Application Note

SPWM Generator for Inverter Design

AN-CM-302

Abstract

This app note implements a SPWM Generator. It describes the implemented logic, GreenPAK implementation detail, and the results obtained.

This application note comes complete with design files which can be found in the References section.

Contents

Figures

Tables

1 Terms and Definitions

IC	Integrated circuit
IR	Infrared
LED	Light-emitting diode

2 References

For related documents and software, please visit:

GreenPAK™ Programmable Mixed-Signal Products | Renesas

Download our free GreenPAK Designer software [1] to open the .gp files [2] and view the proposed circuit design. Use the GreenPAK development tools [3] to freeze the design into your own customized IC in a matter of minutes. Find out more in a complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the GreenPAK IC.

[1] Go Configure™ Software Hub | Renesas, Software Download and User Guide

[2] AN-CM-302 SPWM Generator.gp, GreenPAK Design File

[3] GreenPAK Development Tools, GreenPAK Development Tools Webpage

[4] GreenPAK Application Notes, GreenPAK Application Notes Webpage

[5] AN-CM-265 Programmable Limits PWM, Application Note

[6] SLG46826V, Datasheet

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3   Introduction

Renewable energy continues to be a massive trend around the world. As methods for capturing wind, solar and other forms of renewable energy have developed, the cost and efficiency of renewable energy systems have become more appealing to both companies and consumers. In fact, in 2016, the global monetary investment in renewable energy fell to the lowest number in years, while simultaneously the record was broken for the largest number of renewable energy installations in a given year. With the tradeoff in cost and development changing so greatly, the market for further innovation is booming.

Amongst the components used for renewable energy resources an inverter stands out as a uniquely critical system component. As most renewable energy is generated in DC, an inverter plays a key role in converting the DC into AC for effective integration into existing power grids. In hybrid power systems (combining different renewable resources) and micro-grid systems, the use of inverters is essential.

Renewable energy inverters play a role in industrial applications where single-phase and three-phase motors and other rotary machines are used. Variable frequency and voltage (obtained from an inverter) is the principle of autonomous control in this type of equipment.

To implement the power conversion, DC-AC inverters usually apply the Pulse Width Modulation (PWM) technique. PWM is a useful technique wherein switches like Power MOSFETs are controlled with pulses of variable widths. In order to obtain an automatic control and regulation, the PWM technique is used to maintain the AC voltage output of the inverter (and its frequency) at the nominal value independent of the output load.
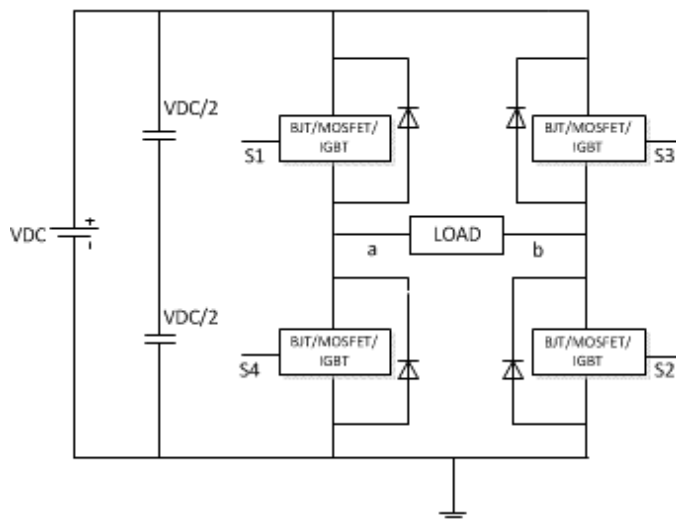
Many studies and technologies have been developed to obtain better response from the inverter control system. Conventional inverters change the output voltage according to the changes in the load. To reduce the sensitivity of the output voltage to load changes, PWM based inverters regulate the output voltage by changing the width of the pulses generated at a comparatively high frequency. As a result, the output voltage depends on the switching frequency and pulse width, which varies according to the value of the load connected at the output. With this type of regulation, the inverters provide a constant nominal voltage and a frequency independent of the output power.

