line ([AD3](#) or [AD Studio](#) / [Studio MAX](#), hereafter referred to as **Device**) and apply it to control the perceived brightness of a LED. The **Case Study** utilizes the Waveform Generator and Oscilloscope instruments in Digilent [WaveForms software](#), as well as NI LabVIEW with the WaveForms Toolkit, to analyze the relationship between duty cycle and LED brightness.

Objectives

- Understand the operating principle of Pulse Width Modulation (PWM)
- Analyze the effect of duty cycle variation on the LED brightness
- Configure PWM signal generation using Digilent devices
- Observe and measure PWM waveforms using an oscilloscope
- Visualize and analyze PWM-controlled brightness in NI LabVIEW

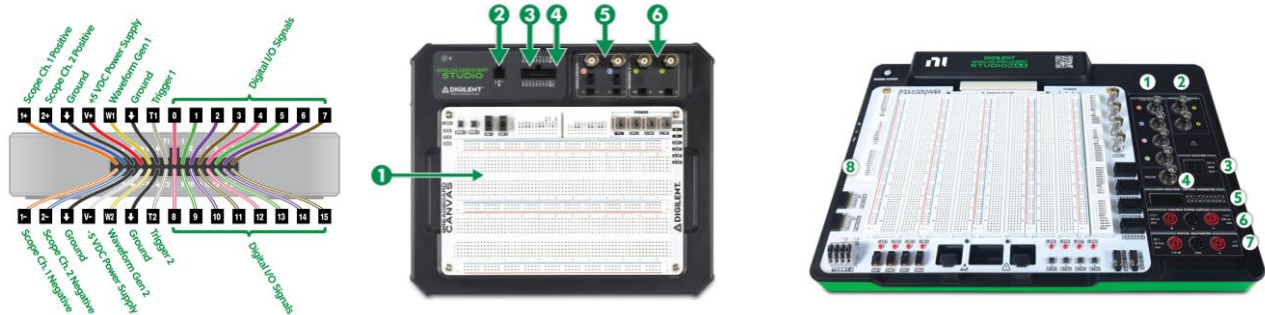
Software & Hardware Requirements

Software		Version
<u>Digilent WaveForms</u> (Runtime + SDK)		Latest (64-bit)
NI LabVIEW		2025 64-bit
WaveForms Toolkit for LabVIEW		Latest
Hardware		Quantity*
Digilent Analog Discovery Product Line		
Option 1	<u>Digilent Analog Discovery 3</u>	1
Option 2	<u>Digilent Analog Discovery Studio</u>	1
Option 3	<u>Digilent Analog Discovery Studio MAX</u>	1
List of Components		Quantity*
Canvas Breadboard		1
LED (5mm, 2-2.5V)		1
Resistor 220 Ω		1
Jumper wires		-
BNC to BNC cable ¹		1

¹ BNC cable required only for the Analog Discovery Studio MAX.

2. Hardware Setup

This section describes the **Digilent Analog Discovery Product Line** hardware setup for **Case studies**. Before assembling the measurement circuit, it is essential to understand the pinout and available connections of the **Devices**. **Figure 1** highlights the pinouts and instrumentations of the Digilent Analog Discovery product line.²



a. Analog Discovery 3

- Power Supplies
- Logic Analyzer and Pattern Generator
- Triggers
- Oscilloscope Waveform Generator

b. Analog Discovery Studio

1. Breadboard Canvas
2. Power Supplies
3. Logic Analyzer and Pattern Generator
4. Triggers
5. Oscilloscope
6. Waveform Generator

c. Analog Discovery Studio MAX

1. Oscilloscope
2. Waveform Generator
3. IV Analyzer
4. Trigger
5. Logic Analyzer and Pattern Generator
6. Variable Power Supplies
7. Digital Multimeter
8. Breadboard Canvas

Figure 1. Digilent Analog Discovery Products Pinout and Instrumentations

Table 1 provides a common reference for physical channels' names across the **Digilent Analog Discovery product line**. The **Case studies** are designed to work with all supported devices, so the generic channels' names shown in the first row are used consistently in all circuit diagrams and wiring instructions. **Table 1** provides a common reference for the physical connections used in PWM-based LED brightness control experiments. Only the **Waveform Generator** output and **Oscilloscope Channel 1** are required for this **Case Study**.

