ISSN: 2688-8645

Design of Mutiple Signal Generators based on DDS

Zhiyu Li[a], Yue Meng[b]

Tianjin University of Technology and Education, Tianjin 300000, China

[a]1935694739@qq.com, [b]1372715438@qq.com

Abstract

The hardware circuit of the signal generator mainly includes the main control module, DDS module, Voltage-Controlled Gain Amplifier (VCGA) module, keypad module, and LCD display module. The main control module is based on the STM32F103C8T6 as the core controller, and the signal processing section employs the low-power, programmable AD9834 DDS device. The VCGA module utilizes the AD8367 module, providing a controllable 32dB gain range to offer a 20mV/dB output. The waveform voltage amplitude can be adjusted by manipulating the potentiometer on the module and fed back to the oscilloscope. Experimental results demonstrate that the signal generator can produce square waves, triangular waves, sine waves, and sweep frequency waves with stable output waveforms and high resolution. Specifically, the sine wave and triangular wave can be generated within the frequency range of 1kHz to 200KHz, the square wave within the range of 75kHz to 200kHz, and the sweep frequency wave with a sweeping range from 1kHz to 100kHz.

Keywords

Signal Generator; STM32; DDS; DAC.

1. Introduction

A signal generator, also known as a signal source, is an essential electronic measurement instrument that provides waveform, frequency, amplitude, phase, and clock outputs [1]. It serves as a crucial tool for electronic engineers in conducting tests on electronic systems. As an electronic measurement instrument, its diverse range of waveform capabilities is applicable to a wide array of scenarios, including but not limited to sine waves, square waves, pulse waves, and triangular waves. The generation of these various waveforms aims to meet different testing requirements. For instance, sine waves are useful for evaluating the frequency response of a system, square waves are suitable for testing the system's rapid switching capabilities, and pulse waves are typically employed for pulse response testing.

In practical applications, the signal generator typically employs the "excitation-response" method to test the entire circuit system. When measuring the performance and parameters of electronic components or systems, engineers rely on the excitation signals generated by the signal source. By injecting signals of specific frequencies, amplitudes, and phases into the system and observing the system's response, engineers can evaluate its performance, identify potential issues, and conduct effective troubleshooting. The analysis of the overall circuit system, including its structure and performance, holds significant importance in gaining insights into its functionality.

2. Waveform Generation

2.1. DDS Principle

The Data Distribution Service (DDS) technology is based on the Nyquist Sampling Theorem. The Nyquist Sampling Theorem is a fundamental theorem for digitizing analog signals. According to this theorem, to completely preserve all information of a continuous-time signal $f(t)$, the sampling frequency f_s must be greater than or equal to twice the highest frequency f_m of the continuous-time signal. Otherwise, due to aliasing, the original time signal cannot be faithfully reproduced.[2]

The Data Distribution Service (DDS) technology is based on the Nyquist Sampling Theorem. The Nyquist Sampling Theorem is a fundamental theorem for digitizing analog signals. According to this theorem, to completely preserve all information of a continuous-time signal $f(t)$, the sampling frequency f_s must be greater than or equal to twice the highest frequency f_m of the continuous-time signal. Otherwise, due to aliasing, the original time signal cannot be faithfully reproduced.[2]

DDS addresses the question of whether a discretized time signal can be faithfully restored to the original signal without distortion. The operational structure of DDS, as shown in Figure 1, consists of n-bit adders and phase registers, n-bit waveform storage, a DAC converter, and a low-pass filter. By writing the frequency control word K to the adder and phase register, both receive data and perform phase data summation.[3] The result is sent to the input of the register and undergoes linear accumulation of the frequency control word under continuous clock stimulation. Finally, after sampling and quantization, the data is stored in the waveform storage ROM to create a waveform data table.

When outputting a waveform, the system, driven by the clock, sequentially selects and reads from the waveform data table. This process yields a digitized signal. The digital signal is converted to an analog signal through the DAC, and, ultimately, the pure waveform signal is obtained after passing through a low-pass filter circuit to filter out the high-order harmonics of the analog signal generated by the DAC. The process of DDS operation, including phase accumulator, waveform storage, DAC conversion, and waveform output through the low-pass filter, is illustrated in Figure 2.

