

RGB LED Color Mixing

Case Study

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1. Overview

Short description: This **Case Study** introduces the practical use of **Pulse Width Modulation (PWM)** for controlling an RGB LED. By using **W1**, **W2**, and **V+** output configurations, the brightness of the red, green, and blue channels can be adjusted separately. Through this method, a wide range of colors can be produced using additive color mixing principles.

The Case Study utilizes the **Digilent Analog Discovery Product Line (AD3 / AD Studio / AD Studio MAX)** together with **WaveForms** and **NI LabVIEW** to generate PWM signals, visualize waveforms, and implement real-time color control.

Objectives

- Understand the internal structure and operation of RGB LEDs
- Learn the principle of Pulse Width Modulation (PWM)
- Control LED brightness using duty cycle variation
- Explore additive color mixing using red, green, and blue channels
- Observe PWM-based LED brightness and output behavior
- Build a real-time RGB controller in NI LabVIEW
- Connect digital signal generation with physical output behavior

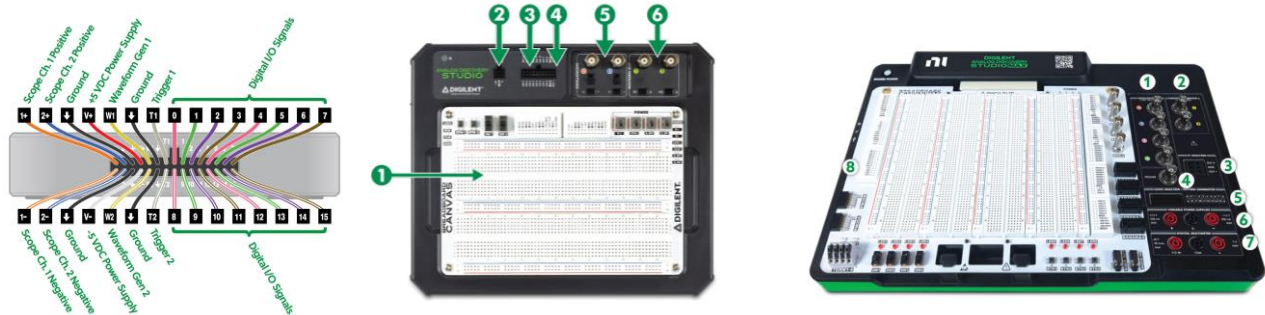
Software & Hardware Requirements

Software		Version
Digilent WaveForms (Runtime + SDK)		Latest (64-bit)
NI LabVIEW		2025 64-bit
WaveForms Toolkit for LabVIEW		Latest
Hardware		Quantity*
Digilent Analog Discovery Product Line		
Option 1	Digilent Analog Discovery 3	1
Option 2	Digilent Analog Discovery Studio	1
Option 3	Digilent Analog Discovery Studio MAX	1
List of Components		Quantity*
Canvas Breadboard		1
RGB LED (Common Cathode) ¹		1
Resistor 220 Ω		3
Jumper wires		-

¹ The RGB LED provides visual indication of color mixing and brightness variation during the experiment.

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. The experiment uses multiple available outputs, including **Wavegen (W1)**, **Wavegen (W2)**, **V+ configured output**, and common **GND** connections.

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 RGB LED control.

Table 1 Physical Channels Mapping for Digilent Analog Discovery Devices

<i>Channel Device</i>	<i>Wavegen Output (W1)</i>	<i>Wavegen Output (W2)</i>	<i>+V</i>	<i>GND</i>
AD 3	Wavegen 1 (W1)	Wavegen 2 (W2)	+VDC Power Supply (Pin V+)	GND Pin
AD Studio ³	Wavegen 1 (W1)	Wavegen 2 (W2)	+5.0V (on canvas board)	GND Pin
AD Studio MAX ³	Wavegen 1 (BNC W1)	Wavegen 2 (BNC W2)	+5.0V (on canvas board)	GND Pin

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

<i>Identifier Device</i>	<i>Device name</i>	<i>FGEN Channel Wavegen Ch.1</i>	<i>FGEN Channel Wavegen Ch.2</i>	<i>PS V+ Output</i>
AD 3	Discovery3	fgen/1	fgen/2	ps/+
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

RGB LED Principle

An RGB LED contains three separate light-emitting diodes inside one package:

- Red
- Green
- Blue

Each channel can be controlled independently. By changing the brightness of each internal LED, different colors are generated.