² For detailed electrical specifications, pin descriptions, and operating limits, always refer to the official datasheets of each device (Analog Discovery 3, Analog Discovery Studio, and Analog Discovery Studio MAX). The latest datasheets are available on the Digilent website:

- [Analog Discovery 3](#)
- [Analog Discovery Studio](#)
- [Analog Discovery Studio MAX](#)

Table 2 provides a common reference for device names and instrument identifiers used in NI LabVIEW with the WaveForms Toolkit across the **Digilent Analog Discovery product line**. The Case studies are designed to work with all supported devices; therefore, **Table 2** lists the device names and instrument identifiers used in NI LabVIEW with the WaveForms Toolkit for PWM signal generation and measurement.

Table 1 Physical Channels Mapping for Digilent Analog Discovery Devices

<i>Channel Device</i>	<i>Scope Ch.1 Positive</i>	<i>Scope Ch.1 Negative (GND)</i>	<i>Wavegen Output (W1)</i>	<i>GND</i>
AD 3	Scope Ch.1 Positive (Pin 1+)	Scope Ch.1 Negative (Pin 1-)	Wavegen 1 (W1)	GND Pin
AD Studio ³	OSCILLOSCOPE 1 (+)	OSCILLOSCOPE 1 (-)	Wavegen 1 (W1)	GND Pin
AD Studio MAX ³	OSCILLOSCOPE 1 (BNC +)	OSCILLOSCOPE 1 (BNC -)	Wavegen 1 (BNC W1)	GND Pin

Table 2 Device Names and Instruments Identifiers in NI LabVIEW (WaveForms Toolkit)

<i>Identifier Device</i>	<i>Device name</i>	<i>Scope Ch.1</i>	<i>FGEN Channel</i>
AD 3	Discovery3	mso/1	fgen/1
AD Studio ³	DiscoveryStudio		
AD Studio MAX ³	ADS_Max		

³ For the Analog Discovery Studio and Analog Discovery Studio MAX, ensure the devices are powered by turning ON the main power switch before use.

3. Background Information

Pulse Width Modulation (PWM) is a digital signal modulation technique used to control analog quantities such as voltage, power, and brightness. Instead of varying the amplitude of the signal, PWM controls the average power delivered to a load by adjusting the ratio between the ON time and the OFF time of a periodic digital signal.

The **duty cycle** is defined as:

$$\text{Duty Cycle (\%)} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100$$

For LED brightness control:

- Low duty cycle → LED is ON for a short time → low perceived brightness
- High duty cycle → LED is ON for a longer time → high perceived brightness

Due to the persistence of human vision, rapid ON–OFF switching at sufficiently high frequency results in smooth brightness perception rather than visible flickering.

Note: The perceived LED brightness is not perfectly linear with duty cycle due to human visual perception.

4. Circuit Design – step by step instructions

4.1 Description

The circuit consists of a LED connected in series with a current-limiting resistor. The LED is driven by a **PWM** signal generated by the Device Waveform Generator. The duty cycle of the PWM signal determines the average current flowing through the LED, thereby controlling its brightness.

Important! Refer to **Table 1** to determine the exact physical pin, connector, or cable corresponding to each generic connection on the specific Digilent Analog Discovery device being used.

4.2 Step by step instructions⁴

1. Place the LED on the Canvas breadboard⁵, ensuring correct polarity (anode and cathode in separate rows).
2. Connect the anode of the LED to the Waveform Generator output (**W1**).
3. Connect the cathode of the LED to one terminal of the 220 Ω resistor. A current-limiting resistor is required to protect the LED from excessive current.
4. Connect the other terminal of the resistor to the **Device GND**.

⁴ Given on Figure 2.

⁵ Use external breadboard in the case of Analog Discovery 3.

