Design and Implementation of DAC Circuit in Waveform Generator

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Abstract. This article combines the different stages and different levels of various courses such as circuit principle, analog circuit, digital circuit, signal and system, single-chip microcomputer principle, FPGA application and practice, and utilizes the flexibility and interest of the "hardwood classroom" personal multi-functional experimental platform. The simulation design and experimental test of the DAC circuit and signal conditioning and waveform reconstruction circuit in the waveform generator are completed step by step, which fully reflects the process and fun of electronic system design.

1. Introduction
Waveform generator is a common instrument and equipment in electronic technology and is an essential assistant for debugging circuits. In the waveform generator, the DAC circuit and signal conditioning and waveform reconstruction circuits also have a crucial determinant for the performance of the device. The design concept of this project comes from a Taobao experience. Because teaching and research require the purchase of waveform generators, the waveform generator on Taobao is often used for thousands of yuan. However, after analyzing its circuit, it is found that its circuit composition is very simple and it can be made at low cost. And each part of the circuit is very suitable for students to carry out progressive practice training in different professional courses, and finally form a complete electronic product. This can not only meet the requirements of curriculum experiments, but also allow students to experience the development process of electronic products, which is conducive to the cultivation of students' innovative ability.

2. Implementation Plan
In the first stage, the contribution of each input voltage to the output in the R-2R resistor network is analyzed using the knowledge of circuit principle, and the circuit is simulated. Operational amplifier is adopted to produce positive feedback and generate square wave signal, then square wave signal forms triangular wave signal through integral circuit, and modulate triangular wave to generate PWM (SPWM) wave by modulating signal.

In the second stage, the back-end circuit of R-2R DAC is designed using the knowledge of the analog circuit, including the choice of the amplifier in the circuit(according to the frequency and voltage range of the output signal), and low-pass filter design(introducing the spectrum of the DAC output signal with the knowledge of the signal and the system to tell the student that the cutoff frequency design of the filter is fout, filtered with an RC circuit or an active filter), designed, and on the bread board. Set up the circuit, used the DIGITAL OUT of the experimental platform to refresh the self-made R-2R DAC (given
the refresh rate, importing different waveform tables to output sine waves of different ranges and frequencies), the measured time compares the waveforms before and after the filter. The output DC level of the signal source of the experimental platform is used to change the DC component of the output signal.

In the third stage, FPGA or MCU minimum system is used instead of the experimental platform to complete the refresh of the R-2R resistance network.

3. Design and Implementation of DAC Circuit

![R2R resistance network DAC](image1.png)

Figure 1. R2R resistance network DAC

The 8bit R2R resistor network DAC circuit principle is as shown in Figure 1, the binary input D0-D7, each bit of voltage is 0 or Vref. The R2R resistance network DAC is a simple resistance network and does not require the assistance of the amplifier. An n-bit R2R resistance network DAC requires only N-1 R resistance and N +1 2R resistance, and only two types of resistance are required. The value is convenient for manual production. In applications with low accuracy requirements, resistance construction can be used directly to avoid the use of integrated DAC, thereby reducing costs. The most amazing thing about this circuit is that regardless of where it is disconnected, the impedance is R inward. The output impedance is fixed to R. Since the output impedance is constant and easy to calculate, it is convenient to match the output impedance. The output of the R2R resistance network DAC is as follow:

\[
V_{out} = \frac{V_{ref}}{2^8} \left(2^7D_7 + 2^6D_6 + \cdots + 2^0D_0\right)
\] (1)

The simulation of the 3-bit R-2R resistance network DAC circuit principle is as shown in Figure 2:

![3bit r-2r DAC circuit simulation](image2.png)

Figure 2. 3bit r-2r DAC circuit simulation

The experimental circuit is constructed on the "Hardwood Classroom" personal multi-functional experimental platform as shown in Figure 3:

![3bit r-2r DAC experimental circuit](image3.png)

Figure 3. 3bit r-2r DAC experimental circuit
Do a 3bit quantization table for sine waves as shown in Figure 4:

| N | Sine wave | Peak-to-peak is 15 | Quantized(4 bits) |
|---|-----------|---------------------|-------------------|
| 0 | 1         | 7.5                 | 7                 |
| 1 | 1.209016989 | 9.81762742 | 9                 |
| 2 | 1.587785244 | 11.90838933    | 11                |
| 3 | 1.609016985 | 13.56762739    | 13                |
| 4 | 1.951056518 | 14.63292382    | 14                |
| 5 | 2          | 15                 | 15                |
| 6 | 1.951056525 | 14.63292395    | 14                |
| 7 | 1.609017016 | 13.56762762    | 13                |
| 8 | 1.587785287 | 11.90838965    | 11                |
| 9 | 1.30901704  | 9.817627802    | 9                 |
| 10| 1.000000004 | 7.500000402 | 7                 |
| 11| 0.690980206 | 5.182372963    | 5                 |
| 12| 0.41221488  | 3.091810996    | 3                 |
| 13| 0.190982543 | 1.423272849    | 1                 |
| 14| 0.048943507 | 0.267076302    | 0                 |
| 15| 0.321965515 | 2.414744-15     | 0                 |
| 16| 0.048943457 | 0.367075929    | 0                 |
| 17| 0.190982952 | 1.423271241    | 1                 |
| 18| 0.41221467  | 3.091810023    | 3                 |
| 19| 0.690982909 | 5.182371816    | 5                 |

Figure 4. 3 bit quantization table

4. Filter Reconstruction Circuit

When the DDS clock frequency is FC and the output frequency is, the spectral characteristics of the sine signal output of DA are shown in Figure 5.

In addition to the main frequency, there are also non-harmonic components distributed on both sides of the output spectrum. The amplitude envelope is a Sa-function, that is, its spectrum is weighted by the Sa-function. When the output frequency is large, the amplitude will decay. In order to obtain the required signal in the frequency band, a low-pass filter needs to be added to the DDS output, and the D/A output step signal is smoothly filtered through a low-pass filter to filter out unwanted frequency components in order to output the spectrum pure waveform signal.

The designed low-pass filter circuit is shown in Figure 6.

Figure 6. Low pass filter circuit simulation
The frequency characteristics of the designed low-pass filter circuit are shown in Figure 7.

![Figure 7. Frequency characteristics of low-pass filter circuits](image)

A filter reconstruction circuit is composed of two RC filter circuits and a homogeneous proportional amplifier circuit to form a second-order low-pass filter. It is characterized by high input impedance and low output impedance.

Use an oscilloscope to observe the DA output waveform as shown in Figure 8. Yellow is the signal before filtering and blue is the signal after filtering.

![Figure 8. Signal before and after filtering](image)

5. Conclusion
This project is a typical application case to solve the actual problems of electronic system engineering. From the point of view of the design process, it is a relatively complete small system design project and needs to be fully stored. Experienced learning research, scheme demonstration, system design, Circuit
welding, unit circuit debugging, integrated circuit modulation testing, design summary, Shen You defense and other processes. This project makes full use of the flexibility and interest of the pocket experiment platform through comprehensive experiments across the course content. Students design and build their own experimental content to complete the gradual experiment content, and fully experience the process and fun of electronic system design. This case can be used to solve practical engineering problems through the application of electronic integrated experimental skills, allowing students to master knowledge such as small signal amplification, power amplification, filtering, Modulo number Modulo conversion, and electronic system design methods. At the same time, the students 'self-study ability, comprehensive application ability, communication ability and collaborative innovation ability are actually cultivated through engineering.

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