Several methods of generating the pulse width modulation have been studied. The efficiency parameters of an inverter, such as switching losses and harmonic reduction, are the main factors considered in any modulation technique evaluation. Because of the analysis of several tests, Sinusoidal pulse width modulation (SPWM) is widely used in power electronics as the modulation method for PWM inverters.

4 SPWM Inverter Concept

A three-phase wave bridge inverter is the most used inverter topology in industrial applications. To simplify the concept a single-phase version is analyzed. The single-phase design includes switching transistors or IGBTs on each arm of the H-bridge with antiparallel freewheeling diodes to discharge when the switch is turned off. Its schematic is shown in Figure 1.

Figure 1: Basic H-bridge circuit

The transistors (usually power MOSFETs) are identified as S1, S2, S3 and S4. The switches are alternated such that both transistors of the same arm are not conducting or opened simultaneously, thereby preventing a short circuit.

To generate the alternating current in load, transistors operate in a pair (S1 and S2 conducting, S3 and S4 opened or vice versa). Table I shows the different switching stages and the applied voltage to the load.

Table 1: Logic of Switches

S1	S2	S3	S4	Vab
ON	ON	OFF	OFF	+VDC
OFF	OFF	ON	ON	-VDC

A square wave inverter (also known as Basic Inverter) is operated by two square waves in opposite phase and with frequency equal to the desired frequency at the output. One of the waves is applied to S1 and S2 and the other waveform to S3 and S4. Figure 2 shows the PWM control signals and the obtained voltage in the load if this type of inverter is used.
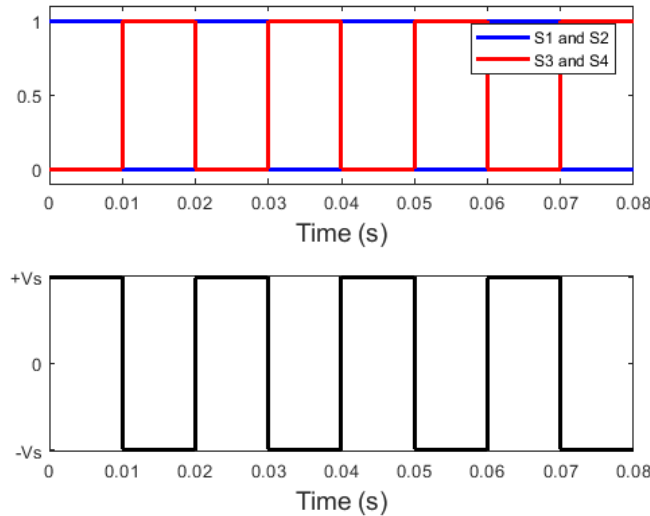
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Figure 2: Basic PWM Control Signals and Output Voltage

PWM is based on the generation of constant amplitude pulses, with modulation of the pulse duration by varying the duty cycle. The reference or modulated signal is the desired signal output (sinusoidal in the case of voltage waveforms at the output of an inverter) and the carrier signal must have a frequency much greater than the modulated one. This is the main reason for the usage of Sinusoidal PWM (SPWM) as the modulation method for PWM inverters.

5   SPWM Characteristics

SPWM modulation is based on constant amplitude pulses with different duty cycles for each period. The width of pulses is obtained by modulation of a carrier to obtain the desired output voltage and to reduce its harmonic content.

The carrier signal of SPWM is usually a triangular wave with a high frequency, generally in several KHz. The modulation signal of SPWM is a sinusoidal waveform with a frequency equal to the desired output voltage frequency (50 or 60 Hz).

