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# **The FlexRay Implementation of By-Wire System for Electric Vehicle**

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## **Abstract**

In the recent years, advanced technologies of electronic devices for the communication and computer engineering have been considered to be widely implemented in the vehicle systems. Among those possible applications, the automotive network which is so-called “X-by-Wire” scheme has been developed for steering control and braking control of the vehicles. It is known that the weight reduction of vehicle systems can decrease the power consumption in the design of electric driven vehicle by replacing the mechanical components with electronic devices. Therefore, X-by-wire system combined with fault-tolerant applications will be a trend in the automotive industry. Under the automotive circumstance, the time-triggered protocol improves the network capacity and guarantees the transmission of all safety related message. In order to ensure the safety of electronic devices, an advanced networking protocol FlexRay has been recently proposed to the design of X-by-wire system. In this paper, such an X-by-wire mechanism is developed for electric vehicle. The proposed design covers the development of a hub wheel motor driven electric vehicle and the design of both electronic control braking module and communication network. For facilitating the application usage, a FlexRay communication node is developed by using microprocessor chip Freescale MC9S12XF512. An electric vehicle is also designed by using four hub wheel type AC motors with DC motor driven braking mechanism for system testing and performance evaluation. A time-scheduling scheme is proposed and configured for each of nine FlexRay nodes to fulfil the tasks of drive-by-wire and brake-by-wire operations. Experimental results demonstrate the success of the proposed design.

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*Keywords:* FlexRay • X-by-wire • motor.

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## **1 Introduction**

Over the past several years, due to the fast development of electronic devices the advanced technologies in communication and computer engineering have been considered to be

implemented in the vehicle systems. Among those possible applications, the so-called “X-by-Wire” scheme has been developed for steering control and braking control of the vehicles [1]-[3]. One of the key advantages by using such a scheme is the weight reduction for saving power in the design of

electric driven vehicle by replacing the mechanical components with electronic devices. However, such a design might result in the reliability issue of the safety-critical functions for electronic components. It is known that failures of safety-critical functions may cause serious injury or death, especially in vehicle system. FlexRay is known to be an advanced networking protocol for by-wire system [4]-[6]. It provides several benefits over CAN (Controller Area Network). For instance, a FlexRay module can provide both time-triggered and event-triggered operations, while a CAN module can only work in one type of operation. For safety concern, FlexRay provides two independent cable paths, called "Channel A" and "Channel B." Two channels can transfer different data or the same data for redundancy. Besides, the baud rate of FlexRay can be up to 10 Mbps and the number of data bytes in a FlexRay frame can range up to 254, which are greater than 1Mbps and 8 bytes in a CAN frame. [7]

FlexRay protocol was initiated and developed as the next generation automobile communication bus by the FlexRay consortium founded by BMW, DaimlerChrysler, Philips, and Motorola in 2000. In the recent years, many automotive and semiconductor industries such as Freescale, and Bosch have joined as consortium members. A FlexRay timing cycle is basically divided into two parts: static segment and dynamic segment. Frames in the segment can occur at a well-defined time schedule and can be configured in advanced. The dual channel topology of FlexRay design provides a means to implement communication systems which can tolerate the breakdown of one channel. Based on those features, it can be applied to the high speed distributed automotive control applications [8]-[11].

In this paper, we apply the FlexRay network to achieve the implementation of the Drive-by-Wire system of which structure integrates four wheel motors with closed-loop speed control. Besides, the brake-by-wire System is also designed by employing the FlexRay network. The proposed brake-by-wire System consists of DC brushed motor driven brake mechanism while the brake force is regulated by the armature current of DC motor. To fulfil the design, FlexRay protocol parameters have to be scheduled for improving the network efficiency. The control messages in the proposed FlexRay communication network include motor control command, status feedback and brake disks actuating status feedback. In

addition, the amount of data size and the data type have to be distinguished as the periodic data or event-triggered data. In this study, the periodic data are configured at the static segment and event-trigger data are configured at the dynamic segment. Finally, the performance of those two by-wire designs are verified in a scale down electric vehicle.

The paper is organized as follows. A recall of FlexRay protocol is given in Section 2. It is followed by the design of X-by-wire schemes. Experimental results are presented in Section 4 to demonstrate the performance of the proposed designs. Finally, concluding remarks are also given in Section 5 to summarize the key contributions of the paper.

