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Design of digital frequency meter based on FPGA

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Abstract. Frequency measurement is one of the key technicals of the electronic measurement field, and the digital frequency meter is an indispensable measuring tool for measuring technology engineering personnel. Nowadays, digital frequency meters are indispensable components in daily appliances such as televisions, refrigerators, washing machines, and other smart home appliances. Therefore, the measurement range of digital frequency meters is becoming wider, and their design structures are becoming increasingly complex. Digital frequency meters play a crucial role in developing electronic products as a whole. Use the Very High-speed Hardware Description Language (VHDL) in Electronic Design Automation(EDA)technology to simulate and verify the digital frequency meter. Through simulation analysis, design the measurement circuit of the digital frequency meter and verify its accuracy. In the design process of a digital frequency meter, its function is to measure SIN signals, unit pulse signals, and the frequency range of various signals, achieved by collecting physical quantities within a unit of time.

Keywords: VHDL, Frequency detection, Digital, Simulation analysis.

1. Introduction

1.1. Subject Background

The faster the development of science and technology, the shorter the product update cycle, especially for digital electronic products. As a type of electronic measuring instrument, the development trend of digital frequency counters mainly focuses on the following three aspects [1]. First, the transition from previous analog device-designed digital frequency counters to digital chip-designed digital frequency counters. This transition makes the design of frequency counters more automated and intelligent. Nowadays, electronic products mainly adopt EDA technology and microcontroller technology as the core control system, supplemented by foreign circuits, to create high-end digital products. Frequency counters are also moving in this direction. EDA technology, using computers as tools, completes the design files based on hardware description language VHDL on the EDA software platform, automatically performing logic compilation, simplification, partitioning, synthesis, optimization of layout, simulation, and even specific target chip adaptation compilation, logic mapping, and programming download. FPGA/CPLD (Complex Programmable Logic Device)is a high-density field-programmable logic chip that can integrate many logic functions into a single device. It provides gate counts ranging from hundreds to millions, meeting different needs. Digital frequency counters have

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significant advantages in development with the help of EDA tools FPGA/CPLD: (1) easy and advanced programming (2) high speed (3) high reliability (4) standardized development tools and design languages, short development cycle (5) powerful functionality and wide applications [2]. These advantages make the design of digital frequency counters simpler. However, using EDA technology in frequency counter development has a drawback. When optimizing the circuit logic synthesis, there may be certain errors in the final design compared to the original design regarding logic implementation and delay, greatly affecting the measurement accuracy of frequency counters. Therefore, EDA technology still needs continuous improvement to solve the existing measurement problems and meet the requirements of electronic product measurement. However, it is certain that using EDA technology for electronic product design and development has great development prospects.

1.2. Development Trend

In recent years, although the domestic frequency meter industry has maintained a stable development momentum and the scale of enterprises has been continuously expanding, there is a serious phenomenon of homogeneous competition among enterprises in the frequency meter industry. The product structure is single, and there is still a large development space for product-added value. It is worth noting that with the increasing influx of external capital into the domestic market, the competition pressure in the frequency meter industry is becoming increasingly fierce, and many small and medium-sized enterprises in China have weak risk resistance. Nowadays, although some products created by the frequency meter industry have successfully entered the market, with the rise and popularization of the information technology industry, customers' perception of the frequency meter industry is undergoing a revolutionary change. The industrialization of the frequency meter industry will become an inevitable trend for future industry development.

1.3. Design Content

Design a frequency meter that can measure the frequency of square wave signals, with automatic calibration and measurement functions and can be calibrated with a standard clock for measurement accuracy. It should have an over-range alarm function, which emits light and sound signals when the measurement exceeds the current range. The measurement results should be displayed in decimal format.

Basic requirements:

1. The frequency range to be measured is 1~100KHz, divided into two frequency bands: 1~999Hz and 1KHz~100KHz.

2. Display the measured frequency using a three-digit display and use LEDs to indicate the unit, such as a green light indicating Hz and a red light indicating KHz.

2. Hardware design

2.1. The Choice of Design Language

Choosing the right FPGA is an important decision requiring several factors. Here are some factors to consider:

1. System requirements: First of all, you need to clarify your system requirements, including performance, power consumption, interface, and latency. These requirements will determine the type and specifications of the FPGA you need.

2. Design complexity: If your design is simpler, it may be more appropriate to choose a smaller, lower-cost FPGA. If your design is more complex, you need a larger, higher-performance FPGA.

3. Development tools: FPGA development requires the use of specific software and tools, such as Vivado and Quartus. When selecting an FPGA, it is necessary to consider whether these tools are suitable for development needs.

4. Supply chain and support: Choose reliable suppliers and FPGA models to ensure adequate technical support and product availability.

5. Cost: Finally, cost is also an important consideration. Choose the right FPGA and development tools for your budget to ensure that project costs are within reason [3].

In summary, selecting the right FPGA requires considering several factors, including system requirements, design complexity, development tools, supply chain and support, and cost. Before choosing, each factor needs to be carefully evaluated, and the FPGA that best suits the needs is selected.

2.2. CLK- Clock Signal Generation Module

2.2.1. Module Introduction. The clock signal generation module is a very important module in FPGA design, which can generate various clock signals, such as system clock, data sampling clock, read and write clock, etc. Here are some common clock signal generation modules.

1. PLL module: The PLL (Phase Locked Loop) module can generate a stable output clock signal according to the input reference clock signal and control signal, with high stability and low jitter, and is usually used to generate high-performance clock signals.