Common Examples

Red	Green	Blue	Output Color
100%	0%	0%	Red
0%	100%	0%	Green
0%	0%	100%	Blue
100%	100%	0%	Yellow
100%	0%	100%	Magenta
0%	100%	100%	Cyan
100%	100%	100%	White

Pulse Width Modulation (PWM)

PWM is a technique where a digital signal rapidly switches ON and OFF. The ratio of ON time to total period defines the duty cycle.

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

Where:

- T_{ON} = signal ON time
- T = total period

Higher duty cycle increases the average drive level and perceived brightness of the LED.

Example

If:

- $T = 10 \text{ ms}$
- $T_{ON} = 2.5 \text{ ms}$

Then

$$\text{Duty Cycle (\%)} = \frac{2.5}{10} \times 100 = 25$$

Why It Matters for RGB LED

- 0% → LED OFF
- 50% → Medium Brightness
- 100% → Maximum Brightness

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 one **RGB LED** and three current-limiting resistors.

Each color channel is driven independently:

- **Wavegen (W1)** → Red
- **Wavegen (W2)** → Green
- **V+ Output (Configured Channel)** → Blue

The common cathode pin is connected to GND.

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. **Insert the RGB LED:** Place the LED on the Canvas breadboard⁵. Identify the common cathode pin and connect it to GND.
2. **Connect Red Channel:** Connect the **Red pin** of the LED through a **220Ω resistor** to Wavegen (**W1**).
3. **Connect Green Channel:** Connect the **Green pin** of the LED through a **220Ω resistor** to Wavegen (**W2**).
4. **Connect Blue Channel:** Connect the **Blue pin** of the LED through a **220Ω resistor** to **V+** output.
5. **Verify Grounding:** Ensure all grounds are common and correctly connected.

⁴ Given on Figure 2.

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

Wavegen outputs **W1** and **W2** are used for dynamic RGB control, while **V+** is used as the third output channel for the Blue LED branch.

- **Wavegen Channel 1 (W1)** drives the red channel
- **Wavegen Channel 2 (W2)** drives the green channel
- **V+ configured output** drives the blue channel

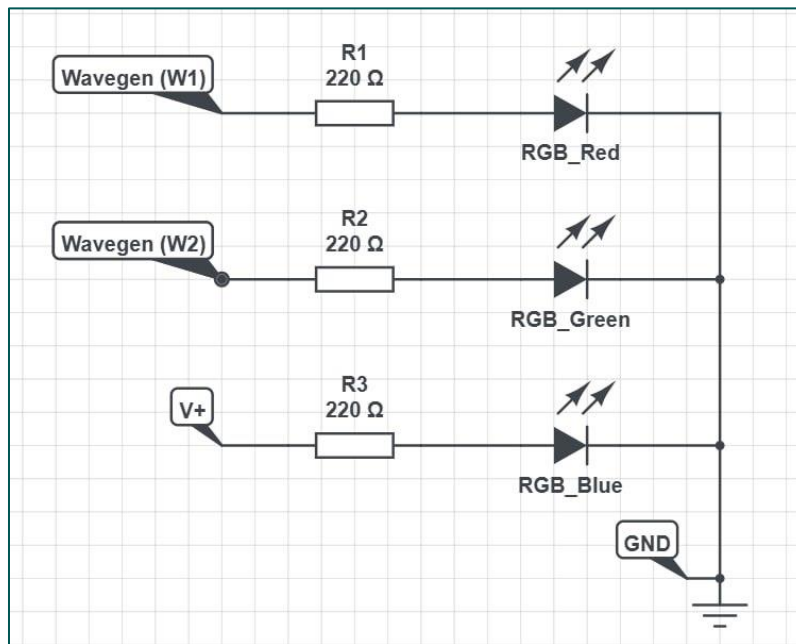


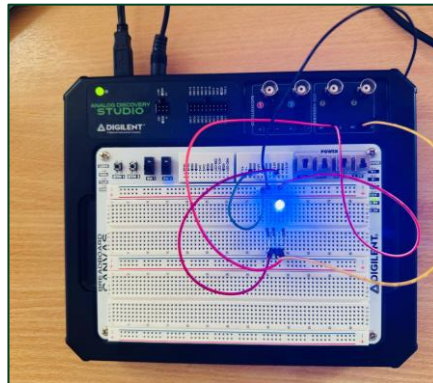
Figure 2. RGB LED Color Mixing using W1, W2 and V+

