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Analysis and Design of Coiled Tubing Drilling Downhole Instrument Bus

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Abstract: In consideration of high transmission rate and high reliability of the coiled tubing drilling measuring instrument, through comparison with the MIL-STD-1553B bus protocol, we proposed a modified CAN version to improve the CAN bus as data transmission scheme for underground communication bus. Comparing the 1553 bus with CAN bus in terms of their basic principles, characteristics and formats of data, the feasibility of CAN bus as underground transmission bus is analyzed. In order to meet the demand of small size coiled tubing instrument, the design of CAN bus controller based on FPGA technology and the improvement of CAN bus protocol are put to enhance the stability and reliability of the CAN bus protocol, meeting the requirements of the measurement while drilling. The modified CAN controller, which is the middle link of downhole instrumentation and telemetry gauge, is equipped with high reliability and scalability.

Keywords: 1553B, CAN, Telemetry System, RT.

1 Introduction

With the development of modern drilling technology, coiled tubing drilling technology (CTD) has been increasingly widely used in the re-drilling and drilling multilateral wells. The advantages of coiled tubing drilling are mainly embodied in slim-hole, underbalanced drilling technology. In horizontal well with a number of branch well as a representative of tiny hole complex structure well construction, in order to timely understand the current state of the BHA and stratigraphic information, need to monitor Angle, azimuth Angle and tool face Angle and orientation parameters and geological parameters, ensuring the bit to the target layer through.

Well logging while drilling (LWD) is mainly used for formation evaluation and geological guide. With modern MWD technology development, the growing number of measured parameters, it requires to carry a large volumes of MWD data that

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must be fast, stable, real-time transmission to the ground system, otherwise it can't accurately react downhole conditions which would affect the normal drilling work. Especially representing the cutting edge of technology, imaging logging system has put forward higher requirements on the type and amount of data of the measured parameters [Yik-kiong hue and Fernando (2006)].

MWD system is composed of downhole instruments and ground equipment composition. Downhole equipment collects the downhole and geological information related to various parameters, and ground equipment is responsible for processing and storing the data at the same time controlling the work of the downhole tool. Downhole instrument works in thousands of meters deep in high temperature and high pressure environment. For downhole instrument design and manufacturing requirement is very strict. In the MWD process, various sensors under the control of the acquisition system measure geological and engineering characteristics of the relevant information, and translate into physical quantity. The electronic circuit of the downhole tool gets the signals. After related processing, The Telemetry System signals transmission to the ground through the cable.

In the process of drilling it is very important to timely send data to operators. The communication system plays an important role. MWD instrument digital communication system is composed of ground communication system, telemetry system and remote terminal unit (RTU). By selecting the appropriate bus, the instruments do not interfere with each other, and timeshare transfer. RTU is the communication interface between electronic measurement instruments and telemetry systems.

Downhole instrument interconnection bus usually uses 1553B (MIL-STD-1553-B bus protocol). According to high transmission rate and high reliability requirements for coiled tubing MWD, by comparison with the 1553B bus , this paper put forward a revision of the CAN bus protocol as communication bus data transmission scheme, in order to meet the MWD instrument transmission requirements [Xiuquan Hao; Jianjun Yang (2002)].

2 1553B Bus Protocol

MIL-STD-1553B is a bus structure is widely used in the military field. The 1553B Bus Protocol supports 1Mb transfer rate, 20-bit word length, 32 words information length, Manchester II code and half duplex mode. Transfer protocol uses command/response mode. Message format includes Bus Controller (BC) –to-Remote Terminal (RT), RT-to-BC, RT-to-RT, broadcast mode and system control mode. It can carry up to 31 remote terminals, such as bus controller, remote terminal, and bus monitor. The transmission medium is shielded twisted pair cable.