2. Frequency multiplier module: The frequency multiplier module can multiply the frequency of the input clock signal to generate a high-frequency clock signal. Frequency multiplier modules are typically implemented using circuits such as phase-locked loops (PLLs) or delay latches.

3. Frequency divider module: The frequency divider module can divide the frequency of the input clock signal to generate a low-frequency clock signal. Divider modules are typically implemented using counter circuitry.

4. Clock selector module: The clock selector module can select a clock signal from multiple signals as output. Clock selector modules are typically implemented using multiple selector circuits.

5. Clock synchronization module: The clock synchronization module can convert asynchronous clock signals into synchronous clock signals to ensure correctness and reliability under timing constraints. Clock synchronization modules are typically implemented using circuits such as bidirectional shift registers.

In summary, clock signal generation blocks play a vital role in FPGA design, which can generate various clock signals to ensure the normal operation of the system and the reliability of data. In the actual design, it is important to select the appropriate clock signal generation module according to the specific application requirements.

2.2.2. Module Design and Waveform. Generate a gate signal of 1Hz and a display scan of 1KHz. Figure 1 shows the part of the CLK module design, and Figure 2 shows the part of the CLK module waveform.

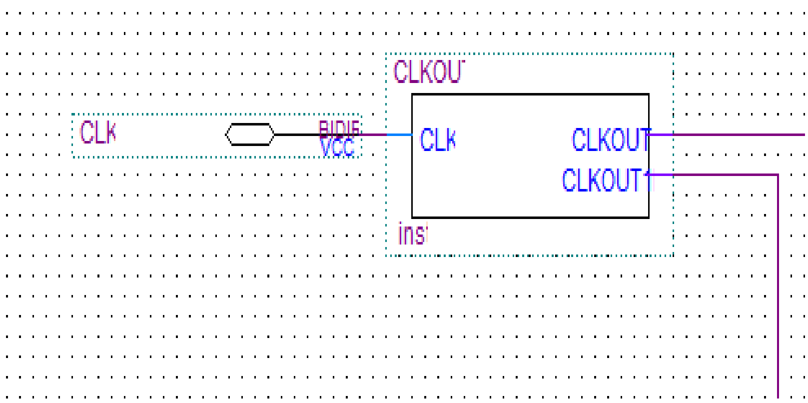

Figure 1. CLK module design.

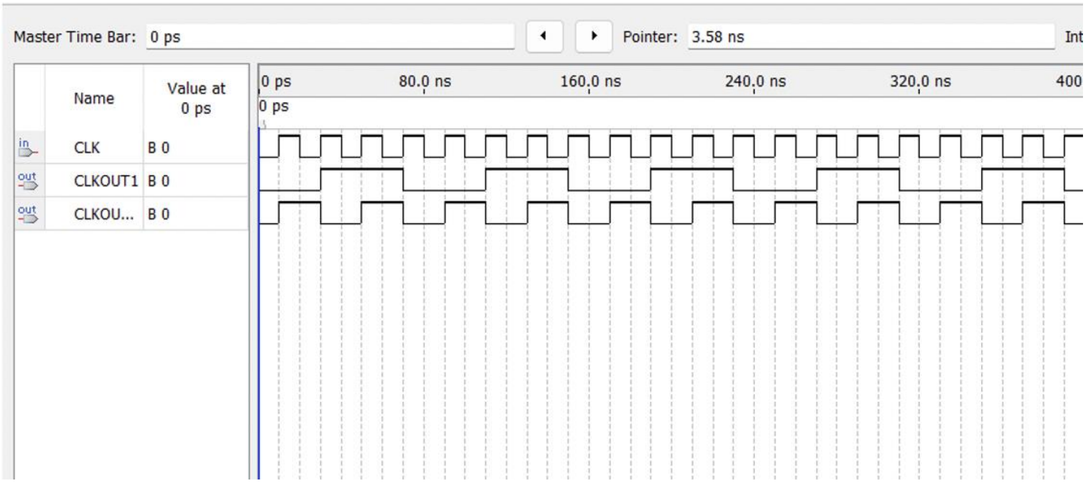

Figure 2. CLK module waveform.

2.3. MUX -The Source Selection Module for the Signal Under Test

2.3.1. Module Introduction. The source selection module under test is an important part of the test system and is used to select the signal source of the device under test. Here are some common source selection modules for the signal under test.

1. Matrix switch module: The matrix switch module can connect multiple signal sources to multiple test equipment and quickly switch signal sources to achieve multi-channel signal selection.

2. Multiplexer module: The multiplexer can convert multiple signal sources into one signal and transmit it to the test equipment through one channel. Multiplexers are typically implemented using analog or digital circuits.

3. Signal amplifier module: The signal amplifier module can amplify the signal source's signal under test to improve signal quality and reduce interference. Signal amplifiers are typically implemented using op amp circuits.

4. Signal filter module: The signal filter module can filter out noise and interference in the measured signal source to improve signal quality and reduce error. Signal filters can be implemented using different types of filter circuits, such as low-pass filters, high-pass filters, and band-pass filters.

5. Signal generator module: The generator module can generate specific signal sources, such as specific frequency, amplitude, phase, waveform, etc., for testing and calibrating test equipment. Signal generators can be implemented with digital signal generators, function generators, and other equipment.

