High-dynamic Bridge Amplifiers with Generator for Piezoelectric Actuator

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Abstract. **Piezoelectric amplifier is a very important part of the piezoelectric actuator.Not only positioning accuracy,but also dynamic performance and power are demanded more and more highly. At present piezoelectric amplifier are mainly used in static applications, power and frequency response are usually incompatible.This paper developed a new type of piezoelectric amplifier to meet high demand for dynamic,which takes dual-power supply, bridge-output to achieved slew rate, power were doubled, and maintain a wide frequency range at the same time. Controller implements DDS unit through FPGA,which could achieve sine, triangle, square and sawtooth.**

Keywords: piezoelectric amplifier, bridge, dynamic,DDS

I. INTRODUCTION

Piezoelectric actuator that owns small dimension, high resolution of displacement, high frequency response, no noise, no heat and other characteristics, is an ideal micro-displacement components [1]. With the deepening studied the microscopic world, piezoelectric ceramics are widely used in electron microscopy, high-speed scanning probe, piezo inkjet printers and copiers, high-performance hard drives, especially in the internal combustion engine fuel injection and fine areas of EDM [2-8]. This requires not only the piezoelectric actuator power higher positioning accuracy, and have a wide range of frequency response, while providing higher power output. But the amplifier gain-bandwidth product is certain, so how to solve the contradiction between high frequency and high power, has important theoretical and practical value. This application is designed for such a high dynamic bridge piezoelectric power supply, and using DDS technology to achieve the power comes with digital signal generator functions, improve the power of integration and convenience.

II. DESIGN OF HIGH DYNAMIC PIEZOELECTRIC AMPLIFIER

A. Common type of piezoelectric actuator power supply.

Now in the widely used PZT There are two main types of power, charge type and voltage type. Charge-control drive power is the use of piezoelectric ceramic piezoelectric displacement charge on the freedom of their linear relationship, with good linear open-loop control, with load capacity, frequency bandwidth. But low-frequency stability is poor, there is charge leakage, the output Voltage saturation and the zero displacement control difficult issues. PZT power supply voltage is mainly applied to static applications, the dynamic application of its amplitude as the frequency increases the output attenuation is very significant, limiting the time of its application in dynamic load capacity.

B. High dynamic bridge drive power

The proposed high dynamic bridge Piezoelectric amplifier overcomes the above contradiction and achieves a high dynamic power drive. The specific topology is shown in Fig. 1.

UA is the main amplification section and the input signal is amplified with -RFA/RA times. UB is the last level enlarged part of the output of the previous level with -RFB/RB times. Usually a unit gain with inverting amplifier is obtained. So the applied voltage of piezoelectric actuator CL is VA-VB and the gain is twice of the previous level of the main amplifier. The unipolar and bipolar output polarity can be achieved according to the polarity of the input signals.

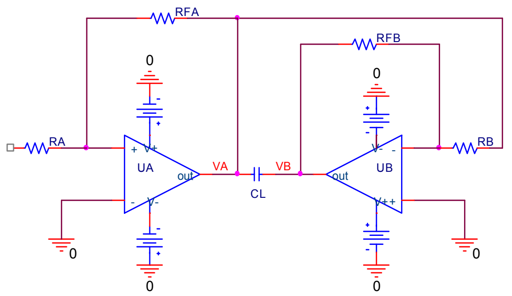

Fig. 1 Bridge amplifier circuit model for spice simulation

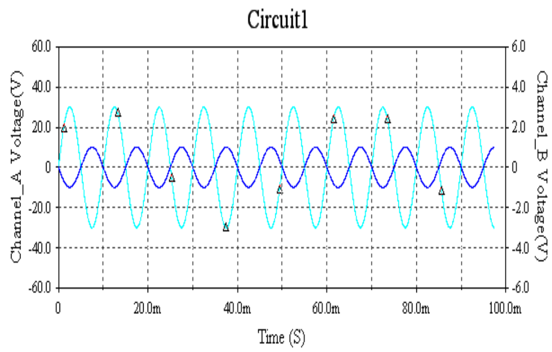

Fig. 2 Bridge amplifier spice simulation

C. Bridge connecting the characteristics

(1) By connecting two amplifier with a bridge style, the output voltage is twice of the single op amp. The bridge circuit is the only way to obtain the bipolar output with single-supply. When power supply voltage is relatively low, amplifier output closes to supply voltage or an amplifier can not provide enough output, the bridge amplifier is very meaningful. Because the output voltage is twice of the single amplifier, the output power is double of the single amplifier.