1553B bus has become the main pillar of the mobile platform electronic system; its

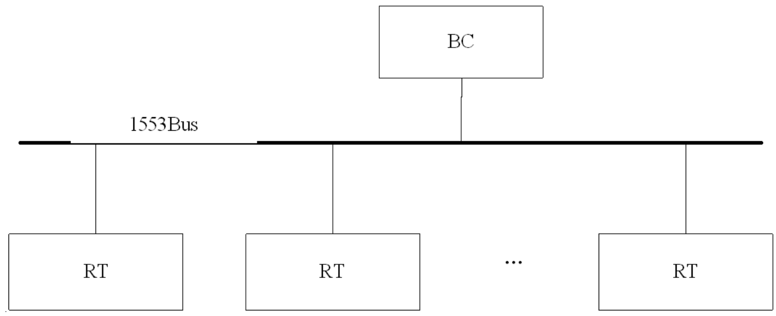

Figure 1: 1553B Bus Protocol

characteristics are as follows [Zongjin Li (1998)]:

1. 1553B bus is a broadcast network of distributed processing computer. The network can be hooked up to 32 terminals, all of the terminal share a message channel. At any moment, the bus can only be a terminal to be occupied. The network structure is simple, and the terminal is convenient to be expanded. Any terminal fault won't cause the interruption of the whole network, but the network is relatively sensitive to the failure of the bus itself. So the structure usually adopts dural-redundant bus.

2. The transmission rate is 1 Mb/s. Each message contains up to 32 words, and each word contains 16 bits.

3. 1553B bus supports command/response of asynchronous operation.

4. Take reasonable error control measures called feedback retransmission method.

3 CAN Bus Protocol

CAN (Controller Area Network) is a serial communication bus defined by the ISO (International Organization for Standardization). It is a new generation of network communication protocol supports a high level of security distributed real-time control and belongs to field bus [International Standard ISO 11898 (1993)].

CAN bus is a multi-master bus system, generally uses twisted-pair, coaxial cable or optical fiber as transmission media. The communication rate is up to 1Mb/s. One of the features of the CAN protocol is to encode communication data blocks. Compared to traditional station address coding which is used in 1553B protocol, the coding range can be extended to 2^{11} (CAN2.0A) or 2^{29}(CAN2.0B) [Baowang Kang; Yong Li (2000)]. This coding method is very useful in a distributed control system, which also allows the different nodes at the same time to receive the same data.

The CAN bus system has high reliability, which is very important for oil instruments. The sub-systems are relatively independent, and any subsystem is available to control the bus. As shown in Figure2:

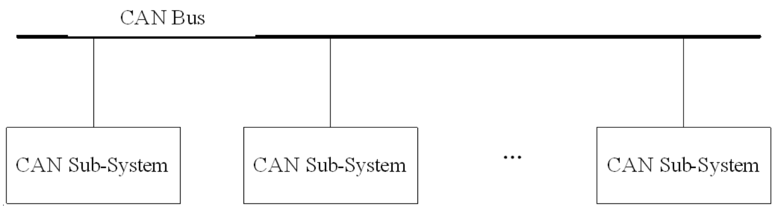

Figure 2: CAN Bus Protocol

The wide range of application of the CAN bus is closely related to its good performance, its characteristics are as follows:

1. CAN bus is a multi-master bus system. At any time a node in the network can actively send information to the other nodes. The communication is very flexible, and do not need the address and information of the aimed node. It can easily form a multi-machine backup system.

2. To meet the real-time requirements nodes of the CAN bus have different priority. High priority data can be transmitted in 134μs at most.

3. CAN bus adopts non-destructive bus arbitration. When more than one node at the same time send information to CAN bus, nodes that have lower priority will active stop sending, and the node that has highest priority will continue. This method can save bus arbitration time.

4. Through the message filtering, CAN bus can implement point to point, point-to-multipoint and global broadcast data transmission.

5. Direct communication distance can reach 10 km when the rate is less than 5kbps.

6. Due to short-frame structure and short transmission time, the interference probability is low.

7. CAN node in the case of a serious error has automatically shut down output function, so the operation will not be affected in other nodes on the bus.

4 Performance Analysis of 1553B Bus and CAN Bus

Response timeis defined as the average time that RT system responds to node data packets. For convenience, assume that packet transmission rate is λ. The distance between the adjacent RT is the same. Message transmission time between adjacent RT is defined as T. Each RT needs the same time to process datagram. Based on the above assumptions, 1553B bus system can be equivalent to a M/D/1 system (Poisson distribution service time fixed queuing system). According to queuing theory and M/D/1 queuing system, it is not difficult to get 1553 b response time $\boldsymbol{T_r}$:

$$T_r = \frac{L(1-\rho)}{2(1-S)} + \frac{S}{2\mu c(1-S)} \tag{1}$$

$\boldsymbol{L}$ is called the total transmission time, which is related to the number of RT. ρ is called traffic intensity, $\rho = \lambda/\mu \boldsymbol{c}$, where λ is called the average arrival rate of the packets, $\boldsymbol{c}$ = 1Mb/s and μ is called the length of the random message. $\boldsymbol{S}$ is system traffic intensity, $\boldsymbol{S = m\rho}$**,** and m is the number of RT.