In Figure 3, a simplified schematic of sinusoidal modulation is shown. The switching signal is generated by comparing the sinusoidal waveform and the triangular carrier waveform. The comparator output is high when sinusoidal voltage is greater than the triangular voltage. The output pulses of the comparator are used as the gate pulses of the H-Bridge presented in the previous section.
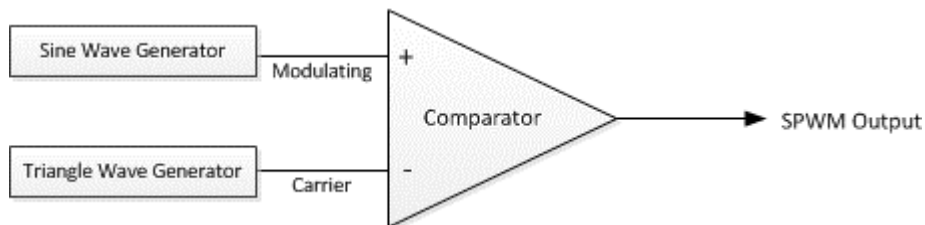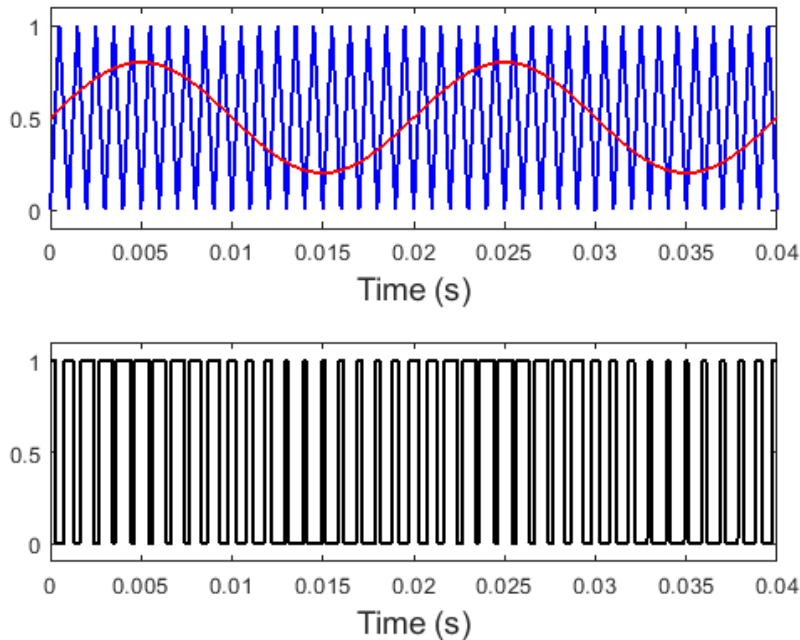

Figure 3: Simplified Schemtica of Sinusoidal PWM Modulation

In order to obtain better results, the frequency ratio between the triangular and the sinusoidal waveforms must be an integer $N = fC/fS$, where fC is the carrier frequency (the triangular waveform) and fS is the modulation frequency (the sine waveform). With this condition, the number of voltage

pulses per half-cycle results in N/2. This effect can be seen in Figure 4, where the triangular, sine and the PWM output waveforms are shown.

Figure 4: Sinusoidal PWM Modulation and Output Signals

If SPWM is analyzed mathematically, a modulation index m can be defined as the ratio between the amplitude of the sine wave (VS) and the triangular wave (VC):