4.3 Assembled Circuit

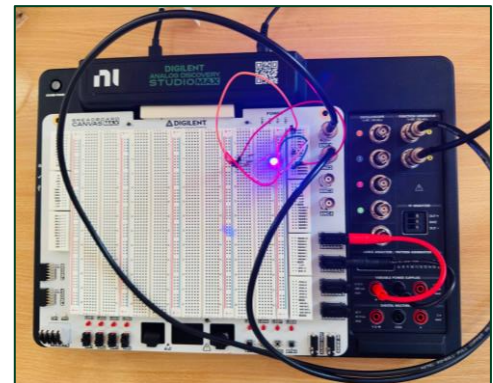
Figure 3 shows complete experimental circuits implemented on different **Digilent** devices.



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 Output Signal Using the WaveForms Generator

- 2.1. Open the **Wavegen / Pattern Generator** instrument in **WaveForms**.
- 2.2. Configure the output channels according to the selected device.

For Analog Discovery 3

Use three available output channels:

- **Channel 1 (W1)** → Red LED branch (**Figure 4a**)
- **Channel 2 (W2)** → Green LED branch
- **Channel 3 (V+)** → Blue LED branch (**Figure 4b**)

Recommended settings:

Channel	Function	Type	Frequency	Amplitude	Offset	Symmetry
W1	Red	Square	1 Hz	2 V	2 V	50%
W2	Green	Square	1 Hz	2 V	2 V	50%
V+	Blue	Square	1 Hz	1 V	2 V	50%

Figure 4 a-d shows the WaveForms output configurations used for RGB LED control on different **Digilent devices**. Depending on the selected hardware, the red and green channels are driven by **W1** and **W2** waveform outputs, while the blue channel is controlled either by the **V+** output channel or by the positive power supply output. The output settings determine the perceived brightness of the corresponding LED colors.

Note: For **Analog Discovery Studio** and **Analog Discovery Studio MAX**, the Blue LED branch is controlled using the power supply output rather than a third independent Wavegen PWM channel. Therefore, Blue brightness is adjusted by changing the **V+** output level.