## 2 FlexRay Protocol

In this section, we recall the FlexRay protocol (e.g., [8]-[10]) which will be used in the design of X-by-wire system in Section 3. Details are given below. The main feature of FlexRay protocol is that it can provide high reliability and high-speed data transmission [8], [9]. Based on TDMA (Time Division Multiple Access) technology, the FlexRay network can ensure that each data will be transmitted at a predetermined time. In addition, FlexRay can provide both time-triggered and event-triggered operations. The FlexRay network contains static and dynamic time slot scheme for arbitration mechanism in every communication cycle.

A FlexRay network node consists of three major parts, namely, Host, Communication Controller (CC) and Bus Driver (BD) [8]-[10] as shown in Fig. 1.

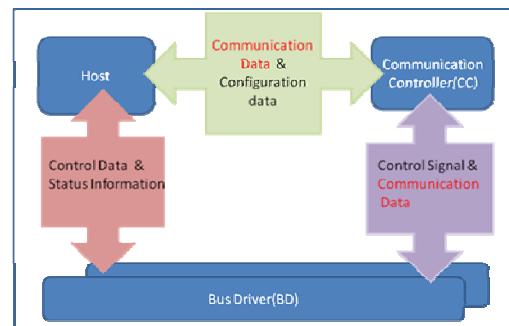


Figure 1: FlexRay Communication Structure

When the Host has completed the network configuration, it will send Configuration Data to the CC to do network configuration. Then the Host can send data at the communication cycle through the help of CC and BD to network bus.

The main framework of the FlexRay protocol possesses four main core mechanisms such as coding and decoding, media access control, frame and symbol processing and clock synchronization processing. In addition, FlexRay also provides a Controller Host Interface for Host to control the Protocol state. A FlexRay communication protocol is defined by the frame format, which is consisted of Header Segment, Payload length, and formed Trailer Segment as shown in Fig. 2.

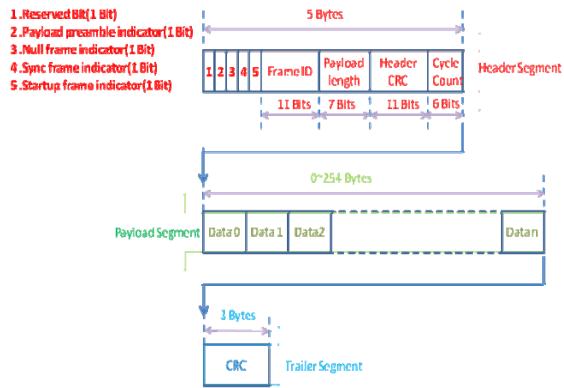


Figure 2: FlexRay frame format

In the FlexRay protocol, the Media Access Control (MAC) mechanism is based on a cycle of the so-called “communication cycle” which provides two medium access methods. They are static methods and dynamic micro-time access to time-slot method. A typical communication cycle is consisted of static segment, dynamic segment, symbol window and network idle time as depicted in Fig. 3.

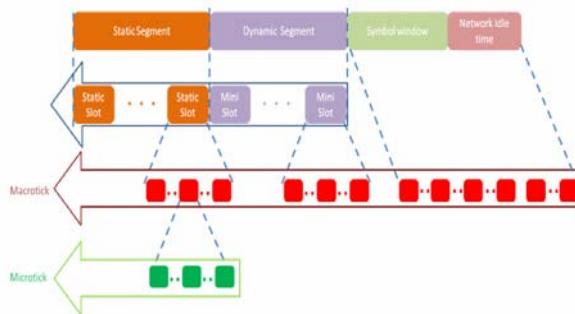


Figure 3: Medium access methods by FlexRay

The static segment can be divided into 2 to 1223 static slots while each static slot have time length of 4 to 661 Macroticks. Similarly, the dynamic segment can have 0 to 7986 Minislots, while each Minislot have time length of 2 to 63 Macroticks. The number of static slot and dynamic slot depends on the application requirement.

### 3 Main Design

In this paper, we consider to implement the functions of X-by-wire by using FlexRay-based communication network. The proposed system architecture contain four main parts: motor control, brake actuators, FlexRay network and wireless control devices as depicted in Fig. 4. For the control structure, drive-by-wire and brake-by-wire are implemented with four FlexRay nodes for hub wheel motor control and four FlexRay nodes for braking, respectively, with one node for acting as main controller through wireless communication. Details of the design for each function are given below.

