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A Few Words about Pulse Width Modulation

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Solution: Pulse Width Modulation, or PWM, is a method of varying the width of a defined pulse over a specified period using a modulating, or time varying, waveform. PWM is typically used to control motors, regulate voltage, and in some audio amplification schemes.

Many arbitrary waveform generators, such as the Rigol DG4000 or DG5000 series of Arbitrary Waveform Generators, will allow you to configure the output to source a PWM signal.

The Rigol DG2041A, DG4000, and DG5000 Series of Arbitrary Waveform Generators support PWM.

In this note, we are going to explain the standard terminology for PWM and also describe some common methods to achieve a PWM output. Finally, we will configure a DS4000 to output a PWM waveform.

Let's start with some common terms. A pulsed waveform is defined by it's amplitude, period or frequency, and the pulse width. With pulsed waveforms, it is sometimes more convenient to use the period, as it uses time-based units.

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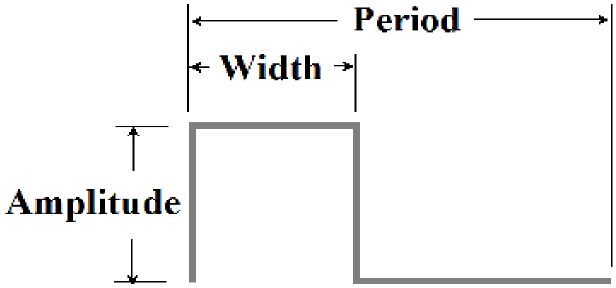


For a PWM signal, the original waveform pulse width varies with time.

Given a waveform period of X, the pulse width is often given as the Duty Cycle which can be represented as a % of X.

$$Pw = P * Pdc$$

Where *Pw* is the pulse width, *P* is the pulse waveform period, and *Pdc* is the duty cycle.

For example, if you had a 1ms waveform period and a 50% duty cycle pulse, the pulse width would be 50% of 1ms = 0.5ms or 500us.

A 25% duty cycle would be 25% of 1ms = 0.25ms or 250us.

When we enable PWM, the pulse width changes with time. It is modulated from a minimum to a maximum pulse width.

The rate of change of a PWM signal is determined by the modulation waveform type, such as sine or square, and the modulating waveform frequency.

The PWM signal has a Pulse Width Modulation Duty Cycle (PWM Duty) parameter.

This is defined as the modulation width of the pulse and is analogous to the modulation depth of an Amplitude Modulated (AM) signal.

The pulse width minimum (*Wmin*) can be calculated by the following:

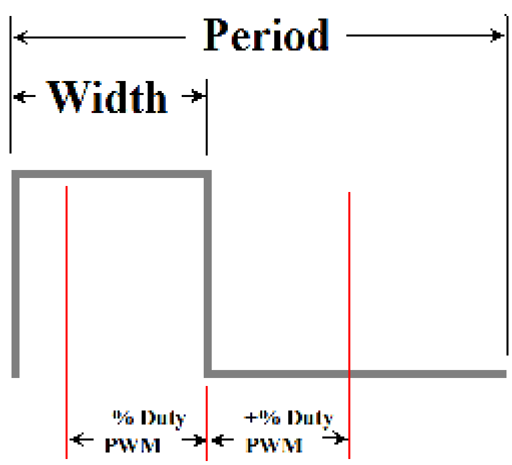
$$Wmin = P\,(Pdc - PWMdc)$$

Where *P* is the period of the original pulsed waveform, *Pdc* is the duty cycle of the original pulse, and *PWMdc* is the duty cycle of the PWM signal.

The pulse width maximum (*Wmax*) can be calculated by the following:

$$Wmax = P\,(Pdc + PWMdc)$$

Where *P* is the period of the pulsed waveform, *Pdc* is the duty cycle of the original pulse, and *PWMdc* is the duty cycle of the PWM signal.



Here are a few examples:

1) Suppose we had a pulsed waveform with a period of 10ms, a pulsed duty cycle of 25%, and a PWM duty cycle of 10%.

   P = 10ms, Pw = 10ms * 0.25 = 2.5ms

   $Wmin = P\ (Pdc - PWMdc)$ = 10ms * (0.25 – 0.10) = 1.5ms

   $Wmax = P(\mathrm{Pdc} + PWMdc)$ = 10ms * (0.25 + 0.10) = 3.5mS

   Therefore, the pulse width will modulate between 1.5ms and 3.5ms.