$$m = \frac{\widehat{V_s}}{\widehat{V_C}}$$

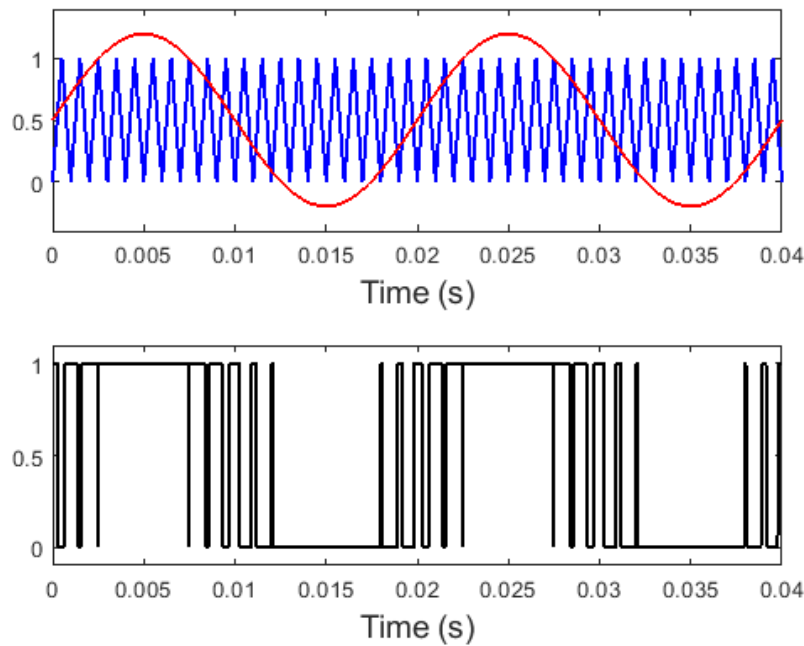For regulation range, m must be equal or less than 1.0. If the previous condition is considered, the output voltage of the H-bridge controlled by SPWM results in:

$$V_{load} = \frac{\sqrt{2}}{4} m V_{DC}$$

Where VDC is the input DC voltage to the inverter.

The modulation process of duty cycle is designed for m equal to or less than one. If m is higher, there will be periods of the triangle signal in which no intersection of the carrier and the modulation signal will exist. The effect on the output signal is shown in figure 5. However, it's important to note that a certain amount of over-modulation is sometimes used with the aim of obtaining a higher AC voltage amplitude.

Figure 5: Over-modulated SPWM

If SPWM is analyzed in terms of waveform quality the harmonics must be considered. The SPWM generates different harmonics of several orders in the voltage waveform. However, the dominant ones are of order N and N±2 (where N was defined as fC/fS). If over-modulation is considered, the output voltage has a higher harmonics content as a trade-off in generating a higher voltage. By varying the sinusoidal voltage, the output voltage can be regulated.

These concepts of triangular waveform with fixed amplitude and frequency and sinusoidal waveform with fixed frequency (equal to the output frequency) and variable amplitude are the basis of the SPWM Generator implemented in this application note.
The SPWM Generator described and implemented in this app note is based on the block diagram shown in Figure 6.
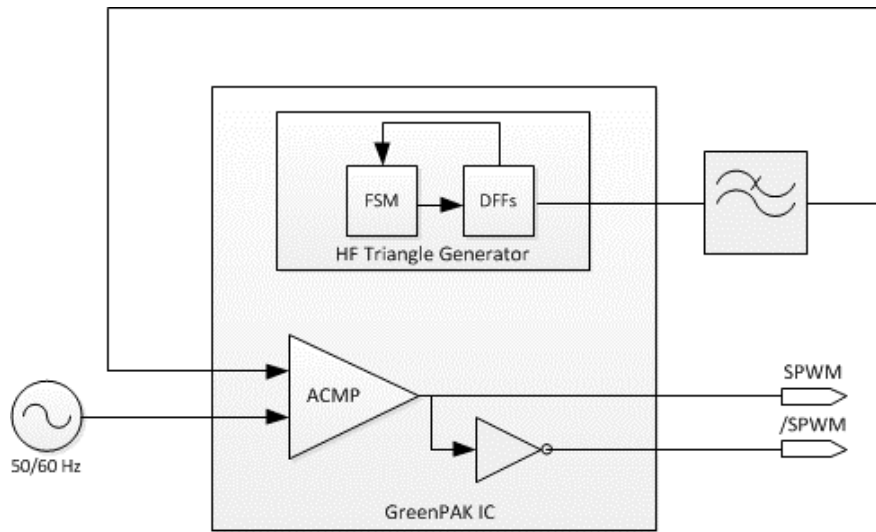
Figure 6: SPWM Block Diagram

A high frequency triangular waveform is necessary to generate the SPWM signals. This task is implemented with finite state machines (FSM)/Counters and D-type Flip Flops and is referenced as HF Triangle Generator in the diagram. The generator is based on the AN-CM-265 Programmable Limits PWM app note [1], generating a PWM with triangular variation of the duty cycle. As a triangular waveform is required, a low-pass filter is applied to eliminate the very-high frequency of the square wave.