5. Connect **Scope Ch.1 Positive** to the LED anode (PWM signal node).
6. Connect **Scope Ch.1 Negative** to GND.

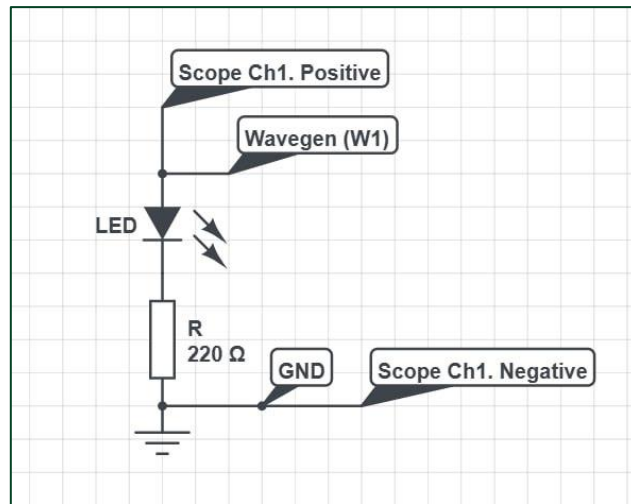
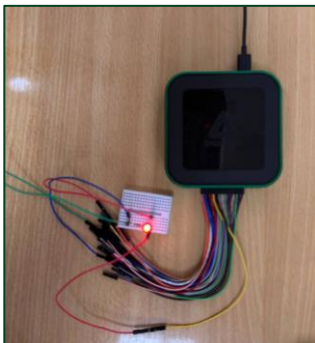


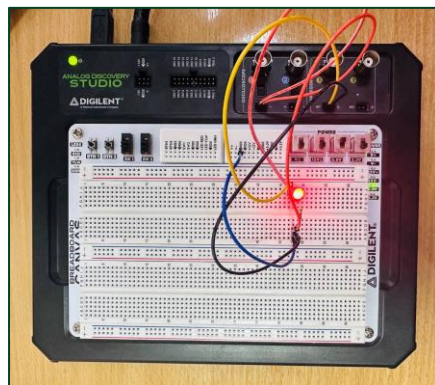
Figure 2. Assembled PWM LED Brightness Control Circuit

4.3 Assembled Circuit

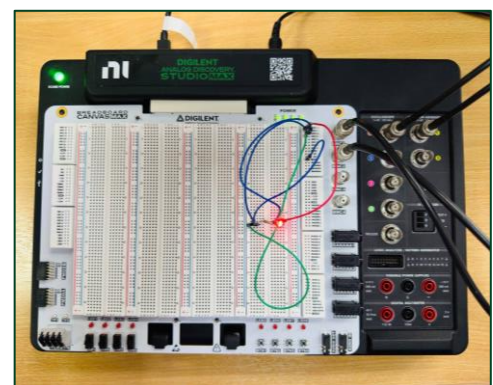
Figure 3 presents complete experimental circuits on different Digilent devices.



a. Analog Discovery 3



b. Analog Discovery Studio



c. Analog Discovery Studio MAX

Figure 3. Assembled circuits for different Devices

5. Software Setup - step by step instructions

5.1 Data Visualization and Analysis in Waveforms

Step 1. Launch WaveForms and connect the device

- 1.1. Connect the **Device** to the computer via USB.
- 1.2. Open the **Digilent WaveForms** software.
- 1.3. Verify that the **Device** is detected and shown as *Currently Selected* in the **Device Manager** (Settings -> Device Manager).

Step 2. Configure the PWM signal using the WaveForms Generator

- 2.1. Open the **Wavegen** instrument in **WaveForms**.
- 2.2. Select **Channel 1 (W1)**.
- 2.3. Set the signal type to **Pulse**.
- 2.4. Configure the signal parameters as follows:
 - Frequency: **100 Hz**
 - Amplitude: **5.0 V**
 - Offset: **0 V**
 - Symmetry (Duty Cycle): **50 %** (initial value)
- 2.5. Enable the output channel to generate the **PWM** signal.
- 2.6. Gradually increase and then decrease the **Symmetry** parameter of the **Wavegen** to observe the resulting changes.

Figure 4 shows the configuration of the PWM signal using the Waveform Generator in Digilent WaveForms. The square waveform represents a PWM signal whose duty cycle controls the ON and OFF duration of the LED.