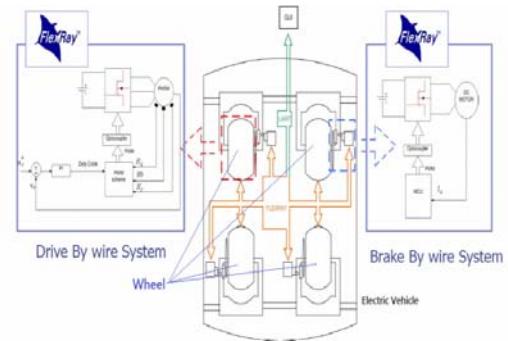


Figure 4: Control structure of EV

#### 3.1 Motor control

In this subsection, we consider the motor control design for the electric vehicle (EV). A scale down four-wheel drive vehicle is built in this study by using four hub wheel PMSM (Permanent Magnet Synch-Motor) motors. A PWM type power driver is developed to control the speed of the hub wheel motor.

First, we consider the control of each of four hub wheel motor. The open-loop time responses of the four motors are shown in Fig. 5.

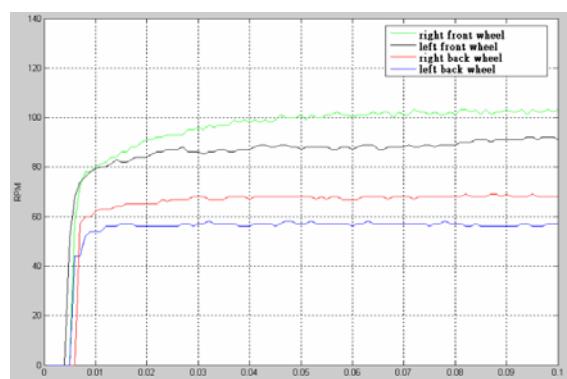


Figure 5: open-loop speed responses of four motors

It is clear that those responses donot meet the performance requirement. For the control design, we try to build up the mathematical model for each of the four motors by using simple system identification technique. In order to provide stable speed output for each motor, PI controller is added in the control loop with feedback signal from Hall-effect sensors as shown in Fig. 6. System simulation is then performed via Matlab Simulink to verify the feasibility of system modelling and search for the feasible control gain as depicted in Fig. 7.

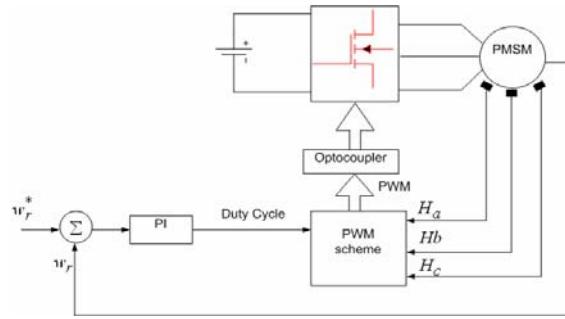


Figure 6: The control loop for hub wheel motor

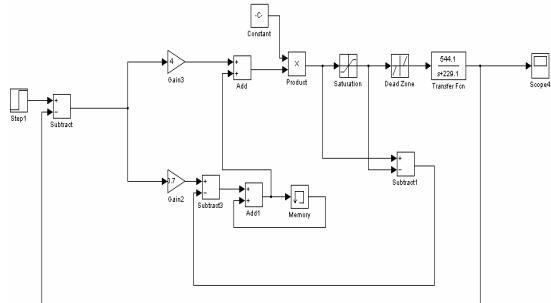


Figure 7: Simulink diagram for PI control

The results of motor speed control for one wheel motor are shown in Fig. 8. It is observed from Fig. 8 that the simulation result is very similar to the practical response.

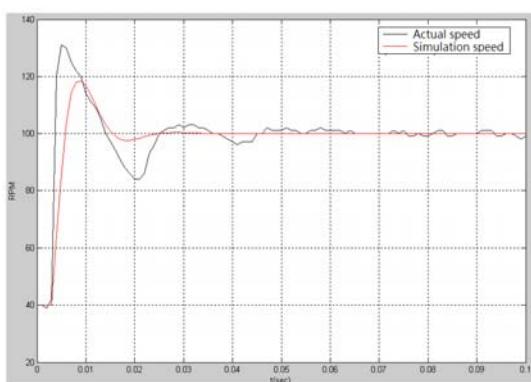


Figure 8: Time responses for speed control

Now, we focus on the motion control of the whole EV instead of that for each of four motors. It is clear that both magnitude alignment and synchronization of the speed for four hub motors play a very imprtant role in making such an operation. As depicted in Fig. 5, the open-loop speed responses of four motors are very different. By using a heuristic control strategy, the speed responses of four motors are controlled to match each other as shown in Fig. 9.