In short, the signal source selection module under test plays a vital role in the test system, which can select the signal source, amplify the signal, filter the signal, and generate the signal to ensure the accuracy and reliability of the test data. In the actual design, it is very important to select the appropriate signal source selection module according to the specific test needs.

2.3.2. Module Design and Waveform. Figure 3 shows part of the MUX module design, and Figure 4 shows part of the MUX module waveform.

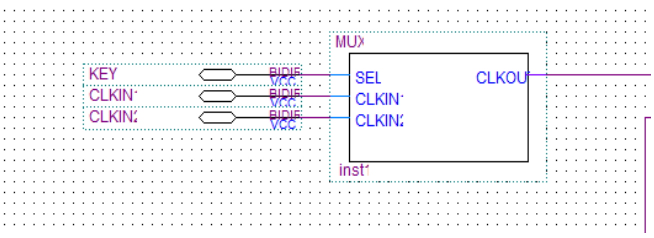

Figure 3. MUX module design.

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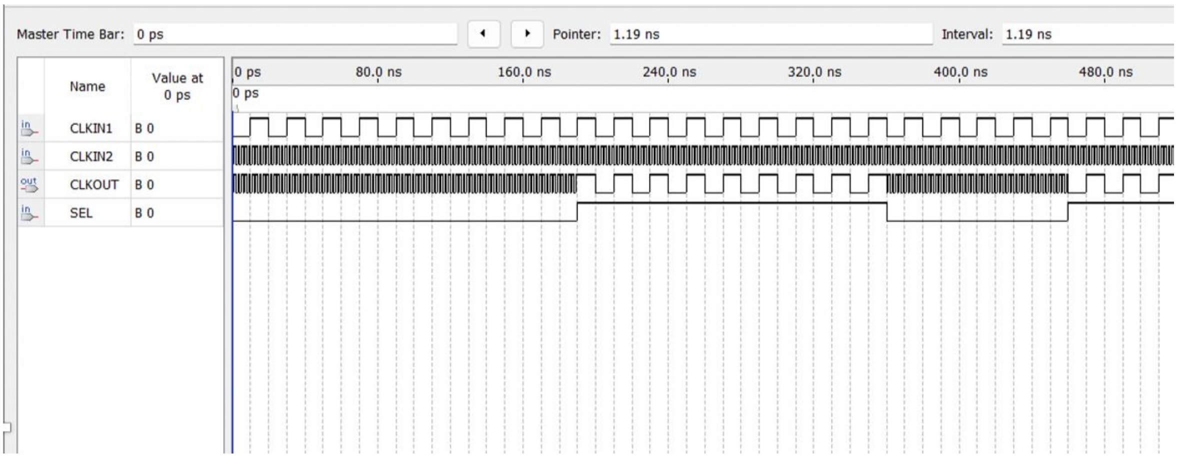

Figure 4. MUX module waveform.

2.4. TELTCL Module

Figure 5 shows the part of TELTCL module design, and Figure 6 shows the part of TELTCL module waveform.

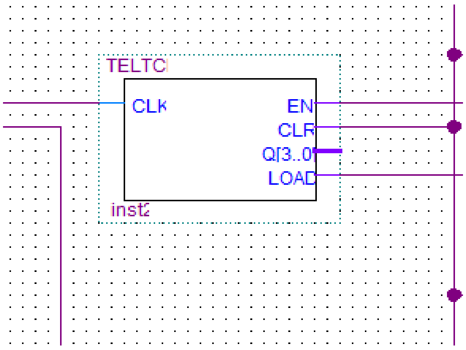

Figure 5. TELTCL module design.

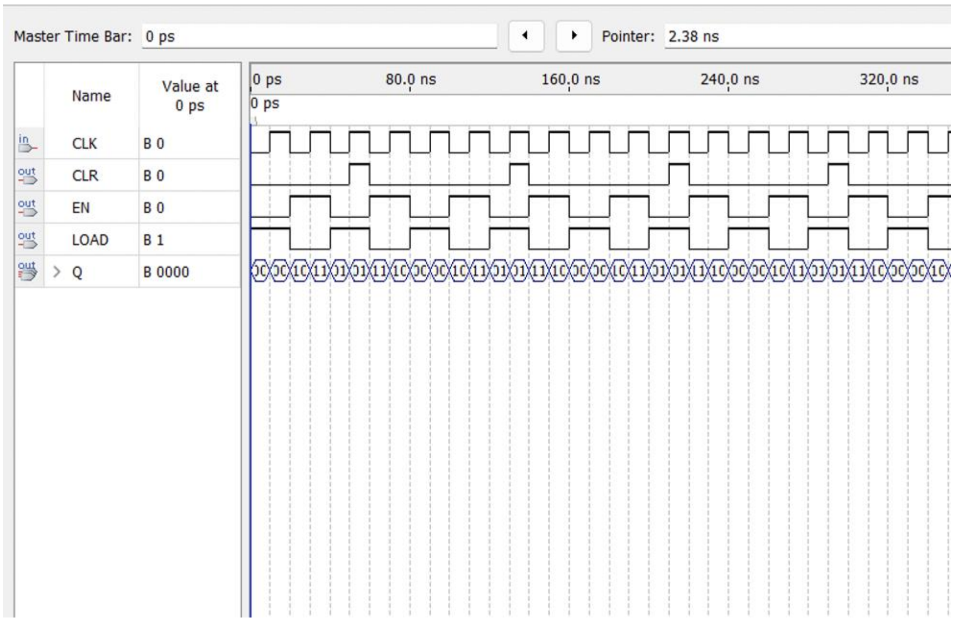

Figure 6. TELTCL module waveform.