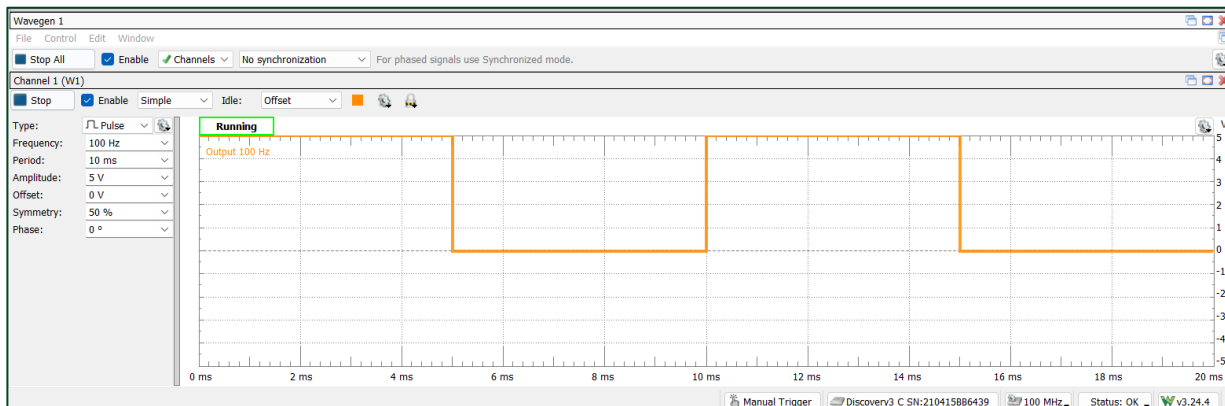


Figure 4. PWM Signal Configuration in WaveForms Waveform Generator

Step 3. Observe the PWM signal using the Oscilloscope

- 3.1. Open the **Scope** instrument on WaveForms.
- 3.2. Enable **Channel 1**.
- 3.3. Adjust the vertical range to **2 V/div**.
- 3.4. Adjust the time base to **5 ms/div** to clearly observe the PWM waveform.
- 3.5. Observe the square waveform corresponding to the generated PWM signal.

Figure 5 shows the PWM signal acquired using the WaveForms Oscilloscope. The waveform illustrates the relationship between ON time, OFF time, and duty cycle.

Note: During the experiment, the duty cycle of the PWM signal is manually adjusted to observe changes in LED brightness.

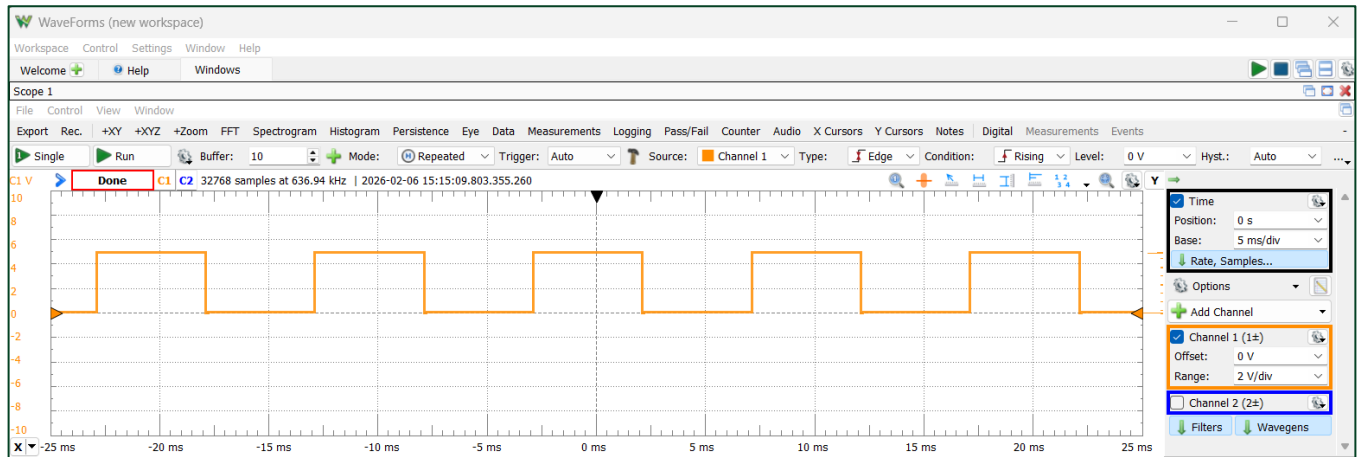


Figure 5. PWM Waveform Observed Using WaveForms Oscilloscope

Step 4. Adjust duty cycle and observe LED brightness

- 4.1. Gradually change the **Symmetry (Duty Cycle)** parameter in the Wavegen settings.
- 4.2. Observe the LED brightness while increasing and decreasing the duty cycle.
- 4.3. Note that:
 - Lower duty cycle results in reduced LED brightness.
 - Higher duty cycle results in increased LED brightness.