This triangular waveform is compared with an external low voltage 50 or 60 Hz sine waveform with the Analog Comparators of the GreenPAK. With this comparison, the sinusoidal modulation of the PWM is implemented as described in the previous section. Finally, an inverter is used to generate the complementary signals for the SPWM outputs.

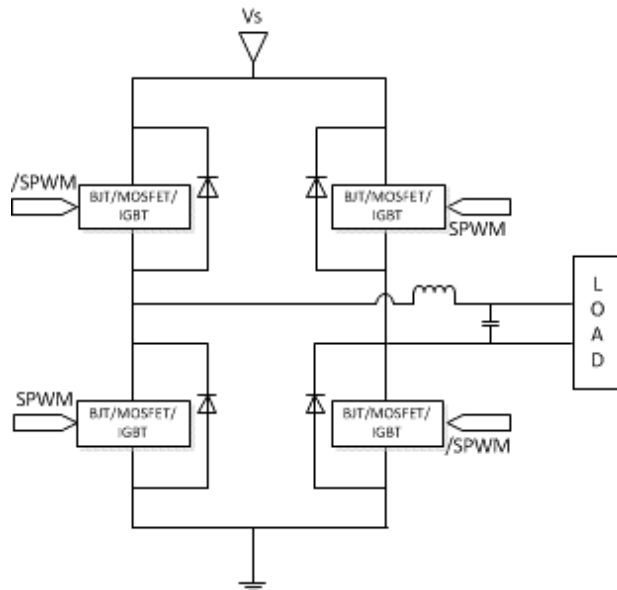The output of the SPWM generator is connected to an H-Bridge as shown in Figure 7.

Figure 7: SPWM to H-Bridge Connection

As seen from Figure 7, SPWM output and its complementary signal are connected one to each transistor of the same leg. The output of the H-Bridge contains an LC-filter so the high-frequency component of the SPWM is filtered, and finally, the sinusoidal waveform of 50 or 60 Hz is applied to the load.

6   Implementation and Configuration of SPWM Generator

The implementation of the SPWM Generator is based on a SLG46826V GreenPAK [2]. This Programmable Mixed-Signal ASIC contains Finite State Machine/Digital Counters, High-speed Analog Comparators and high-frequency Oscillators that can be used for generating the required triangular waveform and the sinusoidal modulation.

The high frequency triangular waveform generator is based on the AN-CM-265 Programmable Limits PWM app note [5] The implementation of the generator can be seen in Figure 8.

Figure 8: Triangle Waveform Generator

The generator uses the internal 25 MHz oscillator, configured for an output frequency of 12.5 MHz. This clock, combined with macrocells CNT1 and CNT2, generates the corresponding square waveform with the desired duty cycle. The configuration of both counters can be seen in Figure 9 and Figure 10.

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Figure 9: CNT1 Configuration

Figure 10: CNT2 Configuration

Counter data of both counters is defined to generate a PWM of 50 KHz by applying the expression:

$$f_{Triang\ PWM} = \frac{f_{RCosc}}{CNT1\ Data + 1} = \frac{12.5\ MHz}{249 + 1} = 50\ KHz$$

Relative phase of counters is varied by CNT0/DLY0/FSM0. The slope of triangular duty cycle variation is configured by setting CNT0 counter data following the equation:

$$Time\ for\ Ramp = (CNT0_{Data} + 1)\ x\ \frac{CNT1\ Data + 1}{f_{RCosc}} = (24 + 1) * \frac{250}{12.5MHz} = 500\ \mu s$$

Figure 11: CNT0 Configuration

With this configuration the triangular waveform has a period of 1 ms, so a 1 KHz triangular waveform is obtained. In this design a 50 Hz SPWM inverter is implemented but can be modified for 60 Hz or other frequencies by changing the period of the triangular waveform.

