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A multi-type output vehicle circuit system based on CANFD communication control

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Abstract: To address the complex control requirements and system flexibility challenges faced by intelligent vehicles and autonomous driving technology, especially with the significant increase in in-vehicle communication demands, traditional automotive networks such as CAN or LIN have gradually exposed issues with insufficient information exchange speed. This research introduces the more advanced CANFD technology, utilizing a circuit control system based on the STM32 microcontroller with CANFD communication support. By integrating high-performance digital-to-analog converters, the system can generate precise level signals within milliseconds, enabling the control of various analog input devices. Additionally, by using pulse-width modulation (PWM) functionality, efficient control is achieved, improving the system's response speed and flexibility. Meanwhile, a low-frequency wireless communication conversion module connected via serial port enables remote monitoring of key vehicle parameters. This allows for real-time monitoring and fault diagnosis of vehicle operation, providing a reliable solution for the development of intelligent vehicles and autonomous driving technology.

Keywords: CANFD; STM32; Voltage output; PWM; Serial port.

1. Introduction

With the rapid development of intelligent vehicles and autonomous driving technology, vehicle control systems are facing increasingly complex demands and challenges. At present, traditional vehicle control methods suffer from issues such as insufficient precision, poor real-time performance, and low system flexibility, making it difficult to meet modern vehicles' requirements for diversified and efficient control. Furthermore, over time, the communication methods of traditional networks like CAN (Controller Area Network) or LIN (Local Interconnect Network) can no longer meet the growing demand for information exchange speed. These issues have also limited the further development and application of intelligent vehicles and autonomous driving technology. [1] [2] [3].

To address these challenges, this paper designs a circuit control system integrated with multiple output signals and proposes a solution based on the CANFD (Controller Area Network with Flexible Data-Rate) communication protocol. As shown in Table 1, the CANFD protocol supports higher data transmission rates and larger data packet capacities, enabling the vehicle control unit (VCU) to transmit and process complex control information more quickly and accurately. More importantly, the CANFD network is compatible with the traditional CAN communication network, [4] making it more suitable for upgrading and transforming current vehicle systems, providing a smooth transition and enhanced scalability.

Based on the CANFD communication protocol, the multi-output signal circuit control system designed in this paper aims to enhance the overall performance of vehicle control systems through efficient data processing and flexible output control. The input section of the board is based on the CANFD communication protocol, enabling real-time reception and processing of information from the Vehicle Control Unit (VCU). The output section provides PWM (Pulse Width Modulation) signals and 0-5V analog voltage output signals, allowing precise control of motors, actuators, and other analog devices. Additionally, the board is equipped with serial communication functionality, [5] enabling the connection of low-frequency wireless communication conversion modules and supporting sensors that monitor real-time data on battery status, tire pressure, engine temperature, fuel consumption, and more. This facilitates remote vehicle management, operation, and monitoring of vehicle information [6].

Table 1. Comparison of Three In-Vehicle Network Performance Parameters

Bus Type	LIN	CAN	CANFD
Maximum bandwidth /(b/s)	19.2k	500k	2-8M
Frame length/byte	8bit fixed data field	8bit fixed data field	64bit variable data field
Protocol complexity	Simple	medium	More complex
Self-recovery capability	weak	Retransmission mechanism	Retransmission mechanism
Power consumption	Low	middle	Slightly higher
defect	Low bandwidth, shared media	Low bandwidth, shared media	shared media
Application Areas	Low-end body control	Automotive power and safety systems	High-bandwidth driver assistance systems

This paper will provide a detailed description of the design principles, hardware architecture, and functionality of the circuit control board, showcasing its potential applications in intelligent vehicle control and autonomous driving. By analyzing the advantages of the new circuit control board in improving vehicle performance, energy efficiency, and safety, the paper further explores its prospects in future vehicle control technologies.

2. System Design

The circuit system uses the STM32F103RET6 as the main control chip. In addition to the basic peripherals required for the STM32 minimum system, the peripheral circuitry incorporates various functional modules, including a power module, CANFD communication module, DAC conversion module, voltage follower buffer module, and servo driver interface module.