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2.5. CNT10- Counter Module

2.5.1. Module Introduction. A CNT counter module is a common counter circuit used to count the rising or falling edge of an input clock signal. CNT counter modules are usually composed of the following parts.

1. Counter register: The counter register is a register used to store the counting value in the CNT counter module, and its bit width determines the counting range of the counter. The value of the counter register can be modified by a clear or load operation.

2. Clock input interface: The clock input interface is used to receive external clock signals, and the CNT counter module usually synchronizes and divides the clock signals to ensure the stability and accuracy of the counter.

3. Counting enable signal interface: The counting enable signal interface is used to control the counting enable of the counter. When the counting enable signal is valid, the counter starts counting, otherwise, the counter keeps the current count value unchanged.

4. Counting direction control interface: The counting direction control interface is used to control the counting direction of the counter, and you can choose to count up or count down.

CNT counter modules are widely used in various digital systems, such as frequency meters, timers, encoders, etc. In the actual design, the appropriate CNT counter module can be selected according to the specific application requirements, and the corresponding configuration and modification are required according to the needs.

2.5.2. Module Design and Waveform. Figure 7 shows part of the CNT10 module design, and Figure 8 shows part of the CNT10 module waveform.

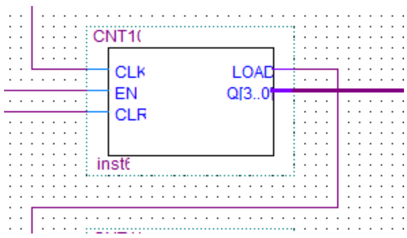

Figure 7. CNT10 module design.

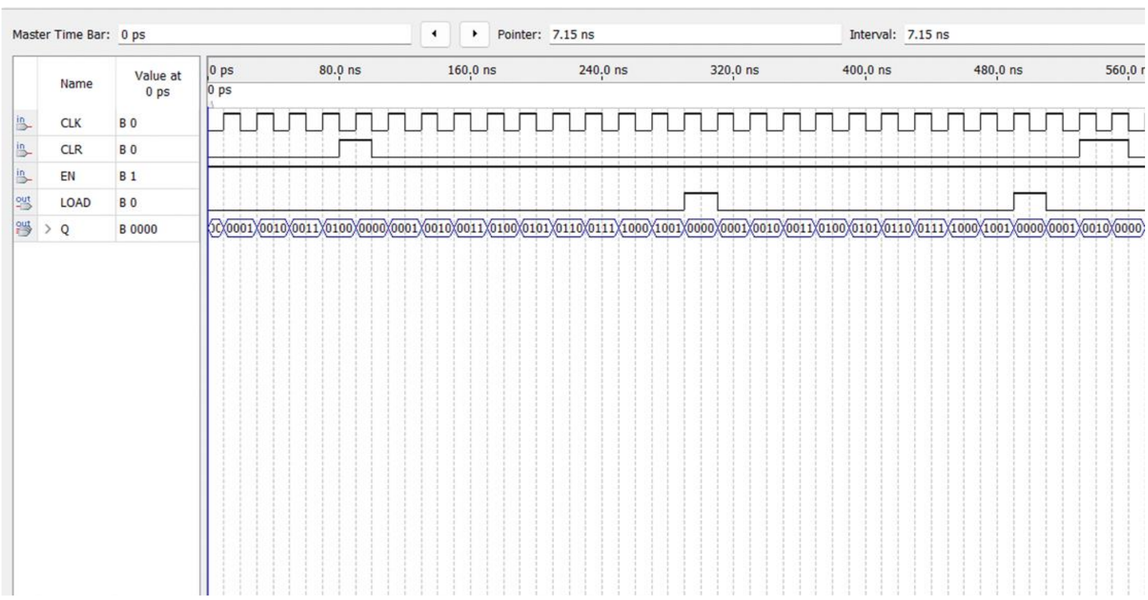

Figure 8. CNT10 module waveform.

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2.6. SEG32B-Latch Module

2.6.1. Module Introduction. A SEG latch module is a common digital logic circuit block that latches input data to an output port to keep data stable. SEG latch modules are typically grouped by the following parts.

1. Data input port: The data input port is used to receive input data, which can be single-bit or multi-bit data.

2. Clock input port: The clock input port receives clock signals, usually the rising or falling edge of the clock, to trigger the latch.

3. Latch memory unit: The latch memory unit is a storage unit used to store input data, which can be different storage units such as D trigger, JK trigger, or SR trigger.

4. Output port: The output port is used to output the data in the latch storage unit to keep the data stable.

SEG latch modules are widely used in digital systems such as registers, state machines, counters, etc. In the actual design, the appropriate SEG latch module can be selected according to the specific application requirements and configured and modified accordingly.

2.6.2. Module Design and Waveform. Figure 9 shows part of the SEG32B module design, and Figure 10 shows part of the SEG32B module waveform.

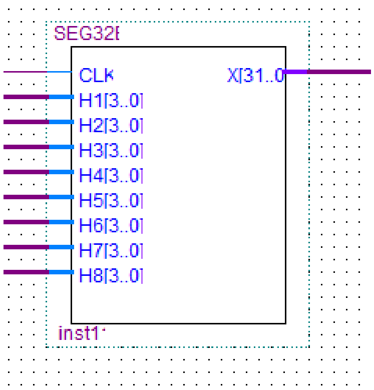

Figure 9. SEG32B module design.