Note: Due to the persistence of human vision, the LED appears to change brightness smoothly even though it is rapidly switching ON and OFF.

5.2 PWM Control and Analysis Using NI LabVIEW WaveForms Toolkit

Step 1. Launch NI LabVIEW and connect the Device

- 1.1. Connect the **Device** to the computer via USB.
- 1.2. Open **Digilent Waveforms** and verify that **Device** is detected and shown as *Currently Selected* in the **Device Manager** (Settings -> Device Manager), then close **Digilent Waveforms** software⁶.
- 1.3. Open the **NI LabVIEW** software.
- 1.4. Create a new NI LabVIEW VI (**File->New VI**)

Step 2. Create Block Diagram and Front Panel in NI LabVIEW

- 2.1. Modify the block diagram as shown in **Figure 6**.

⁶ Before running NI LabVIEW, please ensure that the Digilent WaveForms software is closed.

Figure 6 shows the LabVIEW block diagram code applicable to Analog Discovery 3, Analog Discovery Studio and Analog Discovery Studio MAX devices.

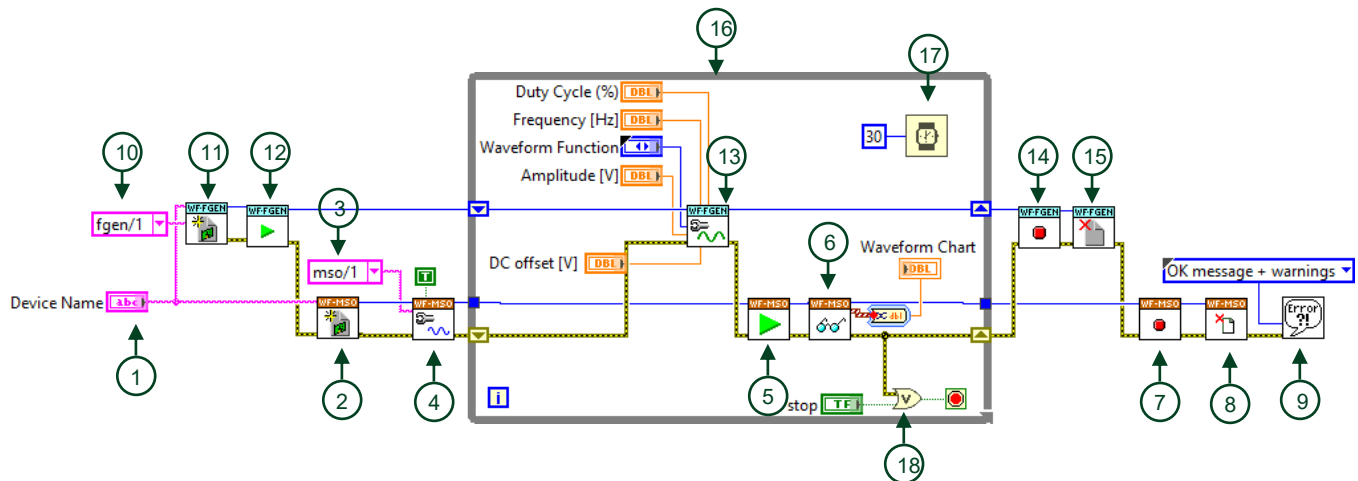


Figure 6 VI Block Diagram for AD3, ADS and ADS MAX

1. **Device Name** - specify the name of your **Device**. Use **Table 2** for your **Device**.
2. **WF-MSO Initialize** - this VI initializes the scope.
3. **Scope Channel** - specify your **Device Scope Ch.1** channel. Use **Table 2** for your **Device**.
4. **WF-MSO Configure Analog Channel** - this VI configures the settings for the measurement channel. Connect Enable Channel to True constant.
5. **WF-MSO Run** - Run the acquisition.
6. **WF-MSO Read** - Transfer data from the **Device** to NI LabVIEW. **Analog Waveforms** output connected to **Convert to Dynamic Data** function then to **Waveform Chart** to visualize the measured data.
7. **WF-MSO Stop** - Stop the acquisition and halt oscilloscope operation.
8. **WF-MSO Close** - Remove the session and reset all values for scope.
9. **Simple Error Handler VI** - Detect and report errors by returning a descriptive error message and optionally displaying an error dialog.
10. **WF-FGEN Channel** - specify your **Device Wavegen** channel. Use **Table 2** for your **Device**. Specify a single waveform generator channel to initialize (e.g., fgen/1).
11. **WF-FGEN Initialize** - Initialize the waveform generator session.
12. **WF-FGEN Run** - start waveform generation on the configured waveform generator channel.
13. **WF-FGEN Configure Standard Waveform** - configure standard waveform parameters for the waveform generator output. Configures the PWM signal parameters (square wave, frequency, duty cycle).
14. **WF-FGEN Stop** - stop the waveform generator output.
15. **WF-FGEN Close** - Remove the waveform generator session and reset its configuration.
16. **While Loop** - used to enable continuous data acquisition.
17. **Wait (ms)** - connect it to an integer constant and set the value to 30 ms.
18. **OR** - Allow the code to stop using the **Stop** button or automatically when an error occurs.