As the control core, the STM32 is responsible for overall control and communication. The system supports a 12V power supply, which is stepped down by an LDO to supply the required voltages for each module. The CANFD communication module is responsible for receiving information from the Vehicle Control Unit (VCU) or feeding back the information processed by the current module to the VCU. The received information is then processed by the main control core—the STM32 microcontroller—and sent to the analog voltage output chip, which generates an analog voltage in the range of 0-5V. This is further isolated by a voltage follower composed of an operational amplifier to enhance the circuit's output drive capability. The chip can also generate a PWM signal, which is then amplified by a transistor to drive other peripherals.

Finally, the system can output information via the serial port for monitoring, or it can connect to a low-frequency wireless communication conversion module through the serial port to obtain the overall vehicle status or the operating state of a specific sensor. The relevant information is then transmitted to the Vehicle Control Unit via CANFD or directly to an external monitoring system wirelessly. The overall system block diagram is shown in Figure 1:

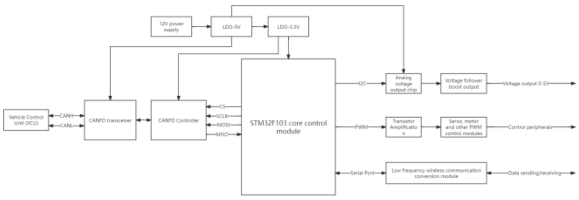

Figure 1. System overall block diagram

3. Hardware system design

The system selects the STM32F103RET6 chip as the control core, with the system powered by the vehicle's onboard 12V battery. The LDO step-down chips used are the AMS1117-5 and AMS1117-3.3, which provide power to the various modules of the system. The control system integrates a CANFD communication module, where the CANFD controller is based on the MCP2517FD chip, and the ATA6563 is used as the CANFD transceiver chip to form the complete CANFD communication circuit.

The control system also integrates an analog voltage output chip, the AD5697RBRUZ. The output voltage is then driven through a voltage follower circuit, which is enhanced by the TLC2262IDR chip that integrates multiple operational amplifiers. Finally, the PWM signal is generated through the timer of the STM32F103RET6, based on the received message information, to produce real-time adjustable control waveforms. The serial communication function is based on the USART communication method of the STM32F103RET6 itself.

3.1. System circuit schematic

The entire system consists of the STM32 main controller, crystal oscillator circuit, reset circuit, BOOT mode selection circuit, SWD download circuit, and test circuit, which together form the STM32 minimum system. In addition, it also includes the LDO step-down power supply circuit, DAC conversion circuit, voltage follower buffer circuit, CANFD communication circuit, and servo driver interface circuit. The system schematic diagrams are shown in Figures 2 and 3.