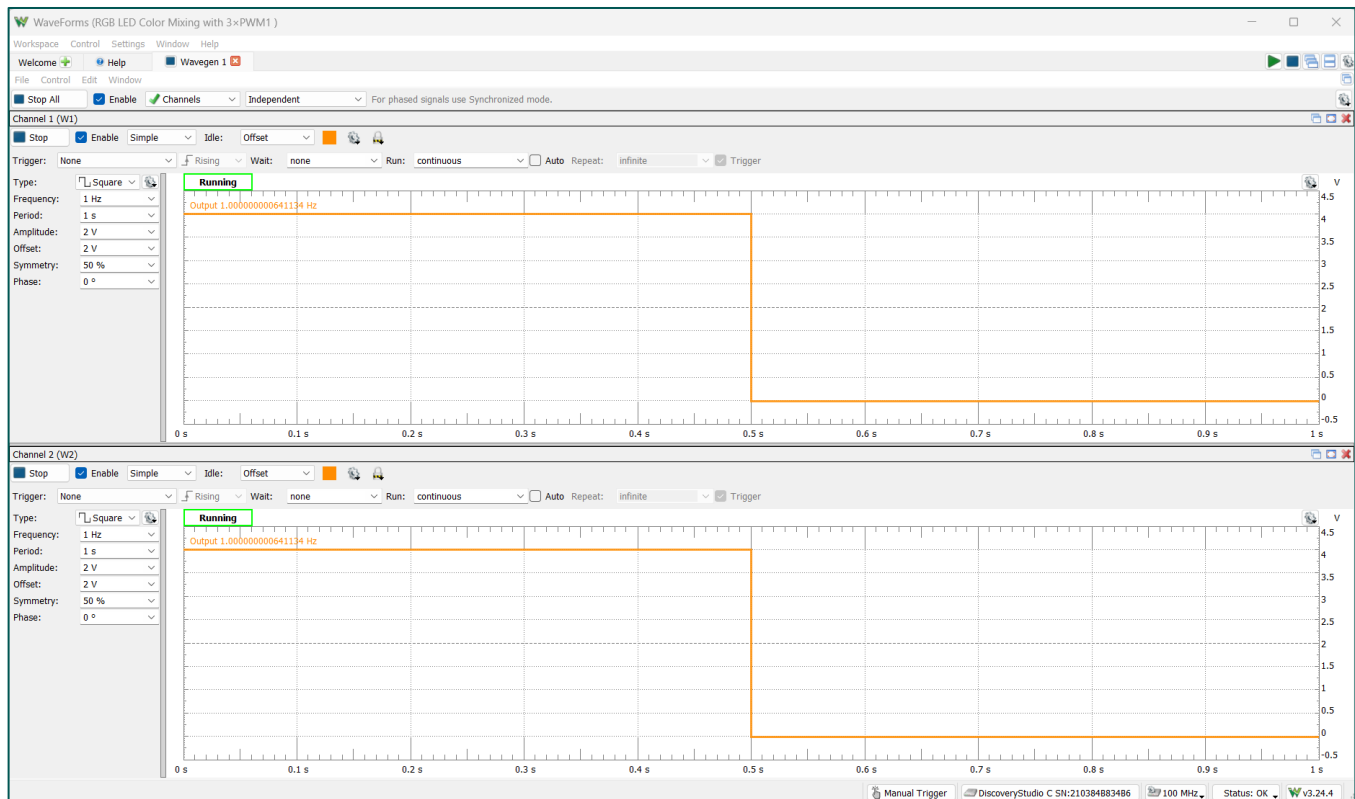


Figure 4a. Analog Discovery 3 – RGB Output Configuration Using W1 and W2

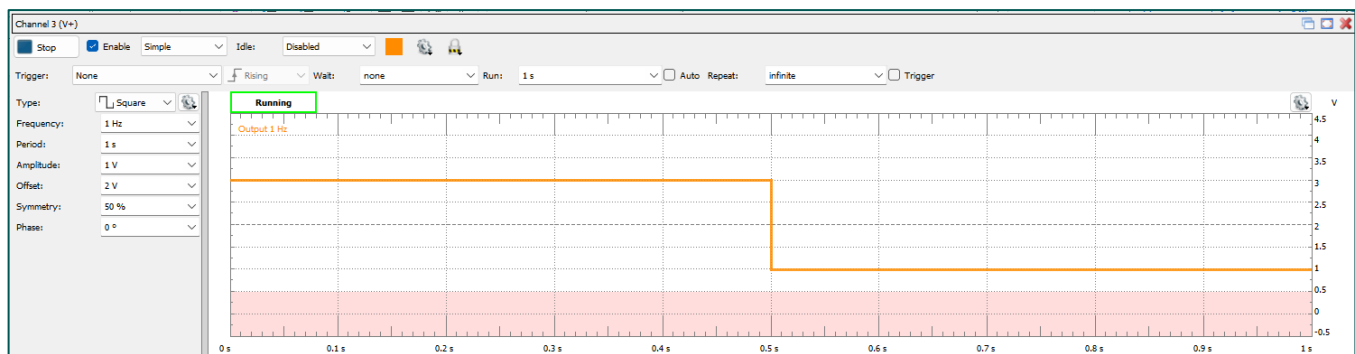


Figure 4b. Analog Discovery Studio – Channel 3 (V+) Output Signal Configuration

For Analog Discovery Studio

Since **Analog Discovery Studio** does not provide the same third Wavegen output configuration, use:

- **Wavegen W1** → Red LED branch (**Figure 4a**)
- **Wavegen W2** → Green LED branch
- **Positive Power Supply V+ = 4 V** → Blue LED branch (**Figure 4c**)

In this case, the red and green channels are dynamically controlled using waveform outputs, while the blue channel is supplied from the power supply output.