CAN bus belongs to bus network. Since the length of the frame and the channel rate is determined, the spent time $\boldsymbol{T_f}$ that it takes to send all bits is determined. Based on the above assumptions, CAN bus system can be also equivalent to a M/D/1 system. According to queuing theory and M/D/1 queuing system, we can get $\boldsymbol{T_f}$:

$$T_r = T_f + \frac{ST_f}{2(1-S)} \tag{2}$$

It is easy to see by following with the number of RT increasing, the response time of 1553B bus will be longer than that of CAN bus [Baowang Kang; Yong Li (2000)]. Because of the imaging measurement requirements for MWD, the types and numbers of sensor will be inevitably increased. Comparing with 1553B bus, CAN bus has certain advantages in terms of real-time response.

5 FPGA design

After comparing 1553B bus and CAN bus, it can be seen that the CAN bus system meet the requirements of MWD down hole transmission. It can provide stable and reliable data transmission. Now commonly use chip (such as Philips SJA1000) as the CAN bus controller.

Due to the high temperature and high pressure working environment and the requirement of small size in the MWD, we use FPGA to implement the CAN bus controller, and we cut the protocol appropriately to improve the reliability of long-hours' underground work. The modified CAN controller, which is the middle link of downhole instrumentation and telemetry gauge, is equipped with high reliability and scalability.

In the underground communication system we collect the MWD data we need through sensors. Use different kinds of sensors, such as azimuth sensor. We use armored cable as a transmission medium which is used to transfer between ground system and telemetry system (underground system). The underground communication system has two parts: digital communication system and data acquisition system. MWD instrument digital communication system is composed of ground communication system, telemetry system and remote terminal unit (RTU). The downhole instrument bus we mentioned in this paper is responsible for the data transmission between telemetry system and RTU, which is Twisted-pair cable. The CAN bus controllers are embedded in telemetry and RTU is used to process data.

CAN bus is multi-master bus. Any node could active transmission as a master. CAN bus protocol supports four frames: data frame, remote frame, error frame and overload frame. When a sensor sends data, the RTU is master, and telemetry system will receive the data frame. When sending control command, the telemetry system will send data frame and the RTU of appointed sensor is receivers. When we want to specify a sensor sending data, the telemetry system will send remote frame to appointed sensor. The appointed sensor will transfer data frame as soon as receiving the remote frame. A backup CAN bus controller in telemetry system will be set up. When telemetry unit is detected to perform abnormally, the backup unit can be activated to ensure the instrument working properly. CAN bus system has good error correction capability. It is very important for downhole data communication for the noise, such as vibration noise and cable intersymbol interference. In some case, for MWD the transmission speed is not the most important. When we implement the CAN bus controller with FPGA, we could reduce transmission speed in order to ensure stability and reliability.

Through the analysis of the CAN2.0 protocol, CAN bus controller basic framework of the program's design consists of two basic functional modules: Interface_Module and Dataflow_Module.

Interface_Module is CAN bus controller interface logic. The main function is to interpret the commands from the microprocessor, control the addressing, and provide interrupts and status information to the microprocessor.

AD_io_0 to AD_io_7 are the address/data composite buses. irq_o is interrupt output signal, used to interrupt the microprocessor. Clk_o is clock output signal to microprocessor provided by FPGA CAN controller. Select_i is chip select input