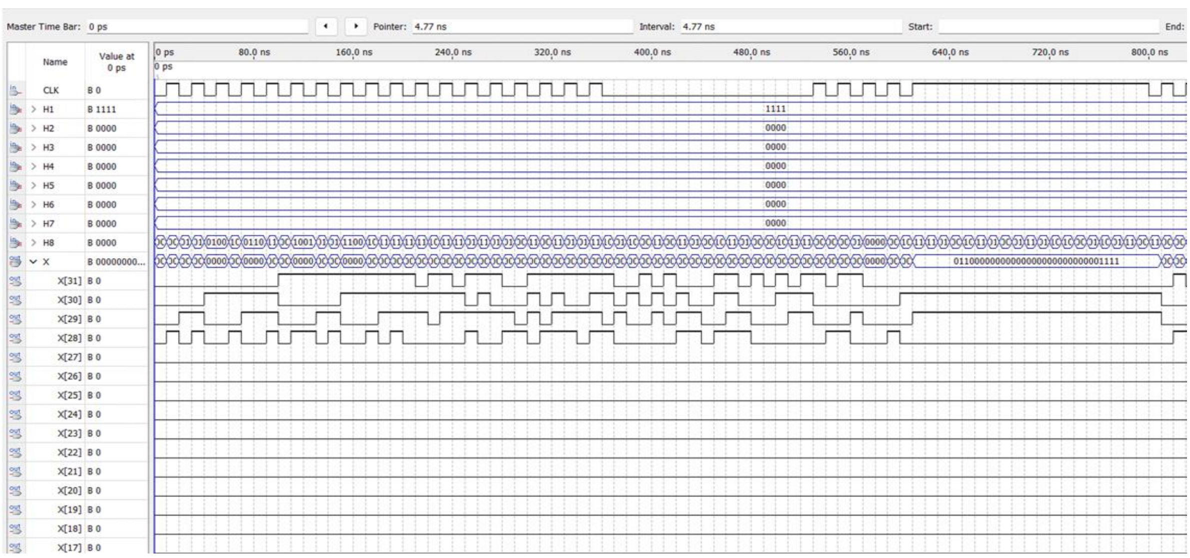

Figure 10. SEG32B module waveform.

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2.7. Display Module

2.7.1. Module Introduction. The display decoding module is a common digital logic circuit module used to convert digital signals into visual analog signals, such as digital tubes, LED lights, etc. The display decoding module usually consists of the following parts.

1. Digital input port: The digital input port is used to receive digital signals, which can be single digits or multiple digits.

2. Decoder: The decoder is the core part of the display decoding module, which can convert the digital signal into the corresponding analog signal. For example, the 7-segment decoder of the digital tube can convert the number 0~9 into the corresponding 7-segment analog signal.

3. Display device: A display device is a device used to display analog signals, such as digital tubes, LED lights, etc.

4. Control interface: The control interface is used to control the display content and display mode of the display device, such as selecting the number of digits of the digital tube, selecting the display position of the digital tube, etc.

Display decoding modules are widely used in various digital systems, such as timers, counters, electronic scales, etc. In the actual design, the appropriate display decoding module can be selected according to the specific application requirements, and the corresponding configuration and modification are required according to the needs.

2.7.2. Module Design and Waveform. Figure 11 shows part of the DOSPLAY module design and Figure 12 shows part of the DISPLAY module waveform.

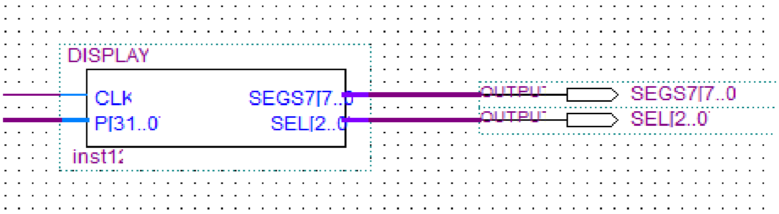

Figure 11. DISPLAY module design.

