Device for Measuring Signal Distortion

"Third Prize, National Undergraduate Electronic Design Contest & University-Level Innovation and Entrepreneurship Project"

Design Requirements

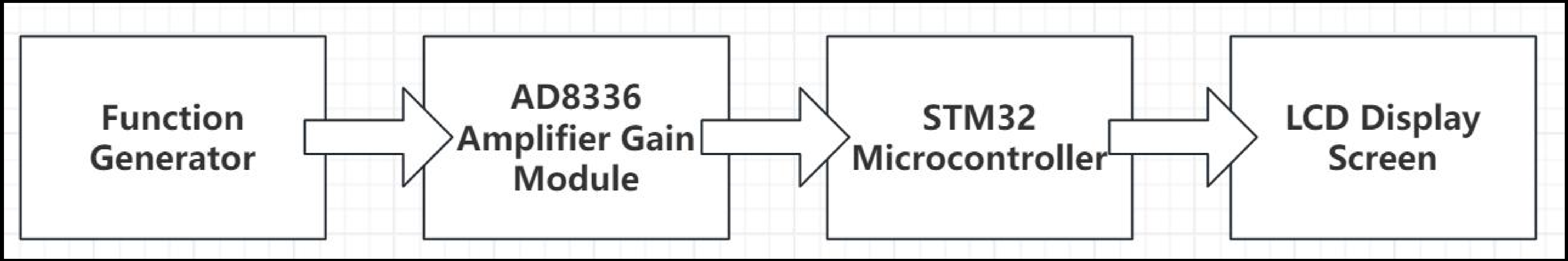
The project involves the design and construction of a **Signal Distortion Measurement Device**, comprising the following modules:

★ **Custom Signal Generation Module:** Produces signals in the frequency range of 1 kHz to 100 kHz with 1 kHz increments. Under a 500 Ω load, it can generate adjustable-amplitude signals from 5 mV to 1 V.

★ **Amplification Module:** Designed with an input impedance of 500 Ω, a bandwidth of 1 MHz to 20 MHz, and a gain of 40 dB, continuously adjustable from 0 to 40 dB. Under a 500 Ω load, the module outputs a 1 V peak-to-peak signal with minimal waveform distortion.

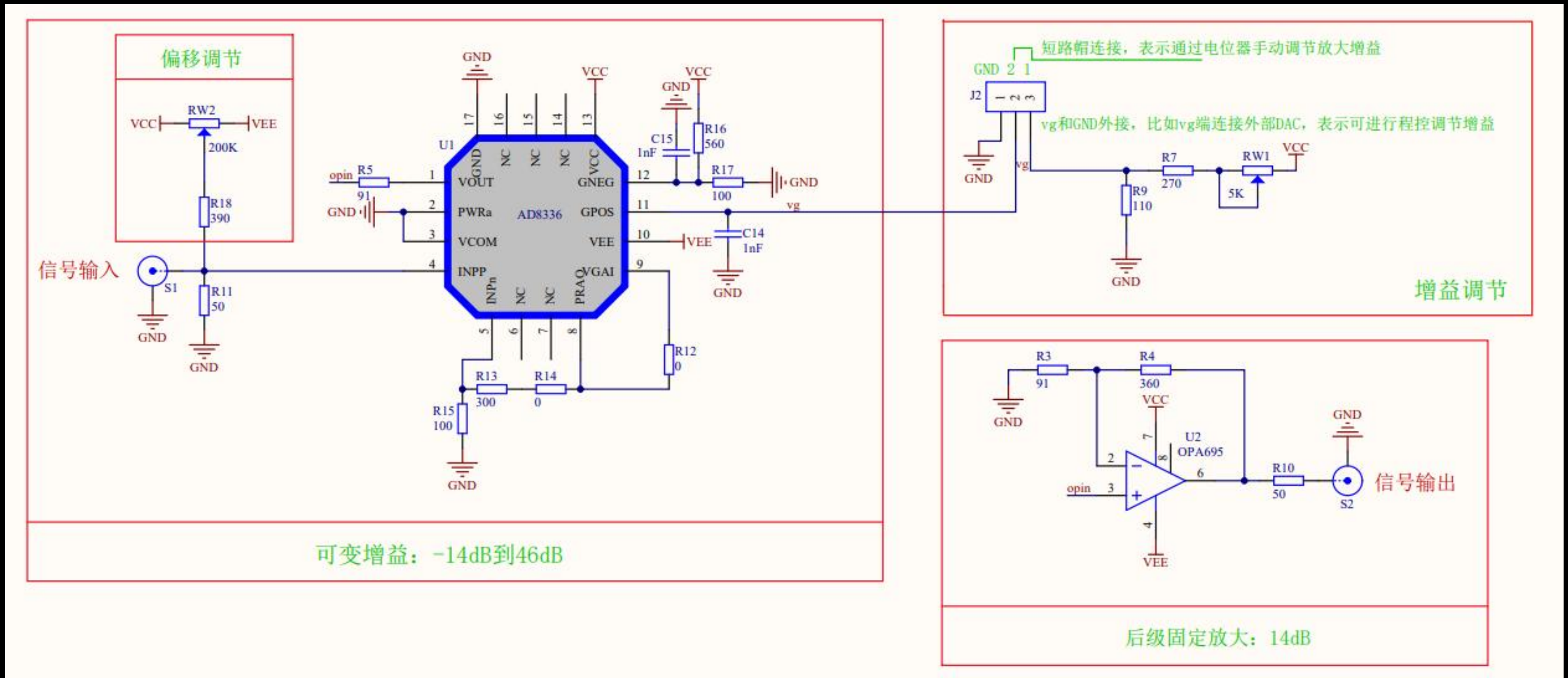
★ **Data Processing Module:** Performs Fast Fourier Transform (FFT) on the acquired digital signals and calculates the total harmonic distortion (THD) from the frequency-domain data.

