

# Using a Function Generator to Create Pulse-Width Modulation (PWM) Waveforms

Application Note 1466

## Introduction

The use of pulse-width modulation (PWM) continues to increase with the rise in digital control logic. Pulse width modulation offers a simple method for digital control logic to create an analog equivalence. Many micro-controllers have PWM capability built-in. PWM is also used in communication systems, since a digital signal is more robust and less vulnerable to noise. This application note provides a brief overview of PWM and offers ideas on how to use a function generator to create pulse-width modulated signals.

## Pulse-width modulation basics

Analog signals can take on any value, and they can be used to control many electronic devices. For example, you can control a light with a dimmer switch. The dimmer switch is a simple rheostat that inserts resistance into the circuit in order to reduce the amount of current that is sent to the lamp. The excess current is dissipated as heat. The rheostat is a simple solution for this application.

Another approach would be to use an on/off switch shown in the diagram below.

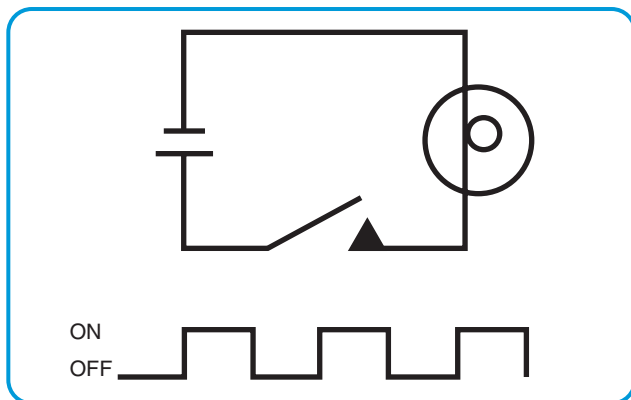


Figure 1. A simple circuit that uses PWM to control the brightness of a light

If you reduce the amount of time the switch is in the “on” position, the light will dim. In our example, the light is shown to be on 50 percent of the time and off the other 50 percent. The repetitive signal used to control the light can be broken down into periods, with a single period being the time it takes to complete one cycle, from off to on and back off. The signal can be further characterized by duty cycle, which is the ratio of the “on” time divided by the period. A high duty cycle will create a bright light, while a small duty cycle will create a dim light. The example shown in Figure 1 has a 50 percent duty cycle.

It is important to understand that the light produced is independent of frequency. In Figure 2, you will see two waveforms with different frequencies; both produce the same amount of light. The amount of light is independent of the frequency, but is proportional to the duty cycle.

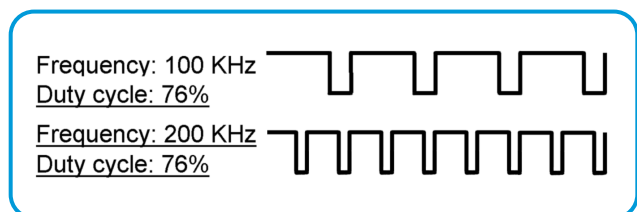


Figure 2. Two pulse trains with the same duty cycle

The frequency range you can use to control a circuit is limited by the response time of the circuit. In the first example, a low frequency would cause the light to flash noticeably. A high frequency can cause an inductive load to saturate. For example, a transformer has a limited frequency range in which it can transfer energy efficiently. In some designs, harmonics (or beat frequencies) of the PWM

frequency can get coupled into the analog circuitry, causing unwanted noise. If you choose the right frequencies, the load being controlled will act as a stabilizer; a light will glow continuously and momentum will allow a motor to turn smoothly.

### Generating PWM signals

You can generate PWM signals quite easily using a comparator with a sine wave as one of the inputs.