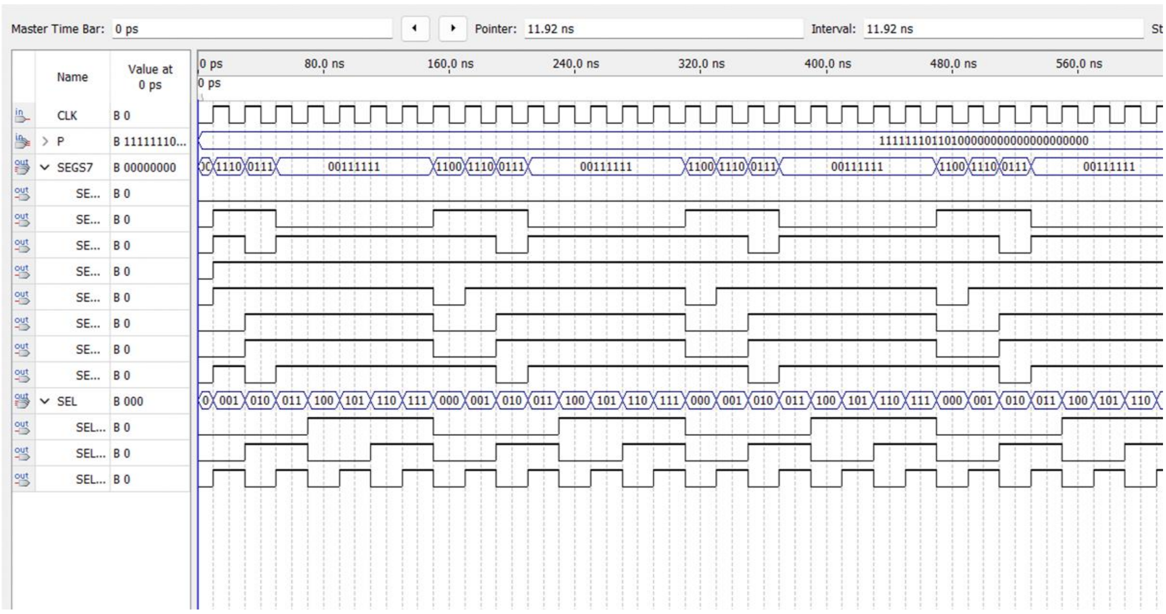

Figure 12. DISPLAY module waveform.

2.8. Module Integration and Control Signal Timing Relationship

Figure 13 shows the total module blueprint combined with all the parts mentioned above.

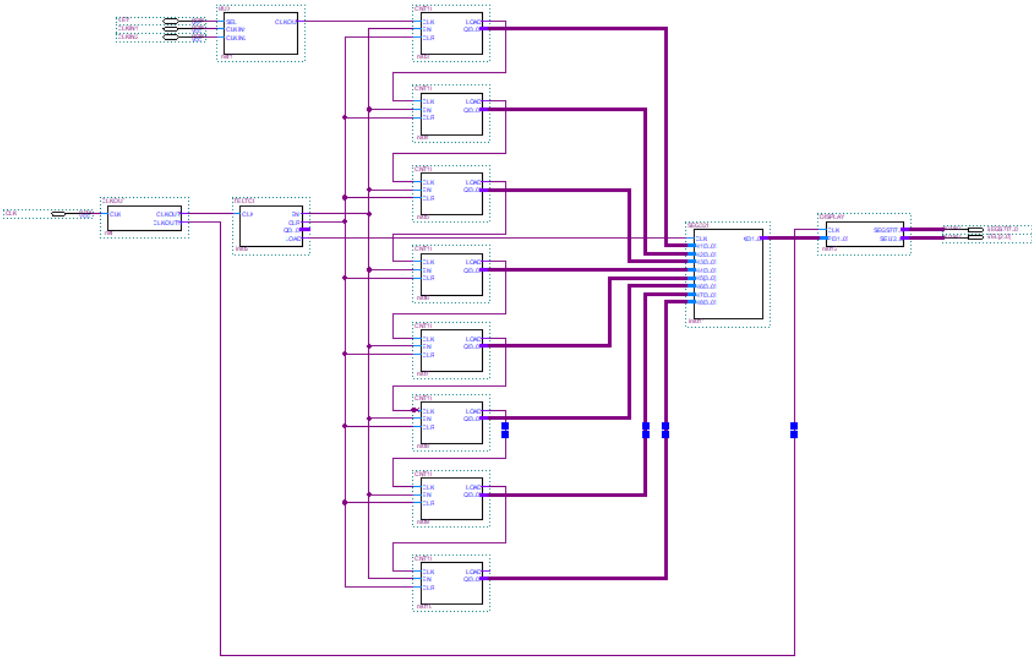

Figure 13. Total module blueprint.

3. Software design

The software part of the FPGA digital frequency meter mainly includes four modules: signal acquisition, digital conversion, data processing, and display [4].

3.1. Signal Acquisition Module and Software Flow Chart

The signal acquisition module extracts the required frequency information from the input signal. A counter or timer is usually used to measure the cycle time of the signal, and then the frequency of the signal is calculated based on the cycle time. In order to improve measurement accuracy, technologies such as multi-stage counters or phase-locked loops (PLL) can be used.

3.1.1. Introduction to the Functions of Phase Locked Loop. Phase Locked Loop (PLL) is a circuit widely used in communication, control, measurement, and other fields. Its main function is to synchronize the phase and frequency of the input signal with those of the reference signal, thereby achieving precise control and processing of the signal. A standard phase-locked loop circuit usually consists of three main parts.

1. Phase detector (PD)

The phase detector is the core part of the phase-locked loop circuit. Its main function is to compare the phase difference between the input signal and the reference signal, and output a pulse signal whose width and polarity are proportional to the phase difference.

2. Loop filter (LF)

The function of the low-pass filter is to filter and smooth the output signal of the phase detector to eliminate high-frequency noise and oscillation while retaining the low-frequency components and sending the output signal to the control voltage-controlled oscillator.

3. Voltage Controlled Oscillator (VCO)

The control voltage-controlled oscillator is the output part of the phase-locked loop circuit, and its frequency depends on the input control voltage. By adjusting the size and polarity of the control voltage, synchronous control of the frequency and phase of the input signal can be achieved.

The working principle of the phase-locked loop circuit is to compare the input signal and the reference signal through the phase detector to obtain an error signal, and then send the error signal to the low-pass filter for filtering processing to obtain a control voltage signal. The control voltage signal is sent to the VCO to control its output frequency, thereby achieving synchronous control of the frequency and phase of the input signal.

Phase-locked loop circuits are widely used in communication, control, measurement, and other fields. For example, in a digital frequency meter, phase-locked loop technology can be used to achieve high-precision frequency measurement. By locking the phase and frequency of the input signal and the reference signal, precise control and processing of the signal can be achieved.