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(2) Due to the amplifier is nonlinear symmetry, the conversion rate is double and the second harmonic distortion can be reduced compared with single amplifier.

(3) The bridge circuit output voltage is twice of the single amplifier. The implementation is achieved with two op amp, which does not affect the bandwidth of a single-stage amplifier to achieve the basis of the voltage amplification. So its frequency response is much higher relative to the commonly used piezoelectric actuator amplifier. Fig. 3 is the prototype of APEX's PA93 bridge amplifier

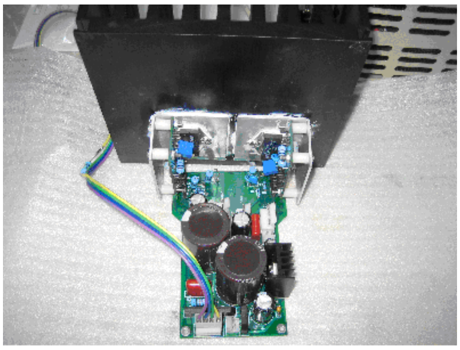

Fig. 3 Prototype of developed bridge drive amplifier

D.Digital Signal Generator Based on DDS

Piezoelectric amplifier in dynamic applications needs to use a variety of dynamic waveforms as the input signal, such as sine, triangle, sawtooth wave, etc.. General signal generator can be used as input signal, but it is too big and costly. PC-stored waveform is also used, then transfer the signal by serial or parallel interface. But the speed of the transmission is limited. Piezoelectric ceramic actuators for dynamic applications based on DDS technology is desiged for a piezoelectric actuator power as the control waveform output module. The module can adjust the frequency and amplitude of output voltage waveform. Thus the piezoelectric ceramics under high-speed dynamic applications can by driven by the signal source.

THE PRINCIPLE OF DIGITAL FREQUENCY SYNTHESIS

DDS technology is built on the basis of the sampling theory, the first step is to generate the waveform and sample. The digitized sampled values will be stored in memory as a lookup table, then the data is read by the lookup table after converting the data into the analog by D/A converte. The basic circuit diagram is shown in Fig. 4.

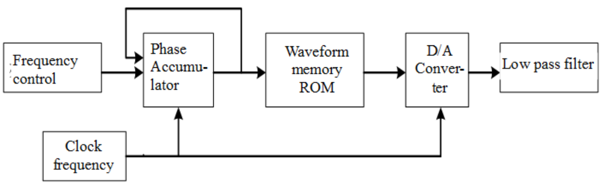

Fig.4 Theory of digital frequency synthesis

The DDS is mainly composed of four parts by phase accumulator, waveform memory, ROM, D/A converter, low pass filter. For each clock frequency signal, M-bit phase accumulator for frequency control word K (frequency control word K is the incremental value of the phase and K is a binary integer) were accumulated to obtain the phase code Φ(m). The phase of the high A-bit code as the address lines of ROM waveform memory addressing, so that the output rate of the corresponding serial number. Then the D/A converts analog zigzag staircase and further smooth the output waveform signal is produced through the low pass filter. Because the phase accumulator word length is limited, accumulator will automatically overflow as soon as the count value is greater than 2M. The waveform memory address plus one. Therefore, the phase will increased in the same clock frequency by changing the conditions of frequency control word K, and the output frequency will be changed. The relationship of output frequency fc, clock frequency fo and frequency control word K is as following.

$$f_o = \frac{K}{2^M} \cdot f_c \qquad (1)$$

Where M is the phase accumulator bits.

By (1), we can get the relation of minimum frequency resolution $\Delta f_{\min}$.

$$\Delta f_{\min} = \frac{1}{2^M} \cdot f_c \qquad (2)$$

A. *Improved DDS digital frequency synthesis*

By analyzing the equation (1), the frequency can be changed by adjusting the fc, M and K. Since M changes slightly, the frequency of the waveform synthesized is decided by the other two variables[9].