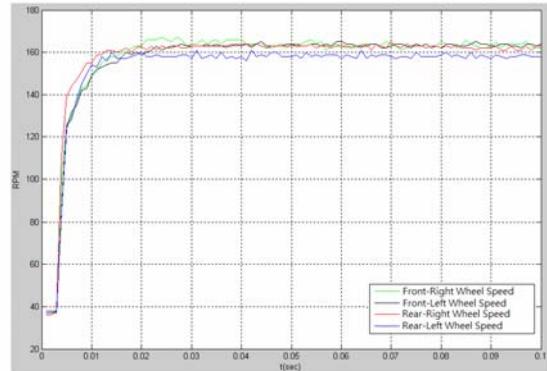


Figure 9: Speed response of four wheel motors

### 3.2 Braking system

In this study, a simple EMB (Electric Mechanical Brake) mechanism is adopted from [12] in the design of braking system. The applied braking force is achieved through a 12-volt DC brushed motor combined with gearbox as depicted in Figure 10. Due to the differences among the four hub wheel motors, the required supply current for providing brake torque of each motor is tested as shown in Fig. 11.

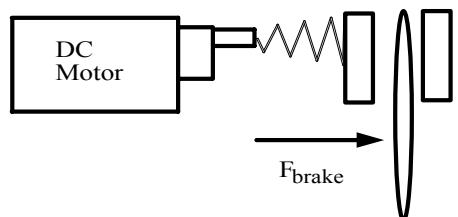


Figure 10: Diagram of brake mechanism

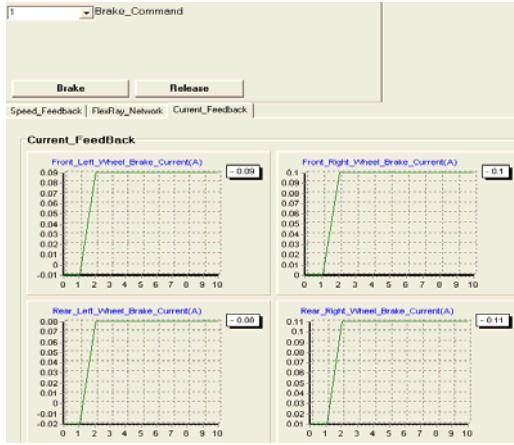


Figure 11: Current charts for brake motor control

### 3.3 Development of FlexRay-based communication node

It is known that the current available FlexRay communication node such as FlexDevel Kit by TZM Company is for technology training only. The size of those kits is too big to be used in the practical application. In order to facilitate the design, in this study we have developed our own FlexRay communication node by using chip Freescale MC9S12XF512 as depicted in Fig. 12. This processor chip carries 512 Kbyte of flash memory, 32 Kbyte of RAM and 4 Kbyte EEPROM for application design [13]. As shown in Fig. 12, the size of the node is 8.9cm by 5.9cm wide. The proposed FlexRay communication node possesses 16 bit analog-to-digital converter, UART interface, six groups of PWM signal output and eight GPIO pins and dual-channel FlexRay communication interface for I/O interface. Based on such a design, it will be easier for the installation in implementing the function of X-by-wire.

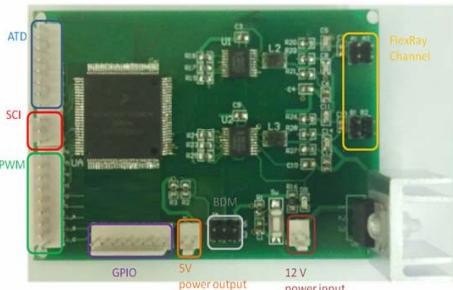


Figure 12: The developed FlexRay node

### 3.4 X-by-Wire

Based on the design presented above, a FlexRay-based network control of hub wheel motor is proposed as depicted in Fig. 13.

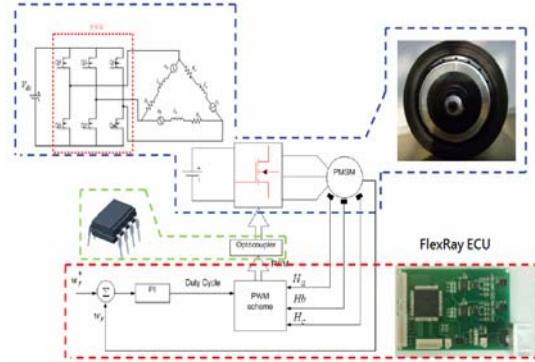


Figure 13: Control structure of hub wheel motor

Now, we focus on the programming and configuration of the FlexRay node. In order to fulfil the tasks of drive-by-wire and brake-by-wire, we can divide the network control messages into three major groups such as motor control group, brake-by-wire group and host control group. The data size for each of the three groups is defined in Table 1 below.