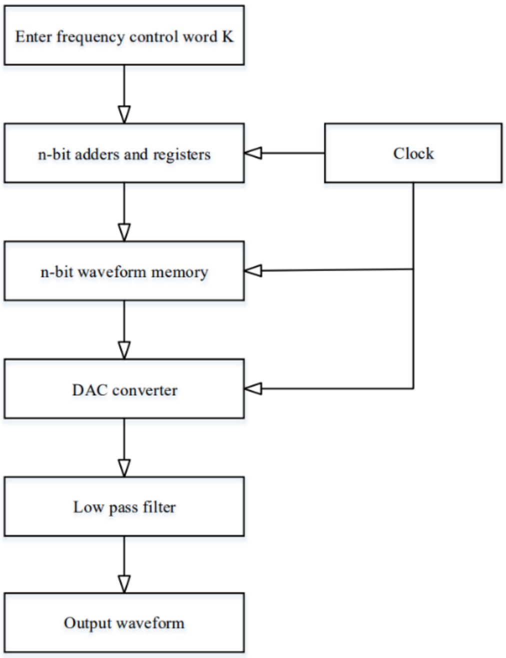

Figure 1. Block Diagram of DDS Working Structure

As depicted in Figure 2, the operation of DDS involves a sequential process comprising the phase accumulator, waveform storage, DAC conversion, and Low-Pass Filter (LPF) output processing. This series of steps completes the waveform output process.

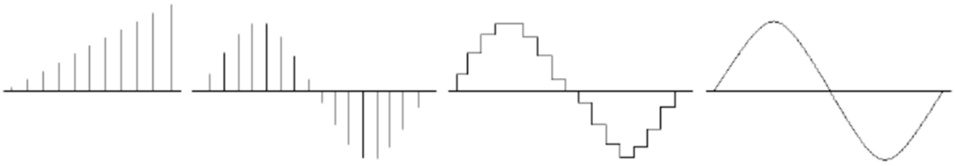

Figure 2. DDS Waveform Output Process

2.2. The Characteristics of DDS Output

DDS is a novel form of digital frequency synthesis that has shown outstanding performance in electronic measuring instruments and has become the mainstream technology in devices related to this field. Its main features are as follows:

1).Arbitrary Waveform Output.DDS can output arbitrary waveforms using a "table lookup" method. The phase determined by the frequency control word is used to find the corresponding amplitude from the data in the waveform storage ROM, making the method simple and fast.

2).High Frequency Resolution.DDS has a large frequency resolution. The theoretical analysis of DDS shows that the frequency resolution depends on the clock frequency and the number of bits in the register. Increasing the number of bits in the register exponentially increases the number of sampled frequency points, allowing for significant improvement in frequency resolution. This enables fine-tuning and facilitates the observation of waveform changes.

3).Frequency Bandwidth.According to the Nyquist sampling theorem, the synthesized frequency can generally reach half of the clock frequency f_C .However, due to limitations such as the low-pass filter and the scattering output characteristics of components, the synthesized frequency often outputs about 40% of f_C [4].

4).Unique Properties of DDS.DDS exhibits unique properties such as strong controllability, high integration, low power consumption, and more.

2.3. Designed using AD9834

The AD9834 integrates two 12-bit frequency registers and two 28-bit phase registers. The phase values range from 0 to 2π.[5] By writing the frequency control word K to the phase registers, it generates waveforms according to the DDS working structure. The 28-bit phase registers allow fine-tuning of the phase, enabling the generation of arbitrary waveforms with adjustable output frequencies.[6]

$$f=\frac{K\cdot f_C}{2^{28}} \tag{1}$$

The phase accuracy of the AD9834 is:[7]

$$\theta=\frac{2\pi}{2^{28}} \tag{2}$$

Table 1. Iout Output Characteristics

OPBITEN Bit	MODE Bit	I_{out}
0	0	Sine Wave
0	1	Triangular Waves
1	0	Square Wave
1	1	Sweep Frequency

SINROM is used for querying and converting phase information, consisting of a 28-bit control register. Among them, the OPBITEN Bit, MODE Bit, SIGN/PIB, and DIV2 Bit four enable ports play a crucial role in waveform generation. The Iout port is responsible for outputting the waveform, and different output ports imply different responsibilities for the four enable ports. Table 1 illustrates the characteristics of Iout output for each enable port [8].

3. Hardware and Software Design Principles

3.1. Hardware Design

The hardware circuit of the signal generator primarily consists of a microcontroller (MCU), Digital Frequency Synthesizer (DDS), Digital-to-Analog Converter (DAC), Voltage-Controlled Variable Gain Amplifier (VCA), and other components. The circuit employs the STM32F103C8T6 as the main control chip, forming the DDS driver board with built-in components such as an analog-to-digital converter, a 128x64 LCD display, JTAG driver port for downloading, and a reset switch. This module operates on a 5V power supply and utilizes DDS technology as the core solution for the signal generator.

In the block diagram, the STM32 main control chip receives commands from the keypad module, controls the LCD12864, and communicates with the AD9834 using the SPI communication protocol. This allows the waveform frequency to be displayed on the LCD12864 screen. The AD9834 can output waveforms, and the gain adjustment module AD8367 is used to achieve a signal output amplitude of up to 5V. Figure 3 represents the overall system block diagram of the signal generator.