   NOTE: The *PWMdc* can't be greater than the original pulse duty cycle. If it were, then the minimum pulse width would be negative in time.

2) Suppose we had a pulsed waveform with a period of 10ms, a pulsed duty cycle of 50%, and a PWM duty cycle of 40%.

   P = 10ms, Pw = 10ms * 0.5 = 5ms

   $Wmin = P\ (Pdc - PWMdc)$ = 10ms * (0.5 – 0.4) = 1ms

   $Wmax = P(\mathrm{Pdc} + PWMdc)$ = 10ms * (0.5 + 0.4) = 9mS

   Therefore, the pulse width will modulate between 1ms and 9ms.

   NOTE: You can achieve the greatest Pulse Width Modulation span by setting the Pulse Duty Cycle to 50% and the Pulse Width Modulation Duty Cycle to 49.999%.

3) Suppose we had a pulsed waveform with a period of 10ms, a pulsed duty cycle of 90%, and a PWM duty cycle of 5%.

   P = 10ms, *Pw* = 10ms * 0.9 = 9ms

   Wmin = P (Pdc– PWMdc) = 10ms * (0.9 – 0.05) = 8.5ms

   Wmax = *P*(Pdc + *PWMdc*) = 10ms * (0.9 + 0.05) = 9.5mS

   Therefore, the pulse width will modulate between 8.5ms and 9.5ms.

   NOTE: The sum of the *Pdc* and *PWMdc* can't be greater than 99.999%. If so, the modulated pulse would have a period greater than the original pulse. When the *Pw* > 50%, the *PWMdc* < (*1-Pdc*)

As you can see, the determination of the pulse width is straightforward, once you have a better understanding of the math that governs the process.

Lets take a closer look at actually setting up a test using a DG4000 and an oscilloscope.

DG4000 Example

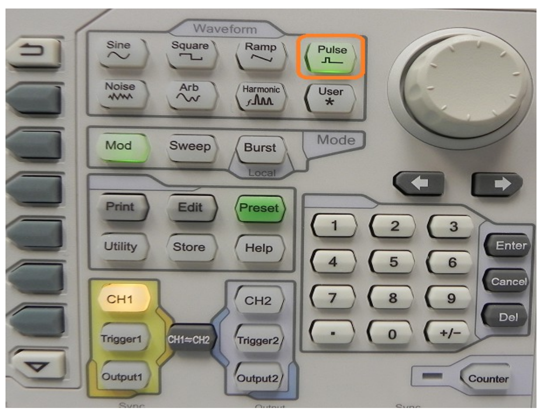
Using the following instructions, we can set the DG4000 to output a PWM signal.

1. Power on the DG4000.

2. Connect the output channel 1 to an oscilloscope using a BNC coaxial cable. We will use the oscilloscope to capture the output waveform.

3. Configure your oscilloscope horizontal scale for 1ms/div, vertical scale to 2v/div, trigger rising edge, trigger value 1v, and set the persistence to 10s or greater.

4. Press the Pulse button on the DG4000



5. Toggle the Frequency/Period menu to Period by pressing the gray key next to the Freq menu selection.

6. Set the waveform period to 1ms using the keypad.

7. Set the Pulse duty cycle to 50%. This will set our pulse width to 50% of the waveform period.. or 50% of 1ms = 500us.

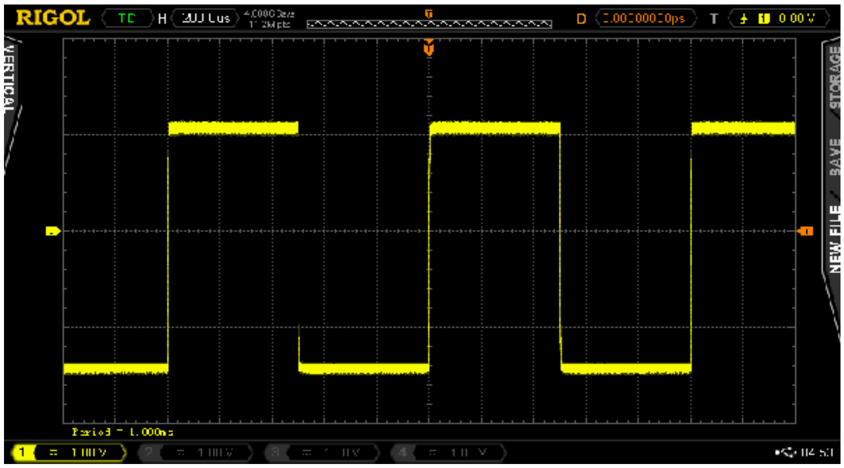


Figure 1: Pulse waveform. 50% Pulse Duty Cycle. Waveform period 1ms.