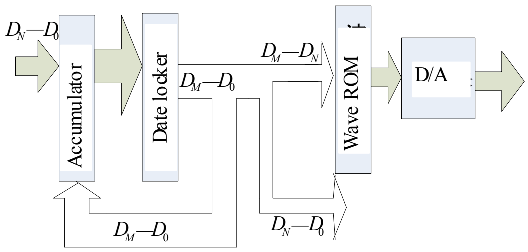

Fig. 5Block diagram of direct digital synthesis

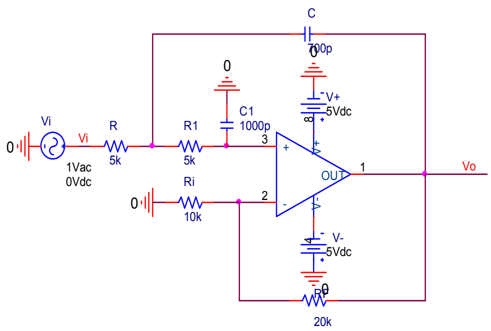

Fig. 6 Simulation of second-order low-pass filter circuit model spice

In practice, the method by changing the clock frequency can obtain a frequency change in a periodic signal. But it is very difficult to get an adjustable high accuracy and stability of the clock signal. By applying wave frequency control method and selecting the crystal oscillator as clock, a high stability clock can be obtained. a great storage space for waveform data is needed in order to get a lower signal frequency. And each time the waveform frequency will be changed with the change of a waveform storage points. The waveform generator of output waveform amplitude is significantly changed. The continuity is poor. To avoid these problems, an improved direct digital synthesis method is applied in the specific design as shown in Fig. 5 [10]. DM-D0 address data is divided into two parts. Position of High DM-DN is connected with the waveform memory, the DN-D0-bit space is not used. DM-DN data growth will not be greater than 1, each of which can be read from the waveform memory data and ensure the accuracy of the output data. Data Fin changes to control DM-DN data rate, thus changes the rate of synthesis waveform data and the frequency of the output waveform to ensure that the same synthetic waveform data points.

III. DYNAMIC PERFORMANCE OF BRIDGE DRIVE AMPLIFIER

A. Performance analysis of Bridge drive amplifier

In the actual circuit, DDS function generator achieves digital signal from the FPGA, the output noise of the FPGA is filtered by designing a second order low pass filter. The schematic diagram is shown in Fig. 6. The triangle, sawtooth, sine and square wave is produced. This article only gives the sine wave frequency in the 1HZ and 1KHZ waveform in Fig. 7 and Fig. 8.

DDS output waveform is amplified through the bridge circuit. The second level unity gain inverting amplifier is omitted and the piezoelectric actuator is German PZ ceramic with electrical capacity 0.7uF. When the piezoelectric actuator is applied voltage of 60V, 80V and frequency is 1K, 3K the output is shown in Fig. 9-12.