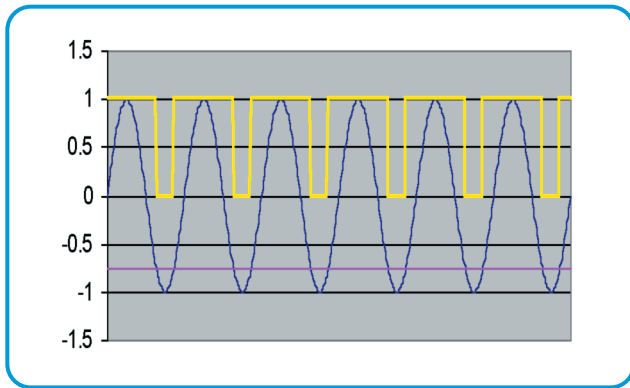


Figure 3a. PWM waveform that results when a sine wave is compared with a -0.75Vdc voltage

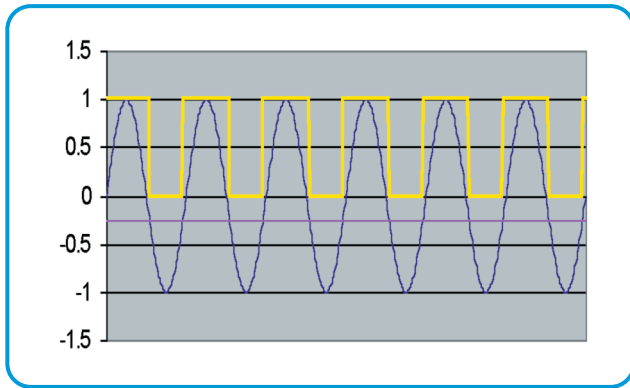


Figure 3b. PWM waveform that results when a sine wave is compared with a -0.25 Vdc voltage

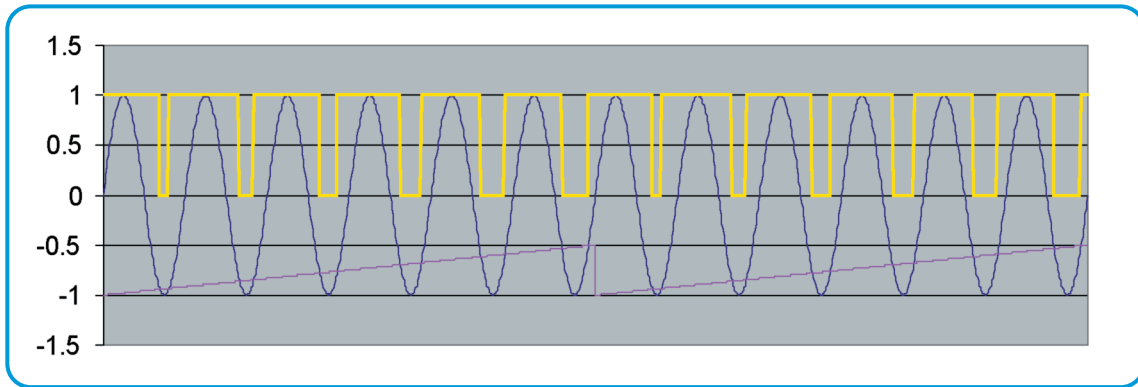


Figure 3c. PWM waveform that results when a sinewave is compared with a linear-ramp signal

Figures 3a, 3b, and 3c show the PWM waveform (yellow) that is generated by a comparator being fed the sine wave (blue) and a signal (red). The output of the comparator will be high when the sinewave is greater than the other input signal. In the first example (3a), we use a steady-state voltage, -0.75 dcV. Since the sinewave is usually greater than the other input signal, a PWM waveform with a high duty cycle is generated. If the dc voltage is increased to -0.25V, the resulting PWM waveform will have a lower duty cycle, as shown in figure 3b. The final example (3c) shows the resulting PWM waveform when a ramp is used as the input signal. The duty cycle of the PWM waveform decreases as the input increases.