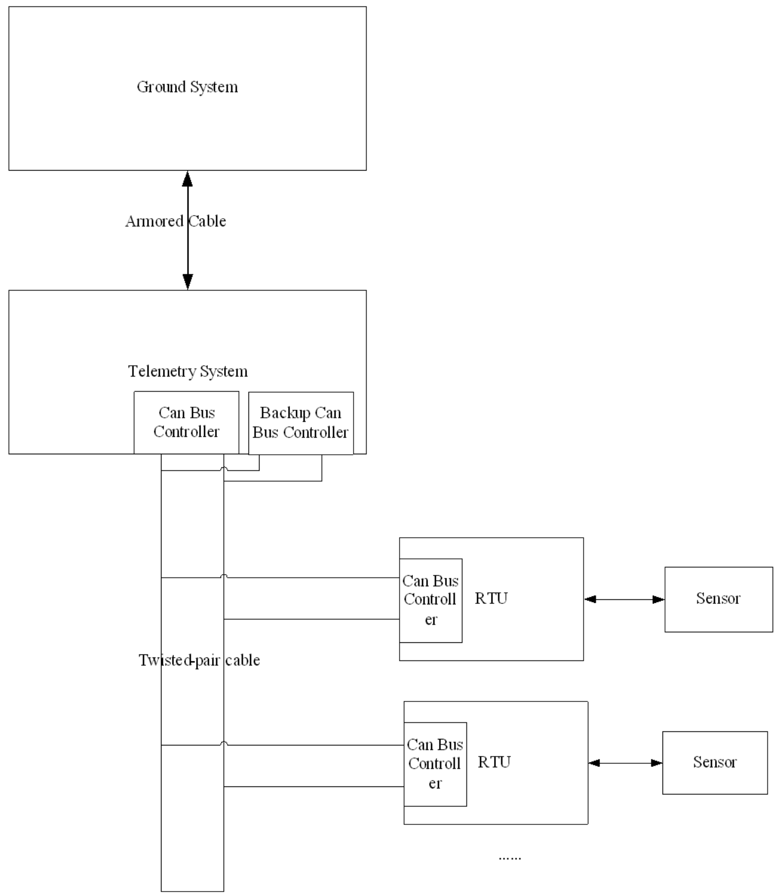

Figure 3: MWD Digital Communication System

signal, when select_i is 0, the CAN bus controller is allowed access to, when select_i is 1, register assignment is allowed. Rd_i and wr_i are microprocessor read enable signal and write enable signal. Rst_i is reset input, used to reset the CAN interface. Bus_off_on is bus interface controlling the bus close and open. Tx_o and rx_i connect with the transceiver to send and receive data to the bus [Shuaijun Duan (2009)].

Dataflow_Module is the core part of CAN bus controller, its function such as the LLC sublayer reception filtering, overload notification and recovery management, the data encapsulation/disassembly of the MAC sublayer, the frame coding, media access management, error detection, error calibration, response and the serializer/de-serializer, and physical layer bit encoding/decoding, bittiming and

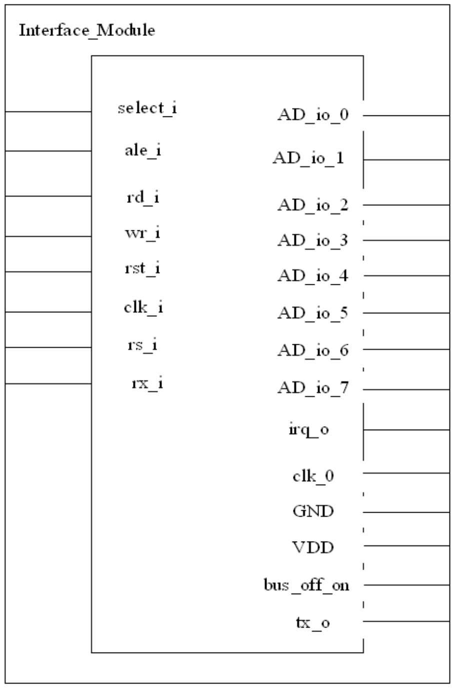

Figure 4: Interface_Module

synchronization, its structure is as Figure 4 [Tao Liu, Xinghua Lou (2006)]:

Bit Stream Processor (BSP) is a generator of CAN bus controller to control the data flow. It consists of four main modules: receiver module, transmitter module, module, CRC check and FIFO. ERROR Management Logic is to monitor and detect the transmission error. Because the microprocessor speed rate is higher than data transmission, so we must use FIFO to store data. We define three 256*8 asynchronous FIFO memory in Bit Timing Login, BSP and received buffer/controlling register, including clock signal, reading data bus, writing data bus, full flag and empty flag. In every above block, there is a register at least to store the status. External microprocessor can access them directly via the address register