- 2.2. Modify the front panel shown in **Figure 7**. Inside **Device name** String Control write your corresponding **Device** name from **Table 2**.
- 2.3. Save the VI.

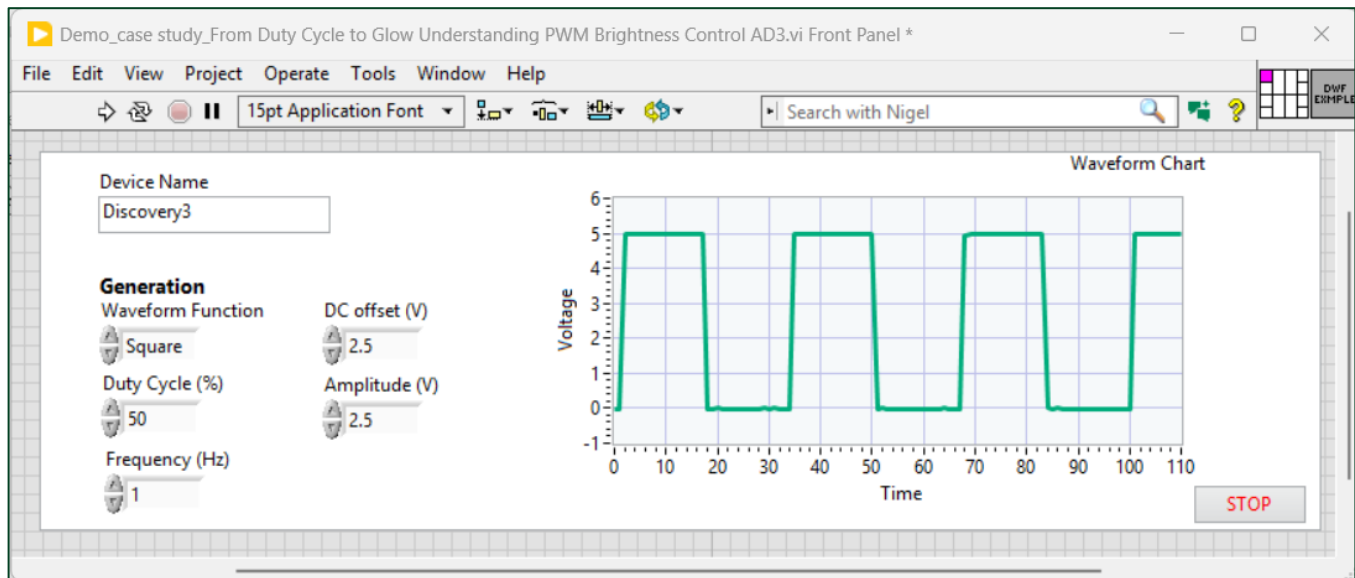


Figure 7. VI Front Panel

Step 3. Configure PWM control from the Front Panel

- 3.1. Add a **Numeric Control** or **Slider** on the Front Panel for duty cycle adjustment.
- 3.2. Set the duty cycle range from **0 % to 100 %**.
- 3.3. Connect the duty cycle control to the **WF-Wavegen Configure** function.
- 3.4. Add a **Waveform Chart** to visualize the PWM signal (Square signal) in real time.

Step 4. Run the code and do measurements in LabVIEW

- 4.1. Run the code by clicking on the **Run button**.
- 4.2. Adjust the duty cycle control on the Front Panel.
- 4.3. Observe:
 - Changes in PWM waveform duty cycle on the Waveform Chart.
 - Corresponding changes in LED brightness.