The high frequency PWM with triangular variation is connected to PIN 16, where the corresponding, external low pass filter is connected. This filter is based on a first-order RC filter, with a 1.5 kΩ resistor and a 10 nF capacitor so the cut-off frequency of the filter results 10.6 KHz.
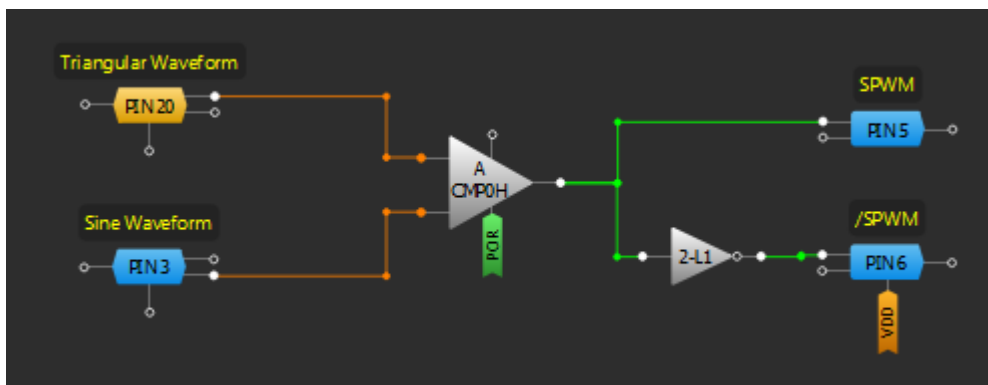
The output of the filter, as shown in the block diagram of Figure 6, is connected to the High-speed Analog Comparator ACMP0H. The Configuration of ACMP0H is shown in Figure 12.

Figure 12: Odd Output Control

This block is used to compare voltage between PIN 20 and PIN 3. For best performance, the hysteresis and the bandwidth limit options must be disabled. Thus, a low voltage sinusoidal waveform generator must be connected to PIN 3 so the sinusoidal PWM modulation is obtained, as shown in Figure 13.

Figure 13: Modulator Block Diagram

In order to generate the complementary signals for PWM output, the 3-L1 look-up table is configured as a logical inverter.

Finally, PWM outputs are connected to Pins 5 and 6.

As Pins 8 and 9 are connected to the I2C module of the GreenPAK IC, it's necessary to connect them with a pull-up resistor to VDD.