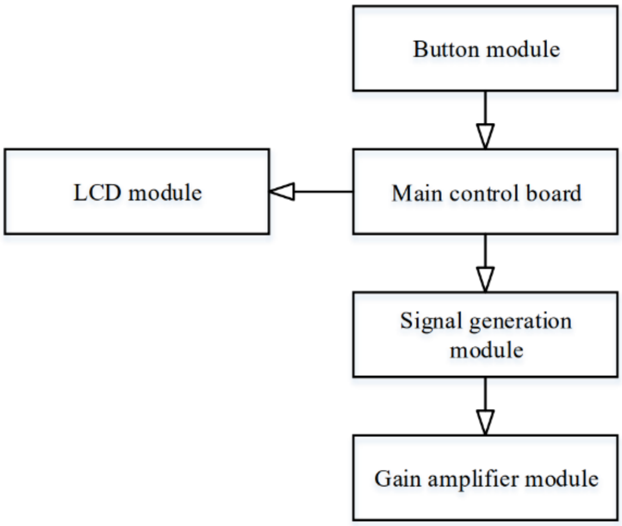

Figure 3. Hardware Design Block Diagram of the Multi-signal Generator

3.2. Software Design

For software design, Keil4 for ARM is utilized as the development environment for C language programming. The program design is mainly divided into the main control module, keypad control module, LCD display module, and waveform generation module.

Upon powering up the main control board, the main function, which includes the main loop, system initialization, and exit, is executed. The system initialization involves delay initialization, keypad control initialization, 128x64 LCD screen initialization, waveform switching initialization, and DAC initialization. After initialization, the program enters the data writing phase for the DAC, followed by entering the main loop.

After writing data, the AD9834 generates waveforms. With the influence of the keypad control module, STM32 performs SPI communication via the three lines (FSYNC, SCLK, SDATA) to send data to the 128x64 display and achieve visual representation. The program design flowchart is illustrated in Figure 4. Additionally, the program can be downloaded through the JTAG port on the DDS driver board. [9,10]

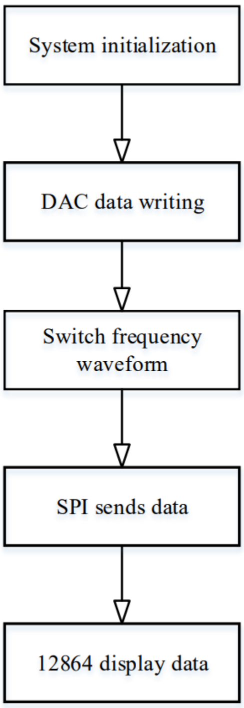

Figure 4. Software Design Block Diagram of the Multi-signal Generator

4. System Debugging and Testing

The output amplitude range for different frequency values of sine waves is summarized in the table below:

Table 2. Sine Wave Test Results

Number	Frequency /kHz	Amplitude Range/V
1	1	0.05—4.55
2	5	0.05—4.60
3	10	0.05—4.60
4	15	0.05—4.60
5	20	0.07—4.60
6	30	0.08—4.65
7	40	0.08—4.65
8	50	0.07—4.70
9	75	0.09—4.75
10	100	0.10—4.80
11	110	0.10—4.80
12	120	0.10—4.85
13	150	0.10—4.85
14	175	0.10—4.85
15	200	0.10—4.85

During the debugging process, the primary focus is on testing different frequency values for sine waves, square waves, triangular waves, and sweep frequency waves to observe their corresponding amplitudes. The testing also includes evaluating the duration and amplitude of the sweep frequency wave within a specified frequency range. The control variable method is applied, measuring the frequency and amplitude of the waveforms multiple times and compiling the data.

The output amplitude range for different frequency values of triangular waves is provided in the following table:

Table 3. Triangular Waves Test Results

Number	Frequency/kHz	Amplitude Range/V
1	1	Distortion
2	5	Distortion
3	7	Distortion
4	8	Distortion
5	9	Distortion
6	10	0.20—3.80
7	15	0.20—3.85
8	20	0.20—3.85
9	30	0.19—3.90
10	40	0.19—3.90
11	50	0.19—4.00
12	75	0.19—4.00
13	100	0.18—4.05
14	150	0.20—4.10
15	200	0.20—4.10

The output amplitude range for different frequency values of square waves is presented in the following table:

Table 4. Square Wave Test Results

Number	Frequency/kHz	Amplitude Range/V
1	1	Distortion
2	5	Distortion
3	10	Distortion
4	15	Distortion
5	20	Distortion
6	30	Distortion
7	40	Distortion
8	50	Distortion
9	75	2.00—5.00
10	100	1.85—5.00
11	110	1.88—5.00
12	120	1.85—5.00
13	150	1.85—5.00
14	175	1.85—5.00
15	200	1.90—5.00

Due to the dynamic nature of the sweep frequency signal, during the testing process, it is necessary not only to measure its amplitude range but also to determine its output time based on its step size and scanning duration.