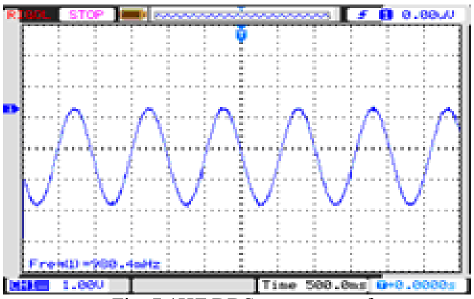

Fig. 7 1HZ DDS output waveform

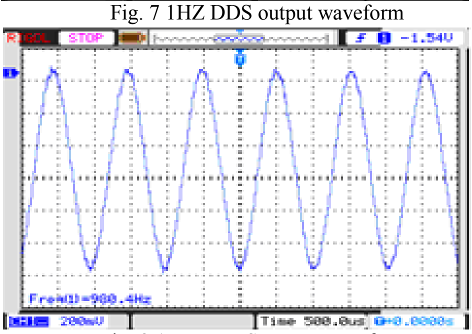

Fig. 8 1KHZ DDS output waveform

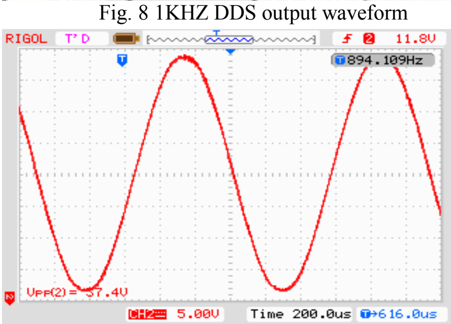

Fig. 9 1KHZ and 60V output waveform

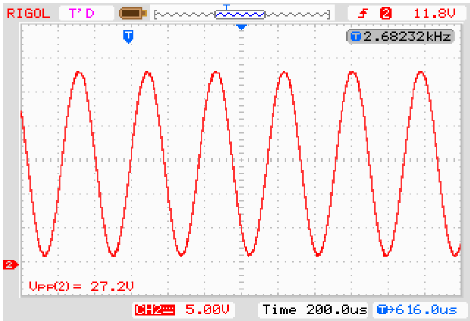

Fig. 10 3KHZ and 60V output waveform

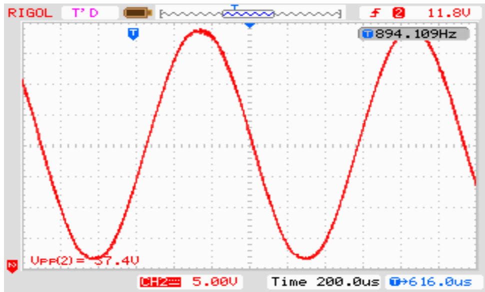

Fig. 11 1KHZ and 80V

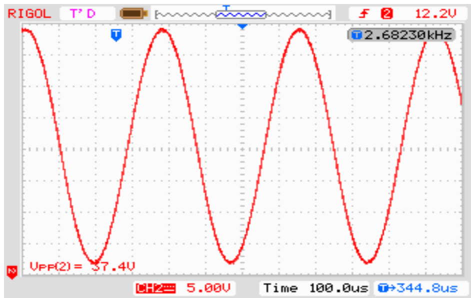

Fig. 12 3KHZ and 80V output waveform with load

B. Static characteristics analysis of bridge drive power

Static characteristics of piezoelectric actuator is the relationship between voltage and displacement. Because the stiffness of the piezoelectric material is stiffness, external forces on the actuator displacement are small. The test results of bridge amplifier is shown in Fig. 13.We Can see that the maximum displacement is up to 9.64um when output voltage is 150V. Step response time of bridge amplifier is only 30us, as shown in Fig. 14.

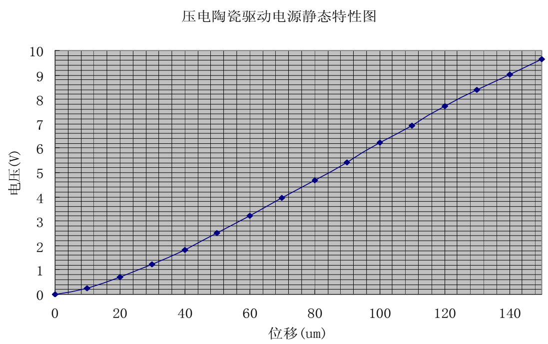

Fig. 13 Static characteristics

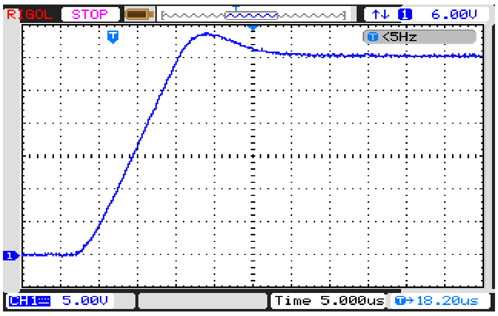

Fig. 14 Step response

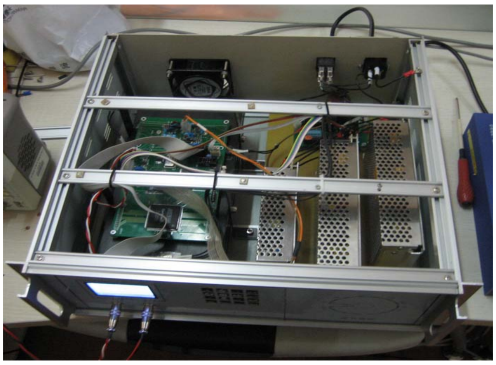

Fig. 15 Power prototype picture

The experimental results show that the developed amplifier can not only meet a large voltage output in dynamic application, but also meet the high frequency response requirements in high dynamic applications. Because of limiting the output power, the output amplitude is relatively small. The prototype picture of developed amplifier is shown in Fig. 15.

IV. SUMMARY

This paper presents a high dynamic piezoelectric actuator based on the bridge drive theory to achieve low-voltage power bipolar, unipolar high voltage output. The output gain is doubled without reducing frequency response speed. Control section using DDS technology realizes the function of digital signal generator, which replaces the large volume signal equipment, achieves a high degree of functional integration, reduces the volume of the power and improves ease of use.

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