General Framework



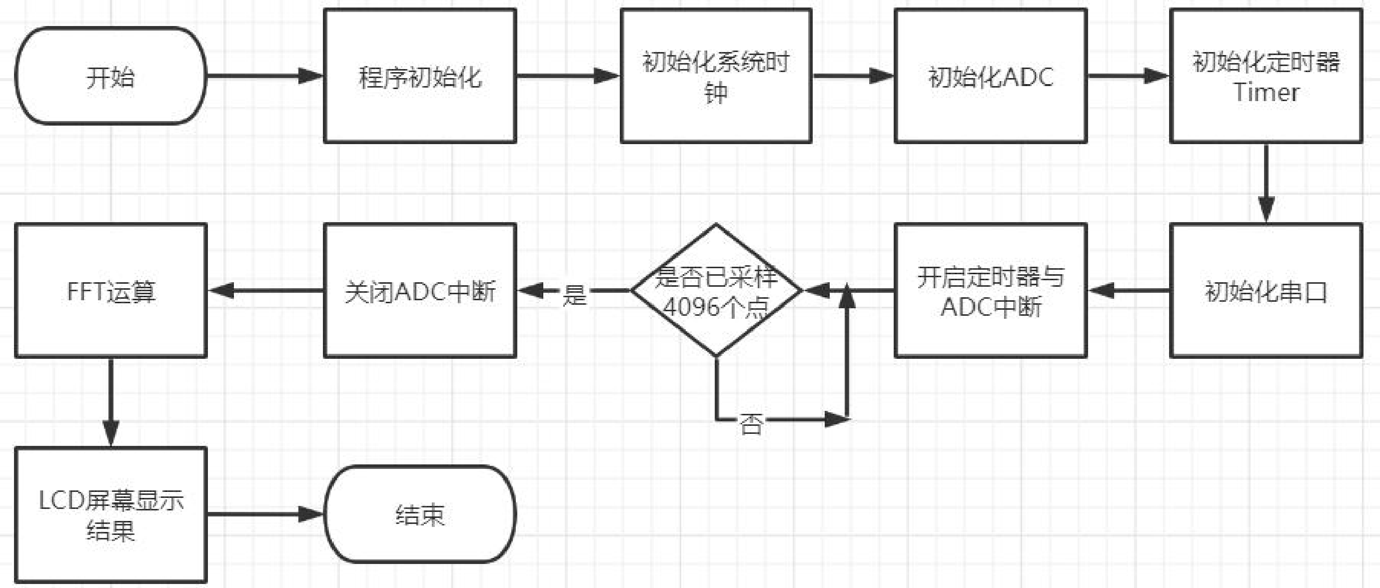
The system is primarily built around an STM32 microcontroller as the core processing unit. A function generator is used in place of the custom signal generation module to produce distorted waveforms. The generated signal is amplified by an AD8336 gain module and conditioned to a suitable amplitude range for microcontroller sampling. The conditioned signal is then fed into the microcontroller for ADC sampling, followed by FFT processing and distortion calculation. Finally, the measured distortion results are displayed on an LCD screen.

AD8336 Amplifier Gain Module



An offset adjustment circuit is incorporated at the front end of the module, allowing signal offset tuning via a variable resistor. At the back end, an adjustable-gain stage and a fixed-gain stage of 14 dB are integrated, enabling overall gain ranges of −14 dB to +46 dB and 0 dB to 60 dB. The gain of this module is configured with a sensitivity of 50 dB/V.