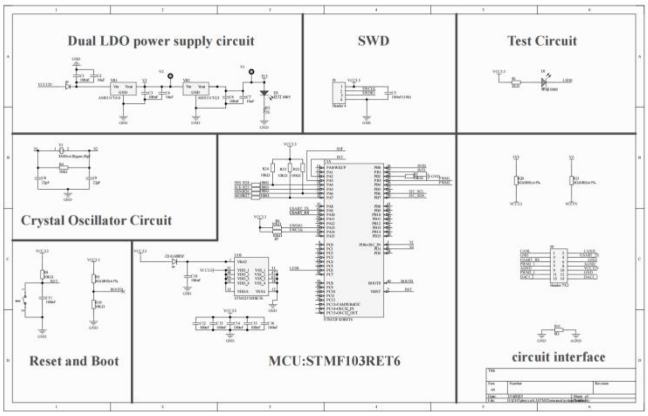

Figure 2. STM32 minimum system circuit

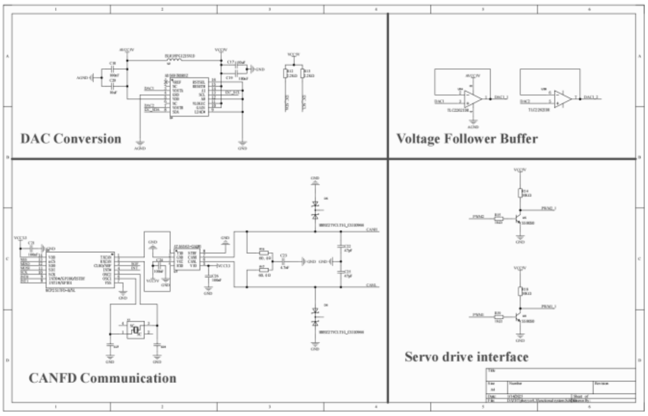

Figure 3. CANFD, DAC, PWM functional circuit

3.2. Main control core

The STM32F103RET6 is a 32-bit microcontroller based on the ARM Cortex-M3 core, offering high-performance processing capabilities. With a maximum clock speed of 72 MHz, it can quickly respond to and process complex control algorithms and real-time data. At the same time, the chip integrates a variety of peripheral interfaces, including multiple USART, SPI, and I2C interfaces, which can meet the diverse communication needs of complex systems. It provides a reliable and efficient solution for intelligent vehicle and autonomous driving control systems.

3.3. Power supply and step-down module

This module is responsible for providing a stable power supply to the entire system. The system design uses the

AMS1117 series LDO (Low Dropout Regulator) step-down converter to reduce the 12V input voltage from the vehicle's battery to the operating voltage required by the main control chip and other peripheral modules. This chip can provide an output current of up to 1A, meeting the current requirements of most embedded systems and peripheral devices. Its powerful driving capability makes it suitable for powering various loads, while the series chips also feature low quiescent current (typically around 5mA), consuming minimal current when not in operation. This helps to extend battery life. Additionally, the chip integrates thermal protection and short-circuit protection functions, automatically shutting off the output in case of overheating or output short circuits, preventing damage to both the chip and the load. This enhances the system's safety and reliability. Furthermore, the chip offers a good balance between performance and cost, making it an ideal choice for power management applications.

In the power design, in addition to a small number of filter capacitors to reduce ripple and noise in the signal, a red power indicator light is added to indicate whether the power supply system is functioning normally.

3.4. Voltage output circuit

The DAC (Digital-to-Analog Converter) module is used to convert digital signals into analog signals, providing a 0-5V voltage output. The AD5697RBRUZ chip used in this module communicates with the main control chip via I2C to receive instructions and generate precise voltage output. The voltage follower buffer module, composed of the TLC2262IDR operational amplifier chip, is used to enhance the drive capability and stability of the DAC output, reducing the impact of load variations on the DAC output.

The AD5697RBRUZ voltage conversion chip has a 12-bit resolution, allowing for accurate analog output signals. Additionally, the chip can quickly update the output voltage, completing updates within microseconds. This makes it highly suitable for control systems requiring fast response, such as real-time signal generation and rapid adjustments. The chip also supports multiple voltage outputs, capable of generating different output voltage ranges. It meets industrial and automotive application standards, offering strong anti-interference capability and reliability. This makes it ideal for use in vehicle electronic systems that require high stability.

3.5. CANFD communication circuit

The CANFD (Controller Area Network with Flexible Data-Rate) communication module is used to receive and send data from the Vehicle Control Unit (VCU). The MCP2517FD chip is selected for this purpose, which sends data to the microcontroller via the SPI interface or receives data from the microcontroller and sends it to the VCU.

The MCP2517FD chip supports CANFD mode, which enables higher data transfer rates and larger data packet sizes, ensuring that the system can quickly and accurately transmit and process complex control information [7] The chip supports various operating modes, including traditional CAN mode, CANFD mode, and hybrid mode. This allows it to be compatible with different CAN and CANFD devices, enhancing the system's flexibility and versatility. The compatibility of the CANFD network provided by this chip makes it suitable for upgrading and retrofitting existing vehicle systems. Most importantly, the MCP2517FD complies with industrial and automotive application standards, offering strong anti-interference capabilities and reliability, making it ideal for automotive and industrial control applications that require high-speed data transmission and stable communication in demanding environments [8].

3.6. PWM drive interface circuit

This module enhances the PWM signal output, which is used to control the angle and movement of the servo motor. The main control chip outputs PWM signals to control the servo driver, achieving precise servo control. This is suitable for applications such as steering wheels and braking systems. It can also be used for motor control to operate features like power windows and windshield wipers [9].

In summary, this design scheme achieves precise control of intelligent vehicles by utilizing the STM32F103RET6 main control chip and multiple functional modules. The system receives and processes data from the vehicle control unit through the CANFD communication module, and implements precise output control via the DAC conversion module, voltage follower buffer module, and servo driver interface module. The LDO step-down converter and ground plane partition design further enhance the system's stability and anti-interference capabilities.