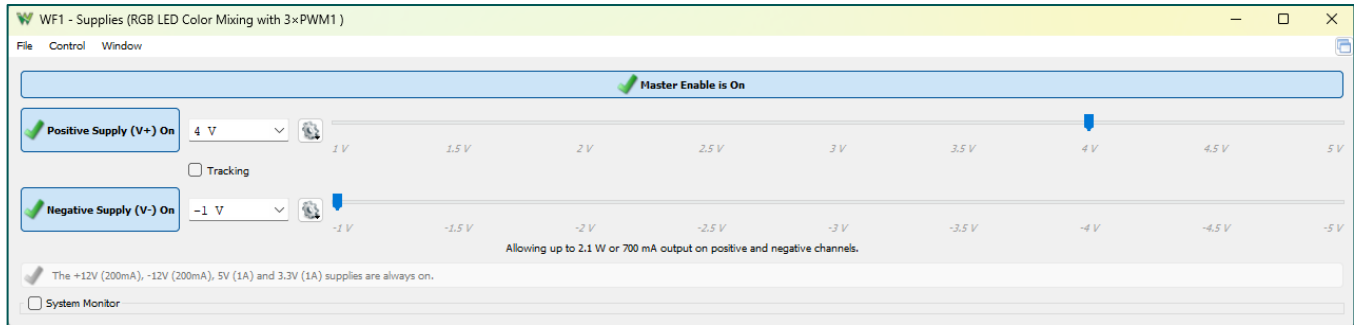


Figure 4c. Analog Discovery Studio – Supplies Interface with Positive Supply Set to 4 V

For Analog Discovery Studio MAX

- **Wavegen W1** → Red LED branch (Figure 4a)
- **Wavegen W2** → Green LED branch
- Use the **WaveForms Supplies** interface (Figure 4d):
 - Enable **Master Enable**
 - Turn **Positive Supply (V+) ON**
 - Set **V+ = 4 V**
 - Set current limit according to the circuit requirement
 - Keep unused supply outputs **OFF** if not required

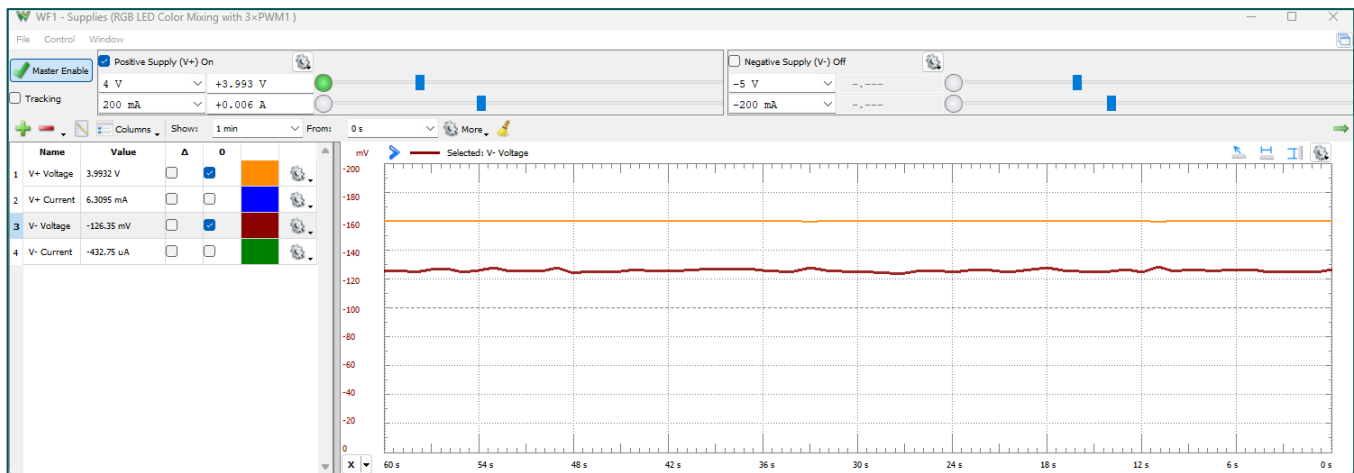


Figure 4d. Analog Discovery Studio MAX – Power Supply Monitoring and Output Configuration

- 2.3. Enable the output channels.
- 2.4. Observe the generated output control signals.

Example configuration:

Channel	Duty Cycle
Red	80%
Green	20%
Blue	0%

This combination creates an orange/yellow tone.

Step 3. Adjust Output Settings and Observe RGB LED Behavior

- 3.1. Change the Symmetry (Duty Cycle) of W1 and observe red brightness.
- 3.2. Change the Symmetry (Duty Cycle) of W2 and observe green brightness.
- 3.3. For AD3, adjust the third output channel used for the blue branch.
- 3.4. For AD Studio / AD Studio MAX, adjust the V+ supply level to change blue brightness.
- 3.5. Combine different red, green, and blue output levels to generate mixed colors.

Step 4. Test Color Combinations

Apply the following output settings and observe the resulting LED colors.