3.1.2. Introduction to the Functions of Multi-bit Counters. A multi-bit counter is a commonly used digital circuit that can be used to count the cycles of an input signal and output the corresponding count value. Multi-bit counters are usually composed of multiple unit counters cascaded. Each unit counter can count the period of the input signal within a certain range and then output the count value to the high-bit counter for carry [5, 6].

3.1.3. Options for Improving Accuracy. Both phase-locked loops and multi-bit counters can be used to measure and control the frequency of signals. Their main differences lie in their working principles and applicable scenarios.

The working principle of the phase-locked loop is to achieve synchronous control of the signal frequency by comparing the phase difference between the input signal and the reference signal and adjusting the control voltage to control the output frequency of the oscillator. The phase-locked loop has the characteristics of fast-tracking and stable locking and is suitable for high-precision and high-stability frequency measurement and control scenarios [7].

The working principle of a multi-bit counter is to obtain the cycle time of the signal by counting the cycles of the input signal, thereby calculating the frequency of the signal. Multi-bit counters are simple, reliable, low-cost, suitable for high-speed and large-frequency counting, and are suitable for industrial automation, counters, timers and other fields. Therefore, phase-locked loops and multi-bit counters are often selected according to specific application scenarios in practical applications. If you need high-precision and high-stability frequency measurement and control, you can choose a phase-locked loop.

3.1.4. Signal Acquisition Module Software Flow Chart

Instrument/Device Drivers: The most fundamental component for communication with the actual data acquisition hardware. Popular ones include NI-DAQmx, IVI drivers, VISA, manufacturer custom drivers, etc.

Configuration Interface: GUI/software that allows configuring the acquisition module parameters like channels, sampling rate, gain, trigger settings, etc., prior to data collection. May have configuration files to save/load settings.

Data Collection: Capability to collect/acquire digitized signal data from the hardware based on configured settings like triggering, buffer size, number of samples, etc. Data is stored/logged on the computer.

Real-time Display: Some software allows real-time display of incoming signal data on a virtual analyzer/oscilloscope during acquisition for setup and verification. It may have signal processing like filtering applied.

Data Analysis: Tools for post-acquisition analysis of collected data like FFT, statistics, filtering, and math operations. Commonly allows export to other apps for advanced analysis.

Logging: Recording of configuration settings and acquired data to files for archiving, traceability and later off-line analysis if needed. Supported file formats may vary.

Report Generation: Ability to generate reports with plots, charts, and configuration details from acquired data for documentation purposes.

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Remote Control: Features for remote monitoring and control of data acquisition system over the network using protocols like VXI-11, Modbus, OPC, etc.

Calibration Tools: Helps with sensor calibration and verifying hardware measurement accuracy.

So, in summary, it integrates hardware control, configuration, data collection/analysis, and reporting capabilities into an easy to use software package [8]. Figure 14 below shows the Signal acquisition module and software flow chart.

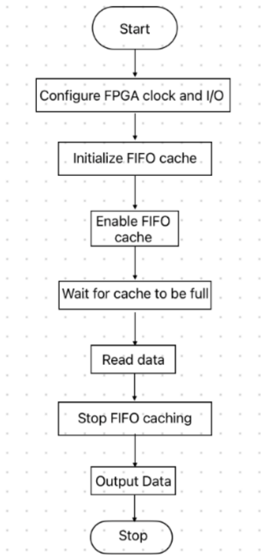

Figure 14. Signal acquisition module software flow chart.

3.2. Digital Conversion Module and Software Flow Chart

The data processing module is responsible for processing and analyzing digital signals and extracting the required frequency information. Commonly used algorithms include Fourier transform (FFT), autocorrelation function, and convolution. It should be noted that the complexity and speed of data processing also have a decisive impact on the performance of the frequency meter.

A digital conversion module is a hardware device that converts an analog signal to a digital format to be processed by digital systems like computers.

So, in summary, digital conversion modules handle the analog-digital interface, and software controls them and processes the resulting digital data [9]. Figure 15 shows the Digital conversion module and software flow chart.

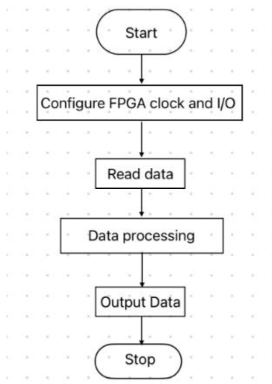

Figure 15. Digital conversion module and software flow chart.

3.3. Display Module and Software Flow Chart

The display module is responsible for presenting the measurement results to the user in a visual form (see Figure 16). It is usually implemented using hardware devices such as LCD monitors or digital tubes.

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It should be noted that the display method and accuracy have an important impact on the user experience and reliability of the frequency meter [10].

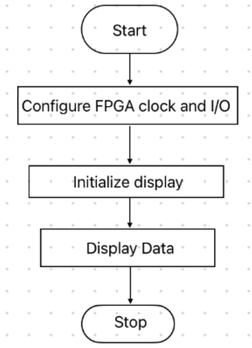

Figure 16. Display module and software flow chart.