3.7. PCB layout design solution

To improve the system's stability and anti-interference capability, the circuit design includes the separation of the digital ground plane and analog ground plane. The digital ground plane and analog ground plane provide separate grounding reference points for digital and analog circuits, reducing the interference of high-frequency switching noise from the digital circuit on the analog circuit.

Due to the involvement of various types of communication circuits such as CANFD, I2C, and SPI between the components on the board, the design requires the related components to be placed as compactly as possible, with routing kept as short and as uniform in length as possible. At the same time, impedance matching considerations are fully accounted for when routing the communication traces, ensuring that the communication signals between chips on the board remain intact and free from reflection. The circuit layout approach is shown in Figure 4.

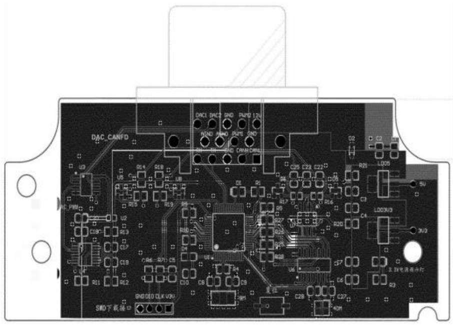

Figure 4. PCB layout and wiring design

4. Software system design

After powering on the system, various modules are initialized, including configuring GPIO ports, initializing the SPI and CAN FD SPI communication modules, initializing I2C and DAC I2C communication modules, initializing the system timer to output PWM based on message requirements, and initializing the serial port, among other operations.

The specific configuration details for the peripherals are as follows: the CPU frequency is initialized to 72 MHz. The clock frequency for the I2C bus is set to 50 MHz. Serial communication is enabled with a baud rate of 115200, and the I2C communication function and corresponding pins are initialized. The SPI communication function and corresponding pins are initialized. The MCP2517FD chip is communicated with via SPI, and its operating clock is set to 40 MHz, along with configuring the relevant input/output pins of the chip. Then, the chip's CANFD control registers, bit time registers, message transmission queue (TXQ), reception and transmission FIFO, receive filters, bit switching operations, and chip working mode are configured [10].

When CANFD-type message data is received, the required data segments are retrieved and analyzed according to the protocol. If PWM control is needed, the timer output is enabled to generate waveform data with the specified duty cycle. After the peripheral completes the specified operation, the timer is disabled to save chip resources. If voltage output control is needed, based on the received message data, after data processing, communication with the AD5697RBRUZ voltage output chip is established via I2C. The output mode, the number of output channels, and the specific output voltage values of the AD5697RBRUZ are configured as per the output requirements.

This process completes the control of serial data, voltage, and PWM waveform outputs. The detailed software flowchart for data handling is shown in Figure 5.

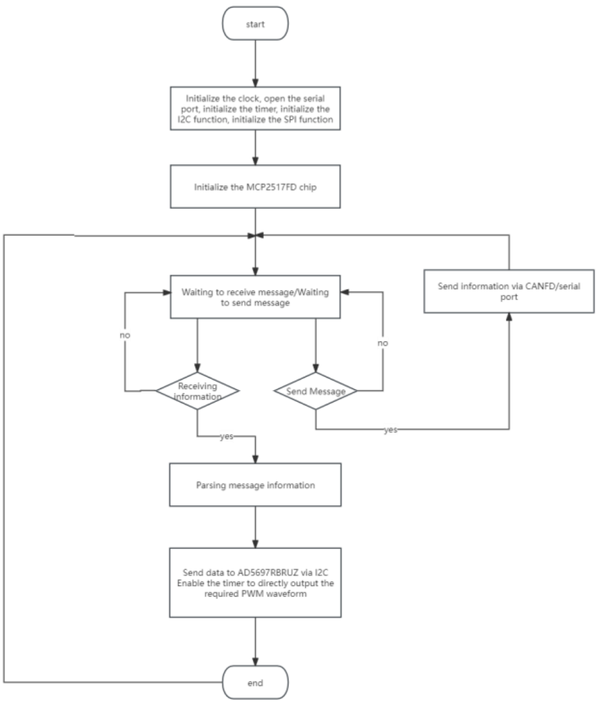

Figure 5. Software Control Flow Graph

5. System Testing

After hardware and software debugging, the design of the multi-type output in-vehicle circuit system based on CANFD communication control was completed, and the system stability and performance tests were conducted. The system's PWM output is generated by the chip's own timer. Therefore, the response test of this circuit system is primarily carried out using the DAC voltage output control as an example.