1). To test the amplitude range of the frequency output, it is essential to fix the waveform, maintain consistent start and stop frequencies for the sweep frequency wave, use a step size as small as possible, and maximize the scanning time.

The test results are presented in the following Table 5.

Table 5. Sweep Frequency Wave Amplitude Testing Results

Number	Frequency/kHz	Amplitude Range/V
1	1	0.03—3.10
2	2	0.07—3.20
3	3	0.11—3.70
4	4	0.14—4.10
5	5	0.15—4.25
6	6	0.15—4.30
7	8	0.18—4.55
8	10	0.19—4.60
9	12	0.20—4.65
10	15	0.20—4.65

2).While ensuring non-distortion, adjusting the appropriate amplitude using the control variable method. The frequency range is set from 1 to 100 kHz. For the first five sets of data, in order to better observe the effect, the scanning time is adjusted to 999 ms, while keeping the scanning time constant, the step size is changed. For the next five sets of data, with the step size unchanged, the scanning time is varied. The results are summarized in Table 6.

Table 6. Sweep Frequency Wave Time Testing Results

Number	Frequency Range/kHz	Step/Hz	Scanning time/ms	Theoretical time/s	Actual time/s
1	1—100	1000	999	99	100.5
2	1—100	2000	999	49.5	51.0
3	1—100	3000	999	33	33.3
4	1—100	5000	999	19.8	20.9
5	1—100	7500	999	13.2	12.2
6	1—100	5000	200	3.96	3.63
7	1—100	5000	300	5.94	6.77
8	1—100	5000	500	9.90	10.14
9	1—100	5000	750	14.85	15.7
10	1—100	5000	999	19.80	20.05

5. Conclusion

The continuous digital signal generated by the AD9834 DDS undergoes sampling, quantization, and encoding to obtain a continuous analog signal. From Tables 2, 3, 4, and the debugging process, it is evident that the amplitude of the signal is significantly influenced by the frequency value due to the AD8367 amplifier. However, it can be observed that the achievable output frequency ranges are 1 kHz to 200 kHz for sine and triangular waves, 75 kHz to 200 kHz for square waves, and 1 kHz to 100 kHz for sweep waves. The output signal remains relatively stable within the range of 0.15 V to 4.60 V. Any values outside this amplitude or frequency range may potentially result in signal distortion.

One reason for distortion may be the absence of a direct current stabilizing source in the vicinity. The high-performance output amplification module supports direct current supplies of 10V and above. All modules are designed for a 5V USB power supply, naturally limiting the output amplitude to below 5V. Additionally, the chosen oscilloscope has a lower resolution and a smaller number of sampling points, potentially leading to incomplete waveform displays. Therefore, when adjusting the potentiometer, caution should be taken not to adjust it too high until saturation, and efforts should be made to keep the signal amplitude below 4.6 Vpp.

References

[1] Zhou Hongyan. Design of Function Generator Based on DDS. [J]. Electronic Science and Technology University. 2007(03). Design and Detection of Square Wave Signal Generator Based on STM32. [J]. Journal of Guangxi University of Science and Technology. 2021,32(01).

[2] Hu Lijian. Design and Implementation of Arbitrary Waveform Generator Based on DDS. [D]. Xidian University. 2009(07).

[3] Shen Hui, Xue Bing, Tang Chaoyang, Yu Jiajia, Jing Jiarong. Design of Signal Generator Based on DDS Technology. [J]. Electronic Measurement Technology. 2020,43(20).

[4] Yang Rui. Design of Signal Source Using DDS Technology. [D]. Huazhong Normal University. 2012 (10).

[5] Xu Fei, Hu Jun, Liu Tong, Xu Linkang. FSK Modulation Signal Based on AD9834. [J]. Yunnan Chemical Industry. 2020,47(05).

[6] Li Yanhong. Design of Signal Generator Based on Direct Digital Frequency Synthesis Technology. [J]. Electronic World. 2012(16).

[7] Zhao Lina. Research and Design of DDS Signal Generator Based on FPGA. [D]. Hebei University. 2013 (02).

[8] Analog Devices, Inc. AD9834, AD9834 (Rev. D) (analog.com), 2003.

[9] Huang Pengyong. (2013). "Design of a Function Signal Generator Based on FPGA." Sci-Tech Square, 11.

[10] Chong Wang,Linlin Chen,Qun Sun,Ying Zhao.Design and Experiments of a Waveform Generator Based on DDS Technology.[J].Recent Patents on Engineering.Volume 14, Issue 4.2020.