Red	Green	Blue	Result
100	0	0	Red
0	100	0	Green
0	0	100	Blue
100	100	0	Yellow
100	0	100	Purple
0	100	100	Cyan

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 **Diligent WaveForms** and verify that **Device** is detected and shown as *Currently Selected* in the **Device Manager** (Settings -> Device Manager), then close **Diligent WaveForms** software⁶.
- 1.3. Open the **NI LabVIEW** software.
- 1.4. Create a new NI LabVIEW VI (**File->New VI**)

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

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

2.1. Modify the block diagram as shown in **Figure 5**.

Figure 5 shows the NI LabVIEW block diagram for RGB LED control using two waveform generator channels and one power-supply output. The Red LED is controlled by **fgen/1**, the Green LED by **fgen/2**, and the Blue LED by **ps/+**.

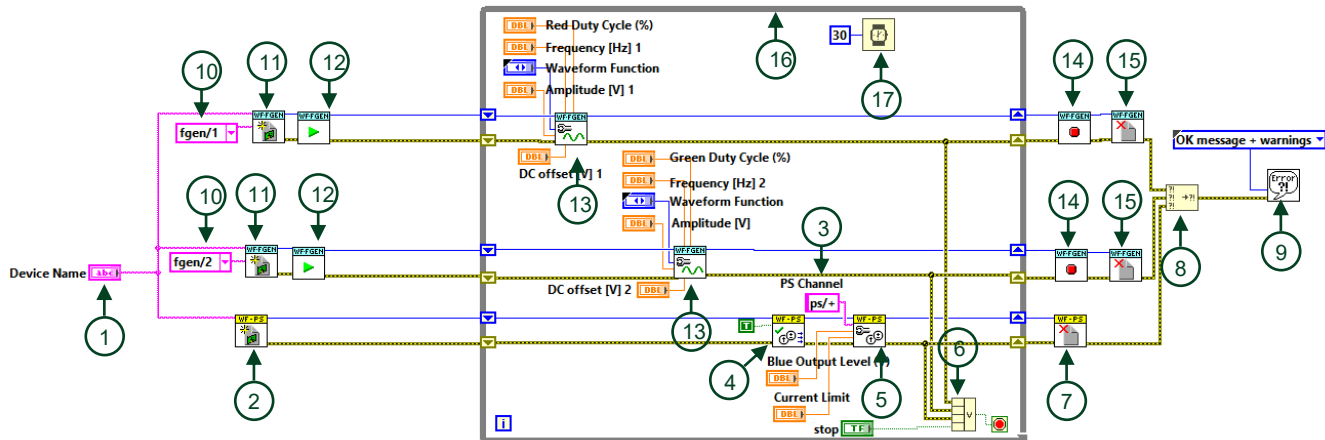


Figure 5 VI Block Diagram for RGB LED Control Using W1, W2, and V+

1. **Device Name** – enter the corresponding **Device** name from **Table 2**.
2. **WF-PS Initialize** – initializes the power-supply session used for the **Blue LED** branch.
3. **PS Channel (ps/+)** – selects the positive power-supply output channel.
4. **WF-Enable All Outputs** – enables the power-supply outputs so that the configured **V+** channel becomes active for the **Blue LED** branch.
5. **WF-Configure Voltage Output** – sets the required output voltage level and current limit for the selected **ps/+** channel.
6. **OR Logic** – combines the **Stop** command and error condition to stop the loop safely.
7. **WF-PS Close** – closes the power-supply session after execution.
8. **Merge Errors** – merges error wires from all output branches into one error chain.
9. **Simple Error Handler** – displays warnings or error messages after execution.
10. **WF-FGEN Channel** – selects the waveform generator channel (**fgen/1** for Red, **fgen/2** for Green).
11. **WF-FGEN Initialize** – initializes the waveform generator session for the selected channel.
12. **WF-FGEN Run** – starts waveform generation on the selected channel.
13. **WF-FGEN Configure Standard Waveform** – configures waveform parameters such as duty cycle, frequency, amplitude, and DC offset.
14. **WF-FGEN Stop** – stops waveform generation after the loop ends.
15. **WF-FGEN Close** – closes the waveform generator session.
16. **While Loop** – enables continuous real-time control of the RGB LED outputs until the **Stop** button is pressed.
17. **Wait (ms)** – connected to a numeric constant and set to **30 ms** to define the loop update rate.