A more robust pulse-width modulation circuit will have the ability to control the modulation depth. Modulation depth can be measured as pulse-width deviation or duty cycle deviation. For example, if you set the duty cycle to 10 percent and then set the deviation to 5 percent, the duty cycle would vary between 5 percent and 15 percent.

### Advantages of PWM

Using pulse width modulation has several advantages over analog control. Using PWM to dim a lamp would produce less heat than an analog control that converts some of the current to heat. Also, if you use PWM, the entire control circuit can be digital, eliminating the need for digital-to-analog converters. Using digital control lines will reduce the susceptibility of your circuit to interference. Finally, motors may be able to operate at lower speeds if you control them with PWM. When you use an analog current to control a motor, it will not produce significant torque at low speeds. The magnetic field created by the small current will be too weak to turn the rotor. On the other hand, a PWM current can

create short pulses of magnetic flux at full strength, which can turn the rotor at extremely slow speeds. The technology has become more pervasive as low-cost microcontrollers incorporate PWM control. Microcontrollers offer simple commands to vary the duty cycle and frequencies of the PWM control signal. PWM is also used in communications to take advantage of the higher immunity to noise provided by digital signals.

### Using a function generator to create PWM waveforms

You can use a couple of different techniques to create a variety of PWM signals with a function generator. Most function generators allow you to use a square wave and vary the duty cycle, and most function generators allow you to vary the duty cycle between 20 and 80 percent. You can achieve higher or lower duty cycles by using burst mode. Burst mode lets you output a single cycle (pulse) of a square wave and then wait a specified period before outputting another pulse. This technique is well documented in Agilent Application Note 1407, "How to Generate Low Duty-Cycle Pulses with a Function Generator." Using the duty cycle function and burst mode works well for creating a static PWM signal. A static signal is the PWM equivalent of a dc voltage. To create a PWM waveform that is a product of a dynamic signal, you will need a function generator with arbitrary waveform capability or a built-in PWM function .

A typical arbitrary waveform generator can hold 16k to 64k points and produce a signal with 12 or 14-bits of amplitude accuracy. It's unfortunate that a PWM signal will not take advantage of the amplitude accuracy. You can create the points by using an algorithm that compares the analog signal to a sine wave. The resulting ones and zeros are downloaded into the function generator's non-volatile memory. Once downloaded, the waveform can be output at different frequencies and amplitudes. However, the duty cycle and variations are stored in the waveform and they cannot be modified without downloading a new waveform.

Some function generators, like Agilent's 33220A, offer a built-in pulse function with PWM. Having quick access to all the PWM parameters (frequency, amplitude, and modulation depth) makes it easy to modify and experiment with a waveform. The modulation source can be an internal or an external waveform. External modulation signals are digitized and the resulting PWM waveform is calculated using digital processing. On a 33220A, you also can set up a PWM waveform using one of the remote interfaces – USB, GPIB or LAN.

### Conclusion

The popularity of PWM will continue to grow as the functionality becomes more popular in microcontrollers and development tools make it easier to use. Having a good understanding of PWM will make it easier to incorporate in your designs. And, when you are working on a PWM design, a function generator can be a great tool for creating waveforms. Based on your needs for creating static or dynamic PWM signals, you can select a function generator that has the functionality you need. Static or dc equivalent PWM waveforms can be generated from the front panel of most function generators by varying the duty cycle or using burst mode. For dynamic PWM, you need an arbitrary waveform generator or a function generator with built-in PWM. The Agilent 33220A is a good example of a low-cost function generator with built-in PWM function.

### Glossary

**Duty cycle** – the percentage of time a pulse train is at its higher voltage

**Period** – how long before the signal repeats

**Pulse width** – how long the pulse is in the "true state" (pulses can be positive or negative)

### Related Agilent literature

Data sheet – 33220A Function/Arbitrary Waveform Generator, pub. no. 5988-8544EN

Application note – How to Generate Low Duty-Cycle Pulses with a Function Generator, AN 1407, pub. no. 5988-7507EN

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