STM32 Microcontroller



The microcontroller initializes the program, system clock, ADC, serial interface, and timer, and then enables the timer and ADC interrupts. ADC sampling is performed within the timer interrupt service routine, with data stored in an array until 4096 samples are collected. After disabling the ADC interrupt, FFT is applied to obtain the harmonic amplitudes of the sampled signal, which are used to calculate the signal distortion. The final result is displayed on the LCD.

Algorithm Principle

FFT Algorithm Principle:

A 4096-point Fast Fourier Transform (FFT) is employed in this system. The FFT algorithm is an optimized implementation derived from the Discrete Fourier Transform (DFT), addressing the limitations of high computational complexity and slow processing speed associated with direct DFT computation. By significantly reducing the number of arithmetic operations, FFT enables efficient transformation from the time domain to the frequency domain, making it well suited for real-time spectral analysis.

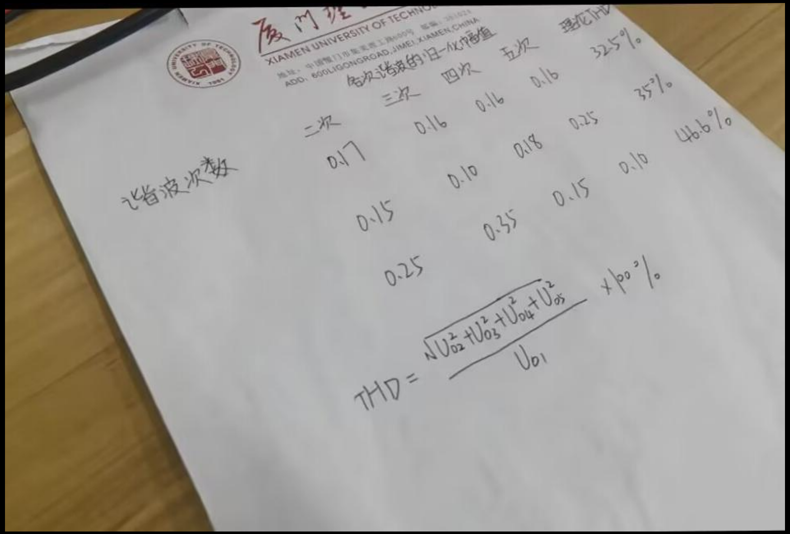
THD Algorithm Principle:

The Total Harmonic Distortion (THD) is calculated using an amplitude-based distortion evaluation method. The amplitudes of the fundamental and harmonic components are obtained from the FFT results and substituted into the standard THD formula to determine the distortion level. This approach features low computational complexity and high calculation efficiency, while providing a convenient means of extracting amplitude information directly from the frequency domain.

Attachment

Experimental Measurement

In this experiment, a normalized amplitude is adopted, with the fundamental component set to an amplitude of 1 V and a frequency of 1000 Hz.



The distorted signal is applied to an oscilloscope, where an FFT is performed to obtain its frequency-domain spectrum. Based on the spectral results, the number of harmonic components and the corresponding amplitudes of each harmonic are identified. These measured values are then substituted into the THD calculation formula as shown below.

$$V_{THD\text{-}F} = \frac{\sqrt{|V_2|^2 + |V_3|^2 + |V_4|^2 + |V_5|^2 + \ldots\ldots |V_N|^2}}{|V_1|} * 100\%$$

Using this method, the theoretical THD of the distorted signal can be obtained. In total, three different test signals were evaluated, and the corresponding results are summarized as follows.

Experimental Measurement

The distorted signals were input into the self-developed signal distortion measurement instrument to obtain the experimental THD values. Subsequently, the theoretical THD was calculated, and the absolute error between the theoretical and experimental THD values was determined. The results are summarized in the following table.

	Second Harmonic	Third Harmonic	Fourth Harmonic	Quintuple Harmonic	Theoretical THD	Experimental THD	Absolute error value
1	0.17 mV	0.16 mV	0.16 mV	0.16 mV	32.5%	30.26%	2.24%
2	0.15 mV	0.10 mV	0.18 mV	0.25 mV	35%	32.43%	2.57%
3	0.25 mV	0.35 mV	0.15 mV	0.10 mV	46.6%	44.55%	2.05%

Based on the experimental results, the absolute error between the theoretical THD and the experimentally measured THD remains within 3%, indicating a relatively small measurement deviation. These results demonstrate that the proposed signal distortion measurement instrument achieves good accuracy in evaluating the total harmonic distortion of amplitude-distorted waveforms.

Notes

★ Function Generator: Generates arbitrary distorted waveforms.

★ Oscilloscope: Observes the harmonic components of the distorted waveforms and obtains their amplitudes.

★ AD8336 Module: Amplifies and conditions the amplitude of the distorted signal.

★ STM32 Microcontroller: Processes the distorted waveform data, calculates the total harmonic distortion (THD), and displays the results.