2.2. Modify the front panel shown in **Figure 6**. Inside **Device name** String Control write your corresponding **Device** name from **Table 2**.

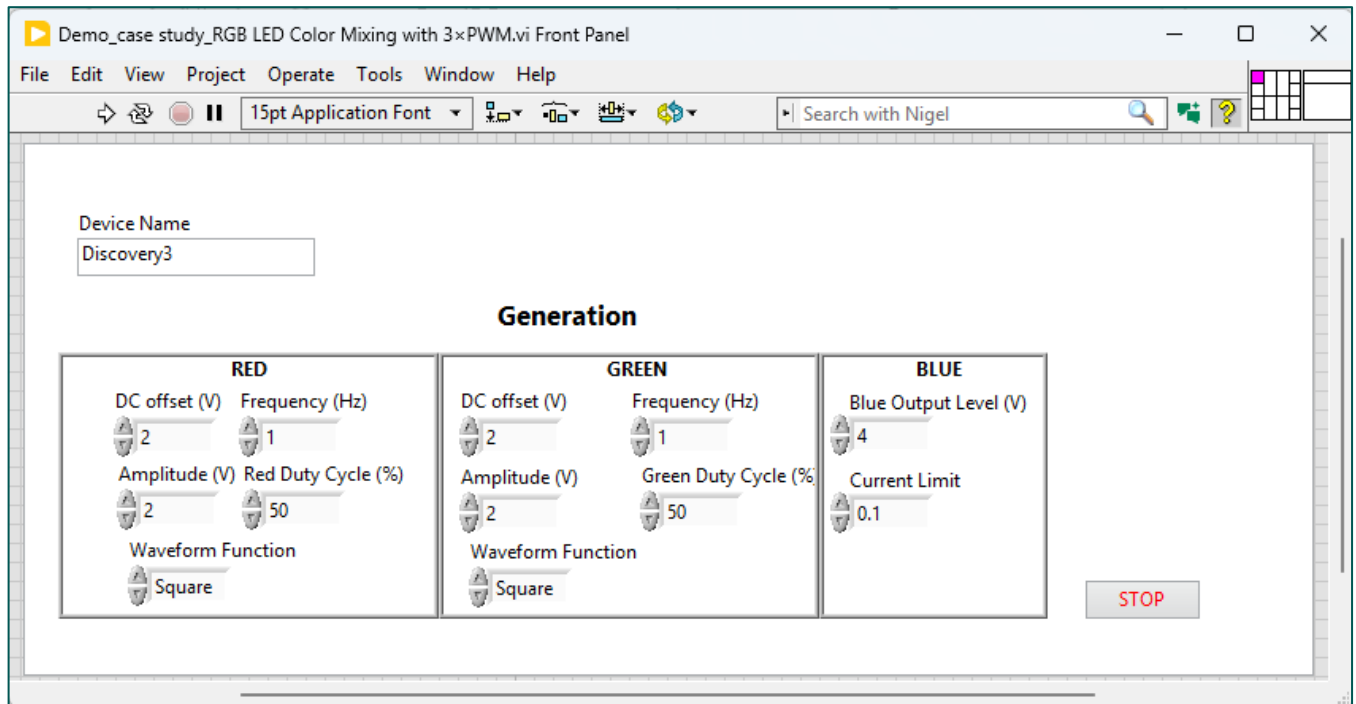


Figure 6. VI Front Panel

2.3. Save the VI.

Step 3. Run the VI and observe RGB LED color mixing.

- 3.1. Click the **Run** button.
- 3.2. Set **Waveform Function 1** and **Waveform Function 2** to **Square**.
- 3.3. Adjust **Red Duty Cycle (%)** to control the Red LED brightness.
- 3.4. Adjust **Green Duty Cycle (%)** to control the Green LED brightness.
- 3.5. Adjust **Blue Output Level (V)** to control the Blue LED brightness.
- 3.6. Change the duty cycle and output values to generate different mixed colors.
- 3.7. Press **Stop** to stop the VI.
- 3.8. Turn off or disconnect the Device after completing the experiment.

Note: In this LabVIEW implementation, **W1** and **W2** provide dynamic PWM control for the Red and Green LED branches. The **V+ output** is used as the third controllable output for the Blue LED branch. The duty cycle controls the perceived brightness of the red and green channels, while the **V+** output level controls the blue channel intensity.