Table 1: Data size for network control parameters

Network control group	Data size
motor control group	Speed state (1byte) 、 Network state (15byte)
brake-by-wire control group	Current state (2byte) 、 Network state (15byte)
host control group	Command (8byte)

In addition, the value for FlexRay network parameters is also defined in Table 2.

Table 2: FlexRay network parameters

Protocol parameter	value
gdMacrotick	1 $\mu$ sec
gdCycle	400 $\mu$ sec
gNumberOfStaticSlot	10
gdStaticSlot	36 $\mu$ sec
gNumberOfMinislot	1
gdMinislot	27 $\mu$ sec
gdSymbol Window	0 $\mu$ sec
gdNIT	13 $\mu$ sec

Both of the timing frame for static slots and dynamic slots are depicted in Figs. 14 and 15, respectively, to demonstrate the success of the programming and configuration for the proposed by-wire network control system.

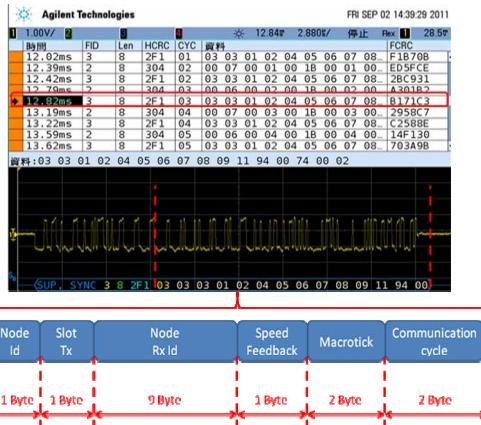


Figure 14: The static slot data for by-wire system

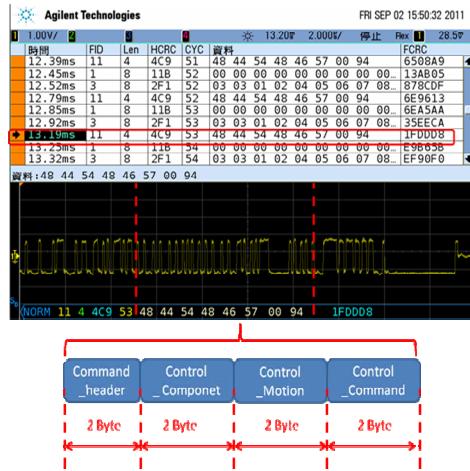


Figure 15: The dynamic slot data for by-wire system

## 4 Experimental Results

The mechanical structure of the designed EV (electric vehicle) is fabricated as depicted in Fig. 16. In this EV, we have four hub-wheel motors for acting as a four-wheel drive vehicle. Each motor is also coupled with an EMB for serving brake. A nine-node FlexRay-based network control system is then established to exhibit the functions of drive-by-wire and brake-by-wire. One of those nine FlexRay nodes acts as system controller to receive and/or send command for the operation of vehicle movement through a wireless communication module. Through the testing on road simulation platform as depicted in Fig. 17 and the real road-test, the functions of drive-by-wire and brake-by-wire are verified to meet the designed performance.

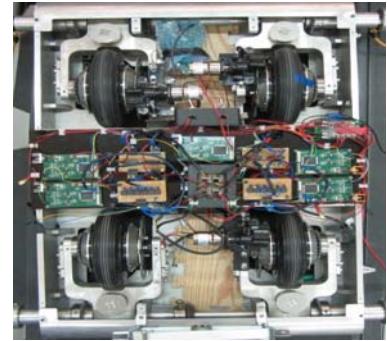


Figure 16: Photo of the mechanical structure of EV



Figure 17: Photo of EV testing on conveyer

## 6 Conclusions

In this paper, we proposed a FlexRay protocol based network control system for drive-by-wire and brake-by-wire of electric vehicle. Based on our own developed FlexRay communication node, we have implemented such a system. The performance testing on both of the conveyer in the laboratory and the real road demonstrate the success of the design. It is found from this study that the size of FlexRay communication node and the control scheme for the synchronization of four wheel motor speed play very important roles in practical implementation of X-by-wire system.

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