Arbitration mechanism is one of features of CAN bus protocol, which is also implemented in Dataflow_Moduel. All the subsystems can be used as the master station to transmit and receive. To avoid bus conflicts CSMA/CD (Carrier Sense Multiple Access/Collision Detect) with bit arbitration is used. When the bus is free, any node can start sending packets. When it is conflicting, the control of bus is determined by arbitration mechanism. When multiple stations simultaneously send informa-

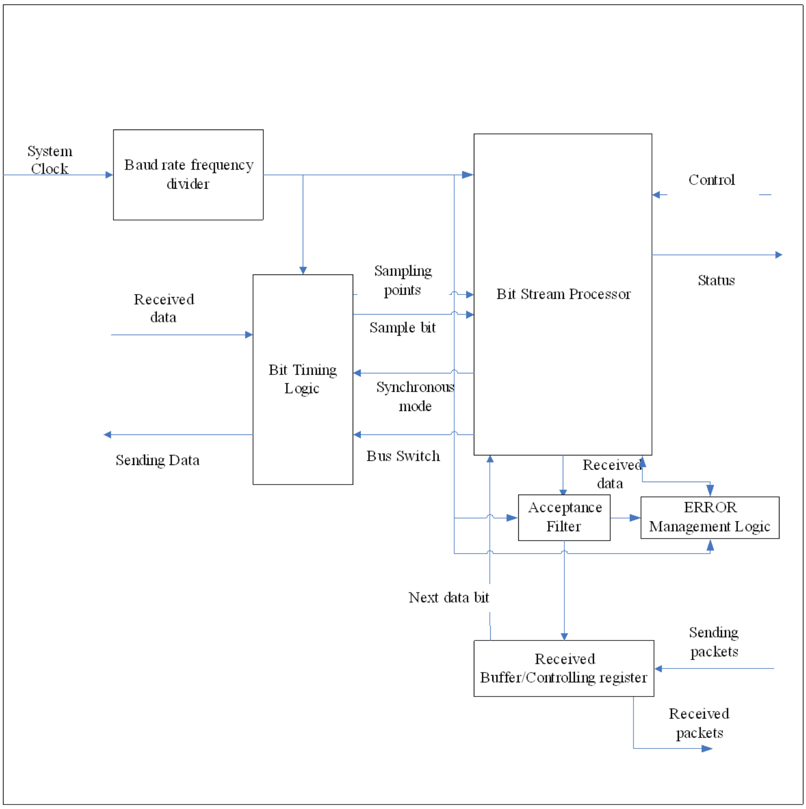

Figure 5: Dataflow_Module Block Diagram

tion, the station that has smaller identifier value sent priority. Other stations stop sending and monitoring of the bus, and then send the request until the bus is idle.

6 Conclusion

The design of CAN bus controller based on FPGA, as the interconnect bus of the downhole equipment, can enhance the reliability of the data transmission system according to the need of drilling, reduce cost and stability performance. And according to the characteristics of the CAN multi-master, a backup CAN bus controller in telemetry system can be set up. When telemetry unit is detected to perform abnormally, the backup unit can be activated to ensure the instrument working properly.

References

Duan, S. (2009): *Design and Test of CAN Bus Controller Based on Verilog HDL.* Jilin: JiLin University.

Hue, Y. K.; Teixeira, F. L. (2006): Analysis of Tilted-coil Eccentric Borehole Antennas in Cylindrical Multilayered Formations for Well-Logging Applications. *IEEE Transactions on Antennas and Propagation,* vol. 54, no. 4, pp. 1058–1064.

Hao, X.; Yang, J. (2002): Analysis EXCELL-2000 imaging logging system communication link. *Petroleum Instruments*. vol.16, no 3, pp.23–27

International Standard ISO 1898 (1993):Road Vehicles–Interchange of digital information–Controller Area Network(CAN)for High Speed Communication. *ISO Reference number ISO 11898.*

Kang, B.; Li, Y. (2000): The Performance Analysis and Comparison on CAN Bus and 1553B Bus. *Measurement & Control Technology,* vol.19, no. 2, pp. 47–49.

Li, Z. (1998): Specification Analysis of 1553B Bus System. *Telecommunication Engineering,* vol 38, no. 4, pp, 30–34.

Liu, T.; Lou, X. (2006): *FPGA digital electronic systems design and development of navigation example.* Beijing: Posts and Telecom Press.

Neumann, P.(2007): Communication in Industrial Automation—what is going on? *Control Engineering Practice,* vol. 15, no. 11, pp. 1332–1347.