The entire SPWM implementation diagram is shown in Figure 14.
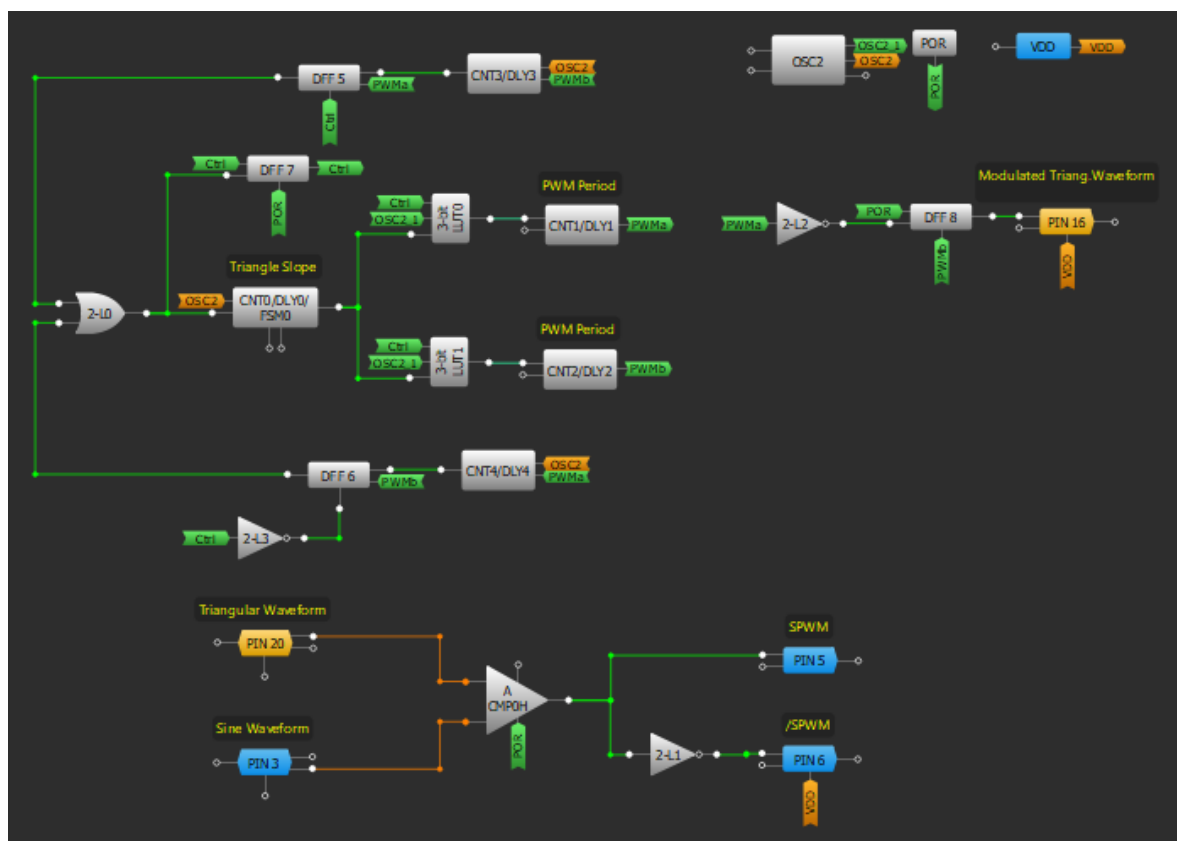
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Figure 14: SPWM Generator Implementation

7   Tests and Conclusion

To test the implementation, the entire system was assembled and analyzed with an oscilloscope. The 50Hz sine wave signal was generated with a function signal generator, with a corresponding amplitude and offset such that it can be connected directly to the SLG46826V. The entire system can be seen in figure 15.
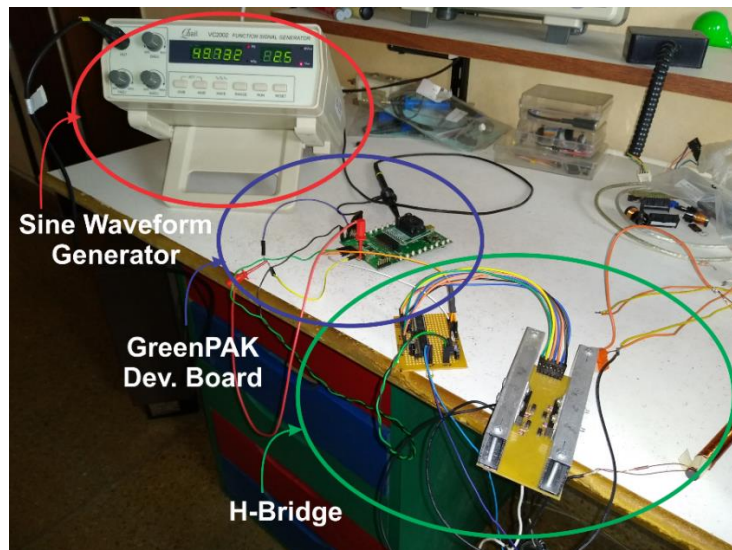

Figure 15: System Implementation

To analyze the results, the voltage waveform at the load and the output signal on pin 5 of the SLG46826V were logged.