4. Physical inspection

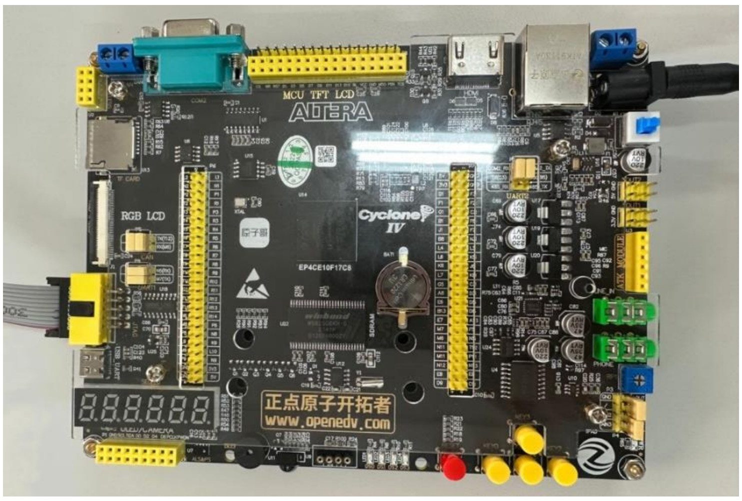

Figure 17. Initial state.

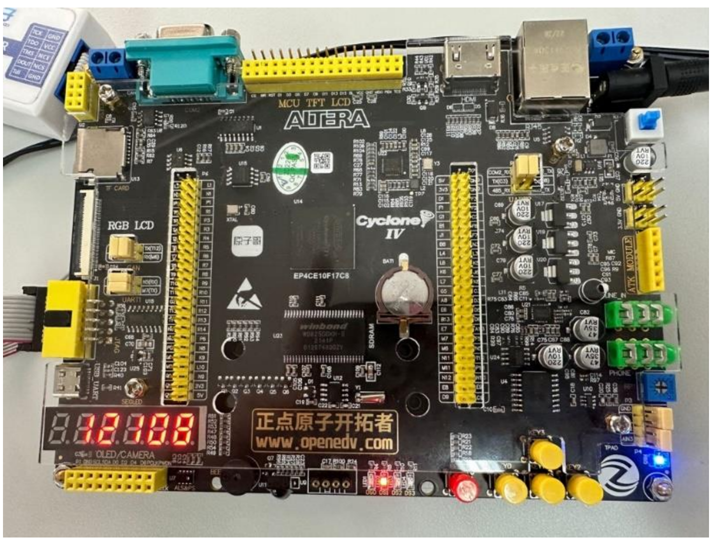

Figure 18. Low frequency band running light status.

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Figure 17 shows the initial state of the digital frequency meter. When the digital frequency meter randomly generates a low-frequency signal band, the digital tube displays the precise frequency value, and the LED becomes a running light.

Figure 18 shows the low-frequency state of the digital frequency meter, and it turns to keep running light status. When the digital frequency meter randomly generates a high-frequency signal band, the digital tube displays the precise frequency value and the LED is always on. Figure 19 shows the high-frequency state of the digital frequency meter and it turns to keep always on status.

Figure 19. High frequency band always on status.

It enters a latch state to keep data stable. Figure 20 shows the latch state of the digital frequency meter.

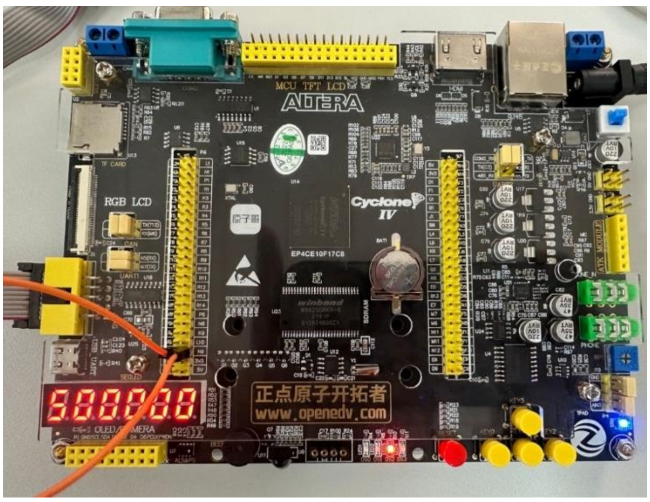

Figure 20. Latch state.

According to experiments, this digital frequency meter can quickly generate randomly generated digital frequencies on the digital tube and distinguish high and low frequencies through running lights or constant light. Its accuracy has not yet been tested with external equipment, but it can be controlled within 1hz.

5. Conclusion

The digital frequency meter we designed above can solve basic problems in many fields. Because it is based on VHDL, this product has strong versatility. It is not a problem to put it into production on a

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large scale. The digital frequency meter market is projected to experience significant growth opportunities from 2023 to 2028, with a Compound Annual Growth Rate (CAGR) of 6.78%. A frequency meter is an essential component of test and measurement equipment that accurately gauges the frequency of an electrical signal. By tallying the signal cycles within a given timeframe, these meters are used in various applications such as microwave and radio frequency measuring, AC motor tuning, and audio frequency tuning. In the telecommunication and wireless networks sector, frequency meters are crucial in measuring signal frequencies in wireless networks such as cellular and Wi-Fi networks. Accurate frequency measurement is vital to ensure optimal performance and avoid interference, particularly with the increasing complexity and deployment of wireless technologies like 5G networks. According to the International Telecommunication Union (ITU), the number of 5G mobile subscriptions is projected to reach 3.5 billion by 2026. I believe that the application and development of electronic frequency meters will get better and better in the future, and more fields will benefit from it.

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