5.1. Test plan

Due to the lack of specialized voltage acquisition and comparison tools, ADC voltage acquisition code was written to complete the voltage collection task using the Wildfire STM32F429-IGT6 development board. The results were then uploaded to the host software and compared with the voltage output required by the VCU to observe the delay during the board's operation. The specific connection method is shown in Figure 6.

A. The raw voltage output data required by the VCU is sent via serial port to the host waveform display software, displaying the raw voltage data in a curve form on VOFA+. Simultaneously, the voltage data required by the VCU is transmitted via the CANFD bus to the C2V vehicle module for processing.

B. The C2V board's voltage output pin is connected to the voltage acquisition port on the development board (STM32F429-IGT6). The development board collects the real-time output voltage data and compares it with the curve data in step A to observe the response effect.

C. The development board is connected to the computer, and the collected voltage data is displayed on the VOFA+ software as a curve. The development board's built-in serial port 1 is used to connect to the computer.

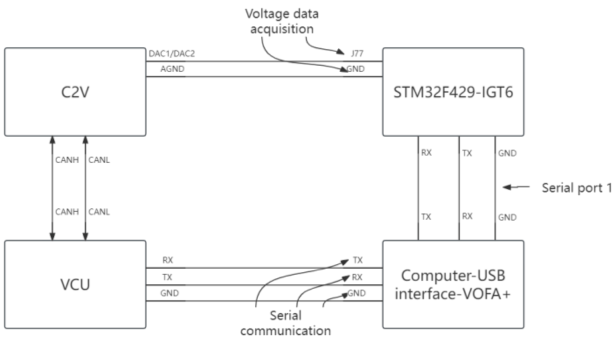

Figure 6. Voltage acquisition test flow chart

5.2. Test Results

System Stability Test: In the long-duration operation experiment, the system ran stably. At any point during the operation, the system could precisely and stably complete both voltage output and PWM output upon receiving a signal. The control system's endurance time and operation functioned normally.

System Performance Test: The system also achieved a high level of performance. The system's response speed can reach millisecond-level instantaneous feedback, ensuring that signals are received and processed promptly during operation. The system's response status is shown in Figure 7.

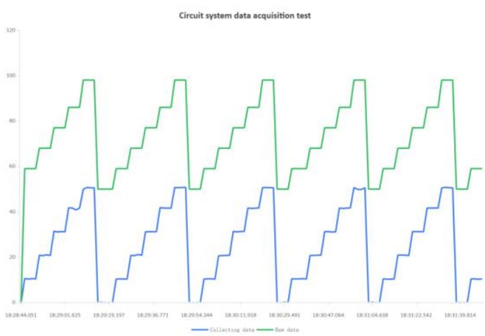

Figure 7. System response test

6. Conclusion

This circuit control system uses the STM32F103RET6 as the main control chip and integrates various functional modules to achieve the design goals of intelligent vehicle control.

The system utilizes the CANFD protocol to significantly enhance data transmission speed and frame length, ensuring fast and accurate reception and processing of complex control information. The diverse output control methods, including PWM signals, 0-5V voltage output signals, and interfaces supporting serial output, enable flexible control of various vehicle actuators.

The high-precision DAC conversion module, voltage follower buffer module, and high-performance STM32F103RET6 main control chip ensure real-time response and reliable operation. The use of an LDO buck converter module achieves efficient power management, reducing system power consumption and making it suitable for long-duration and battery-powered applications. The separation of digital and analog ground planes minimizes interference, enhancing the system's anti-interference capability and stability.

In addition, the system supports serial and low-frequency wireless communication conversion module direct connection, enabling wireless control and enhancing the system's scalability and flexibility. In summary, this circuit control system provides a reliable and efficient solution for the development of intelligent vehicles and autonomous driving technology.

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