In Figure 16, the output voltage applied to the load is shown. It can be seen that the output voltage has a sinusoidal shape if measured after the LC Filter.
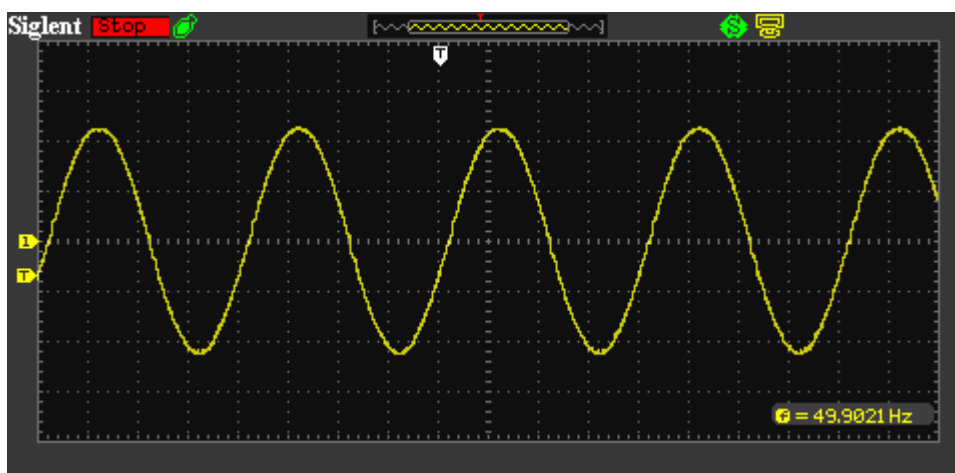

Figure 16: SPWM Output Voltage

In Figure 17, the SPWM output signal at pin 5 of the SLG46826V is illustrated. It shows how the output modifies its duty cycle with a sinusoidal variation.
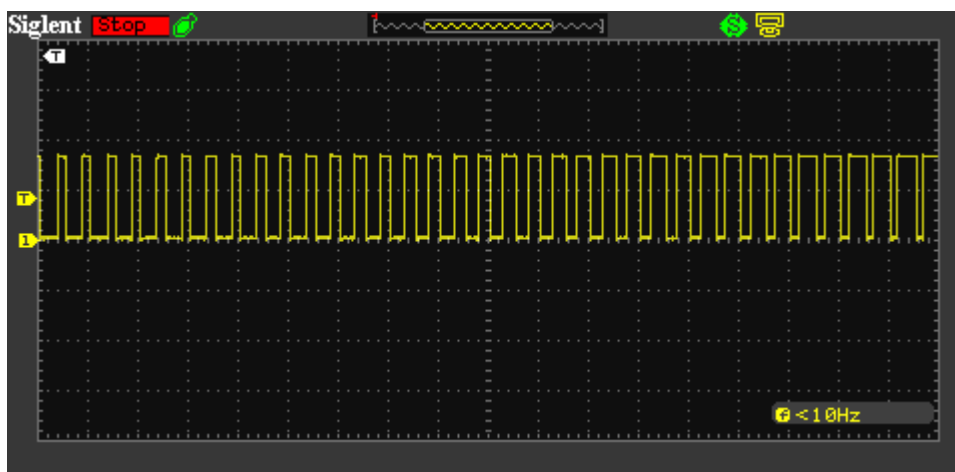
Figure 17: SPWM Output Signal

Conclusion

In this application note we implemented a Sinusoidal Pulse Width Modulation Generator. Sinusoidal pulse width modulation (SPWM) is one of the most widely used methods for implementing power inverters, useful for different applications such as motor controls and renewable energy applications.

There are several methods of implementing SPWM. In this application note, one of the simplest and most used methods is shown. Each step of SPWM generation and how it can be connected and filtered at the output is described.

The size of the entire measurement system is smaller than many other implementations and outlines where GreenPAK can be used and replace other programmable devices, such as a microcontroller or discrete circuitry.

Revision History

Revision	Date	Description
1.0	13-Oct-2020	Initial Version

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