A RISC-V Based SoC with Configurable CPK Sensor Interface for ECU on Motorcycle

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***Abstract*—A RISC-V based SoC (system on chip) with a configurable crankshaft position sensor (CPK) interface for an engine control unit (ECU) on a motorcycle is presented. The proposed SoC is the first SoC with RISC-V core for a motorcycle ECU, integrating a dedicated configurable engine crank position sensor interface to facilitate accurate and low-latency fuel injection and ignition control for the internal combustion engine on a motorcycle, while greatly reducing the computational capability demand for the MCU inside the ECU.**

***Index Terms*—RISC-V, system on chip, SoC, crankshaft position sensor, CPK sensor, engine control unit, ECU**

I. Introduction

An engine control unit (ECU) for motorcycles controls multiple systems of an internal combustion engine, such as the fuel injection system [1], [2], the ignition system [3] and the variable valve timing [4]. Among sensors used by ECU, the crankshaft position sensor is the most critical. It detects the position of the crankshaft for the ECU to control fuel injection and ignition [5]. Most ECUs use general microcontroller units (MCU)s and GPIO-based software for crankshaft position sensor (CPK) sensor signal processing. Because the ECU for motorcycles is price-sensitive, the MCU's performance is limited. The rotation speed can be as high as 12000rpm, therefore the computational load is typically high for the MCU. The performance of limited performance of the MCU decreases the positioning accuracy of the CKP sensor, thereby reducing the efficiency of the engine.

RISC-V is an open-source, license-free, modular, extensible instruction set architecture and is suitable for custom silicon chips. These advantages make RISC-V an ideal choice for applications that require in-depth optimization for performance, power, cost and security [6]. In addition, the enhancement of integrated solutions such as clock management [7], [8], placement [9], congestion [10] and routing [11] can reduce the time-to-market and development costs of SoC (System-on-Chip) solutions. The improving SoC solutions further enabled us to develop a SoC solution with the RISC-V.

While SoC solutions become more popular [12]–[14], RISC-V is one of the better choices for the customization of various applications [6], [15]. In this paper, we propose a RISC-V-based SoC for ECU on motorcycles. The main contributions of this study are as follows:

- To the best of our knowledge, this is the first RISC-V-based SoC for an ECU on a motorcycle. A dedicated configurable CKP interface module is designed and integrated, which significantly improves the accuracy and reduces the latency and software workload.
- Major design considerations for the configurable deglitch module, single-tooth processing module and multi-tooth processing module in the CKP sensor interface are presented.

II. Configurable CPK Sensor Interface Design

Most CPK sensors are inductive, in which a magnetization core and a copper conductor winding are mounted on an isolated coil. The CPK sensor, cogwheel and the output of the sensor are shown in Fig. 1. The Configurable CPK sensor interface comprises a deglitch module, a single-tooth processing module(STPM), a multi-tooth processing module(MTPM) and other modules.

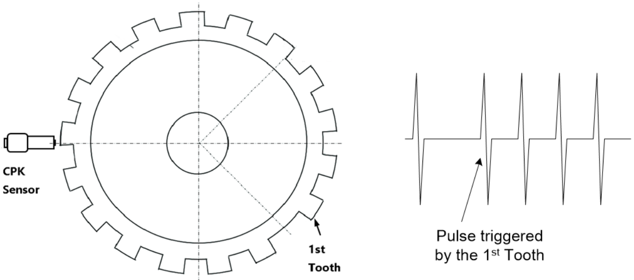

Fig. 1. CPK sensor and its output signal

A. Configurable Deglitch Module

The output of a crankshaft position sensor is analog and susceptible to interference; therefore, glitches are usually generated after this analog signal is converted to a digital signal. A configurable deglitch module is designed to filter out these glitches. To enhance its flexibility, the filter parameters can be configured through an inner-chip bus by the RISC-V core. Specifically, the proposed filter is designed to effectively filter out pulses up to 15 µs. The output of the deglitch module goes to the STPM or MTPM.

To control injection and ignition, the position information of the crankshaft is crucial, which is usually referred to in terms of the angle in degrees. The software starts the injection and ignition at appropriate angles. The single-tooth processing module (STPM) and multi-tooth processing module (MTPM) obtain the output of the configurable deglitch module, calculate the angles of the crankshaft, and generate interrupts to signal the software to take further action.

In low-cost motorcycles, only one tooth is present on the crankshaft cogwheel. When the tooth approaches the CKP sensor, a distinct signal is generated. This signal serves as an indicator of the initiation of a new round and is processed by the deglitch module and output to the STPM. Based on the number of clock cycles in the previous round, the STPM can detect the instant position and trigger interrupts, injections or ignitions when the positions meet the target positions configured by the software.

If the ECU enables auto-ignition and angle calculation features in the STM module, once the ECU configures the ignition timing parameters for the STPM, it can offload massive real-time calculations, leading to improved engine efficiency and performance. The features mentioned above are shown in Fig. 2.

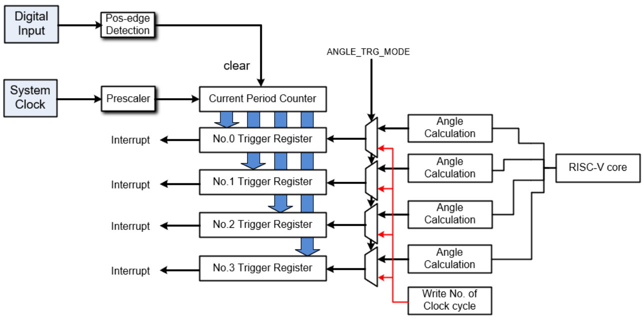

Fig. 2. STM triggering mechanism

B. *Multi-Tooth Processing Module*

The Multi-Tooth Processing Module (MTPM) is developed to process the CPK signals when the cogwheel has multiple teeth.

In the case of multiple teeth, the number of pulses generated by the CPK sensor in a round is the same as the number of teeth, thus providing more information for successive processing. More information demands more processing capabilities for the ECU. The MTPM implements most of the calculation and control functions for injection and ignition control, which greatly reduces the workload of the software.

The proposed MTPM also incorporates an automatic tooth number detection algorithm and control logic for multi-cylinder engines.

Compared to GPIO-based software processing, the proposed circuit-level STPM and MTPM achieve higher precision and much lower latency, as shown in the table below:

TABLE I
CHARACTERS OF TWO CPK SENSOR INTERFACE IMPLEMENTATIONS

	Proposed interface	GPIO-based emulated interface
Latency	<3 clock cycles	20 clock cycles or more
Cost	Extra logic	Higher MCU usage rate
Precision	High precision	Execution time may vary

III. Conclusion

A RISC-V-based SoC for ECU on motorcycles is presented. By integrating a dedicated configurable engine crank position sensor interface, the SoC can improve the accuracy and response speed of the engine control, while lowering the MCU cost by offloading most crank position detection and calculation tasks from the MCU.

For the engine crank position sensor interface, configurable digital deglitch logic is designed to filter out noise and interference. Single-tooth and multi-tooth processing modules are applied to a cogwheel with single and multiple teeth respectively. In both cases, the proposed CKP sensor interface receives and processes the position information accurately and effectively, achieving high quality with competitive price ECU design for motorcycles.

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