8. Now, press the Mod button on the front panel.

9. Press PWM Freq and set it to 100Hz. This setting controls the rate of repetition for the modulating waveform.

10. Set the Duty cycle of modulation (*PWMdc* from the theory section above) by selecting DutyDev. Set it to 10%.

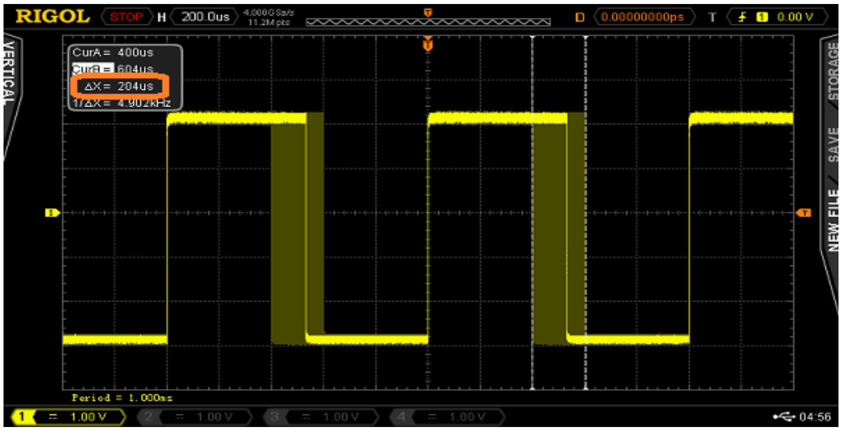


Figure 2: Pulse waveform. 50% Pulse Duty Cycle.
PWM enabled. 10% PWM Duty Cycle (DutyDev).

NOTE: The pulse width modulation spans 200us. This is twice the PWM setting. Also, note with the scope persistence enabled, you can see the waveforms path over time. We are indeed modulating +/- 10% around the original pulse width as we expected.

11. Now, let's set the duty cycle to 40% and observe the output waveform with the scope.

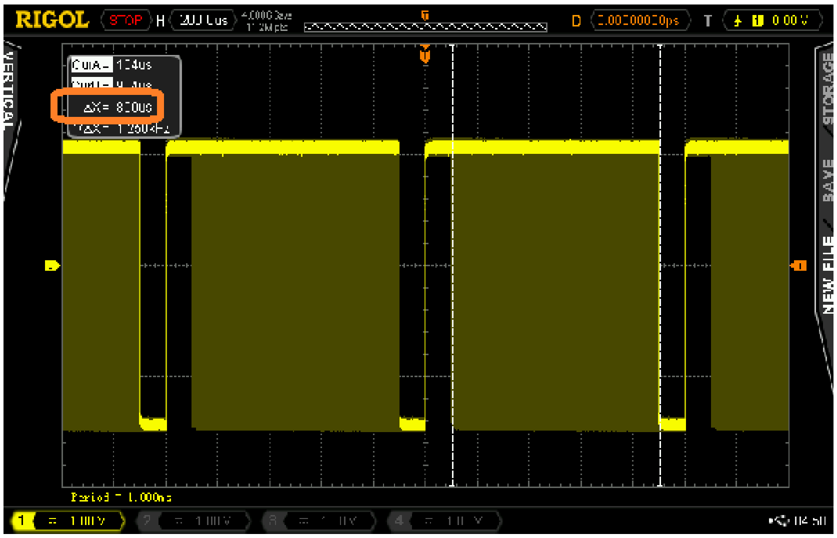


Figure 3: Pulse waveform. 50% Pulse Duty Cycle.
Waveform period 1ms.
Pulse Width Modulation = 40%.

NOTE: The pulse width modulation spans 800us. This is twice the PWM setting.

Pulse and PWM Performance for current products

Model	Max Sine Frequency (MHz)	Min Pulse Width (ns)	Min Pulse Width/Full PWM*
DG2041A	40	12	2us
DG4062	60	18	"
DG4102	100	10	"
DG4162	160	12	"
DG5071	70	4	"
DG5101	100	"	"
DG5251	250	"	"
DG5351	350	"	"

*Full PWM is defined as the largest span in modulation. Pulse waveform duty cycle set to 50% of the waveform period and a PWM of 49% or greater.