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Evaluation of Power Efficiency for Digital Serial Interfaces of Microcontrollers

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Over the recent years, novel low-power microcontrollers have been introduced. This has allowed the development of various applications, which can operate over long periods of time and fulfill their tasks having very limited amount of energy, such as e.g., Wireless Sensor Networks (WSN).Nonetheless, for fulfilling their tasks such devices in addition to the central processor often have to include several microcontrollers or some peripherals, such as sensors, external memory chips or other application-specific hardware. All those peripherals, except the energy for actual operation also require some energy for communicating to the central processor. In the paper we are investigating and comparing the energy consumption for three most widely used embedded systems' digital serial interfaces, namely I2C, SPI and UART. The presented results have been obtained using the real-life microcontroller (PIC18F family from Microchip) and reveal the energy consumption for different interface implementation methods (hardware vs. software) and various scenarios (idle interface, different data transmit or receive scenarios). The presented data can be valuable as well for researchers and engineers and allow to choose the most energy efficient communication interface and its implementation method to be used in the most energy critical applications.

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I. Introduction

The technology advances of the recent years allowed to develop wide range of novel embedded systems with extremely low power consumption. Nowadays, the low-power embedded processors are widely used as core processing systems in various portable consumer electronics, including communication devices, computers and medical devices [1], [2]. Nonetheless, although the embedded processors themselves often have quite high power efficiency, the peripheral components (e.g., sensors, external memory chips or cards, graphical user interfaces hardware) that are required in many applications could significantly increase the energy consumption for the whole device. The energy, that is consumed by those peripherals consists as well of the energy for their actual operation and the energy for peripheral communication with core processor. As has been revealed e.g., in [3], sometimes the energy consumption for the communication with a peripheral appears to be even higher than the one for this peripheral operation. Especial importance the problem of energy efficiency overall and energy efficiency for communication in particular achieves for applications, where continues autonomous operation is required, such as e.g., many real-life applications of Wireless Sensor Networks (WSN) [4] or personal communication devices with multiple processors [5]. Although some disparate scraps of information can be found in the works focusing the energy efficiency of the WSN platforms and other portable communication devices (see e.g., [3], [5]), the actual problem of energy efficiency for the most widespread embedded systems' communication interfaces, to the best of our knowledge, has not been considered previously at all. Therefore, in this paper, we evaluate the most widely used digital interfaces and compare them from the point of view of energy efficiency.

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***Abstract*—Over the recent years, novel low-power microcontrollers have been introduced. This has allowed the development of various applications, which can operate over long periods of time and fulfill their tasks having very limited amount of energy, such as e.g., Wireless Sensor Networks (WSN). Nonetheless, for fulfilling their tasks such devices in addition to the central processor often have to include several microcontrollers or some peripherals, such as sensors, external memory chips or other application-specific hardware. All those peripherals, except the energy for actual operation also require some energy for communicating to the central processor. In the paper we are investigating and comparing the energy consumption for three most widely used embedded systems' digital serial interfaces, namely I^2C, SPI and UART. The presented results have been obtained using the real-life microcontroller (PIC18F family from Microchip) and reveal the energy consumption for different interface implementation methods (hardware vs. software) and various scenarios (idle interface, different data transmit or receive scenarios). The presented data can be valuable as well for researchers and engineers and allow to choose the most energy efficient communication interface and its implementation method to be used in the most energy-critical applications.**

***Keywords*-digital serial interface; energy consumption; embedded systems; power efficiency; wireless sensor networks**

I. INTRODUCTION

The technology advances of the recent years allowed to develop wide range of novel embedded systems with extremely low power consumption. Nowadays, the low-power embedded processors are widely used as core processing systems in various portable consumer electronics, including communication devices, computers and medical devices [1], [2]. Nonetheless, although the embedded processors themselves often have quite high power efficiency, the peripheral components (e.g., sensors, external memory chips or cards, graphical user interfaces hardware) that are required in many applications could significantly increase the energy consumption for the whole device. The energy, that is consumed by those peripherals consists as well of the energy for their actual operation and the energy for peripheral communication with core processor. As has been revealed e.g., in [3], sometimes the energy consumption for the communication with a peripheral appears to be even higher than the one for this peripheral operation. Especial importance the problem of energy efficiency overall and energy efficiency for communication in particular achieves for applications, where continues autonomous operation is required, such as e.g., many real-life applications of Wireless Sensor Networks (WSN) [4] or personal communication devices with multiple processors [5]. Although some disparate scraps of information can be found in the works focusing the energy efficiency of the WSN platforms and other portable communication devices (see e.g., [3], [5]), the actual problem of energy efficiency for the most widespread embedded systems' communication interfaces, to the best of our knowledge, has not been considered previously at all. Therefore, in this paper, we *evaluate the most widely used digital interfaces and compare them from the point of view of energy efficiency*.

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II. SERIAL INTERFACES

As revealed in [6] and [7], out of the wide range of existing communication interfaces, nowadays the most widely used are the analog interface and I^2C, SPI, UART and 1-wire digital interfaces. Each of these interfaces has some specifics, that influence the data rate, energy consumption and available additional interface's features (e.g., robust communication or device identification support). Many of those interfaces are nowadays already implemented by the hardware modules that are integrated into the majority of contemporary microcontrollers [8].

A. UART

The interfaces based on Universal Asynchronous Receivers/Transmitters (UARTs) (later in the paper those will be addressed as "UART interfaces") are often used for implementing such standards as Electronic Industries Alliance (EIA) Recommended Standards RS-232, RS-422 and RS-485. UARTs are nowadays one of the most commonly used method for communication between an embedded system and an external device [9]. As Fig. 1 revels, UARTs provide full-duplex asynchronous serial peer-to-peer communication. The data transmission over UART usually starts with a start bit(S), that alerts the receiver that a word of data is about to be sent and allows the receiver to synchronize clocks with the transmitter. After the start-bit, the actual data is transmitted starting with the least-significant bit. Once a data word has

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