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Design of a low-power, low-cost UHF RFID reader module

Özgür BOSTAN[1,2,*], **Hüseyin Ulvi AYDOĞMUŞ**[1,3], **Serkan TOPALOĞLU**[2,4]
[1]RFtek Elektronik Ar-Ge Dan. San. ve Tic. Ltd. Şti., İstanbul, Turkey
[2]Department of Electronics Engineering, Graduate School of Science and Technology, İstanbul Technical University, İstanbul, Turkey
[3]Department of Computer Engineering, Institute of Science and Engineering, Yalova University, Yalova, Turkey
[4]TRON Elektronik Sistemler San. ve Tic. A.Ş., İstanbul, Turkey

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Abstract: A new low-power, low-cost ultrahigh-frequency (UHF) radio frequency identification (RFID) reader module for short range low/mid-powered applications is presented in this paper. AS3993 is used as the reader IC, which integrates all building blocks including an analog front-end, a microcontroller unit interface, a voltage-controlled oscillator, and a phase-locked loop in a 48-pin QFN (7 × 7 × 0.9 mm) package. It has a new architecture for lowering the power consumption with a DC supply of 2.7 V and a current of 65 mA, and improved –90 dBm sensitivity. A power amplifier with medium power and high efficiency is also integrated to fulfill the function of the UHF RFID reader module. The reader module fully supports EPC Class 1 Gen2 ISO 18000-6C protocol and ISO29143 air interface for mobile RFID. With the use of the AS3993 reader IC it is possible to reduce the total cost. This paper describes all the hardware and software designs and experimental results of the designed system. The measurement results indicate that the set output power value in the chip is achieved quite successfully.

Key words: AS3993, low-cost, low-power, reader IC, reader module, radio frequency identification, short range, ultrahigh-frequency

1. Introduction

Radio frequency identification (RFID) is a system that uses wireless communication technology (by means of radio waves) to identify objects, humans, and animals. It is a subbranch of automatic identification (AUTO-ID) technologies [1].

In recent years, there has been a growing interest in RFID systems in both industry and academia. The application of RFID is very popular in many areas such as purchasing and distribution logistics, service industries, etc. [2]. Especially ultrahigh-frequency (UHF) RFID applications are becoming more and more popular since systems at the UHF band have longer ranges in comparison to other available bands and moreover they are capable of transmitting higher data rates.

A basic UHF RFID system consists of a host server, tags, antennas, and a reader. Readers generate electromagnetic waves via antennas for transferring the information between tags and host servers. RFID progressed as a discrete technology and has spread out to many fields of daily life. With the increasing popularity of UHF RFID applications and technological advancements, demands for short-range (mobile) applications have

*Correspondence: ozgur@rftek.com.tr

already attracted attention. Based on this circumstance, the following important criteria have emerged: power consumption, size, and the total system cost. Considering these issues, a low-power, low-cost UHF RFID reader module for short-range applications has been designed within the scope of this work. With the newly released IC design technology, the proposed UHF RFID reader module has a low power consumption feature.

There are some works in the literature in the field of UHF RFID reader design. A UHF RFID reader module based on the R1000 RF reader IC was designed, which has 27.5 dBm output power and its dimensions are 90 *times* 55 *times* 10 mm [3]. In the work of Tang et al. [4], a design of a UHF reader based on AS3991 was presented. It has 20 dBm output power with dimensions of 90 *times* 35 *times* 5 mm. Peng et al. [5] presented a low-cost, low-power UHF RFID reader IC for mobile applications, which has 0.18 *mu* m CMOS technology and area of 14 mm^2, consuming 471 mW. A fully integrated single-chip RFID reader developed using the 0.18 *mu* m CMOS process was also presented in the literature [6]. In that work, the reader has 7.4 dBm output power, 10.9 mm^2 area, and 116.18 mW power consumption. In the work of Ye et al. [7], a UHF band RFID reader transceiver design was presented with 20 dBm output power in 13 mm^2, consuming 135 mW.

The emphasis of this work is on the hardware design as well as the design of the embedded software. Furthermore, according to the authors' knowledge, this paper is the first implementation of AS3993 for short-range UHF RFID applications.

2. System architecture

The simplified architecture of the RFID reader module comprises two principal blocks: the RF transceiver unit and the control unit. The basic block diagram of the module is shown in Figure 1. Communication between units is provided via a serial peripheral interface (SPI). The RF transceiver unit is composed of an analog front-end, a microcontroller unit (MCU) interface, a voltage-controlled oscillator (VCO), a phase-locked loop (PLL), two baluns, a power amplifier, and a directional coupler. All transmitting and receiving operations are executed in the RF transceiver part of the reader module. The control unit consists of a PIC24FJ64GB002 microcontroller, a USB, and a UART interface. The control unit has the functions of clock generator, reset control, system mode control, and communication with the host server. Another mission of the control unit is power regulation for the MCU and reader IC.

Another essential part is the software block, which controls the whole system as an executer. Standard RFID protocols (EPC Class 1 Gen2) are implemented in the embedded software. Based on the application requirements, the embedded software also enables the communication between the host server and reader IC via USB or UART interface.

3. Hardware design

A UHF RFID reader module has been designed based on the AS3993 reader IC with low-power and low-cost features. The reader module circuit has two main parts: the RF transceiver (reader) unit and the control unit. The RF transceiver unit has a power amplifier for amplification of the RF signal, a coupler for isolation, and RFID reader IC (AS3993), which integrates transmission, reception, and protocol processing of RFID. The main functions of the control unit are data processing and management, communication with the host server and tags, and execution of the commands from the server software.

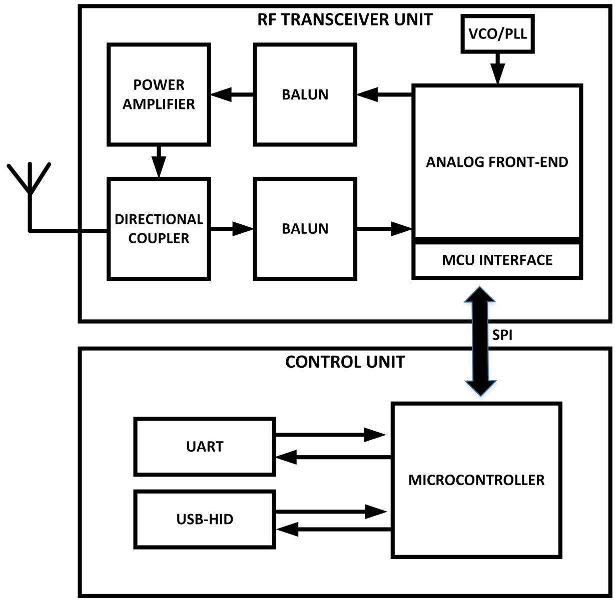

Figure 1. Block diagram of reader module.

3.1. RF transceiver unit

AS3993, which is the latest third-generation EPC Class 1 Gen2 RFID reader IC from Austria Micro Systems (AMS), was selected as the core unit of the reader module for transceiving and protocol processing operations. It has a quite small QFN48 7 *times* 7 mm package. Its rather newly released architecture exhibits low power with a DC supply voltage of 2.7 V consuming 65 mA, along with its small form factor enabling its use in handhelds and embedded applications while retaining the flexibility, integration, and simplicity of the previous generations requiring a very simple 8-bit microcontroller, making the AS3993 an ideal solution for low-power and low-cost applications [8]. The reader IC has an integrated analog front-end combining all the relevant protocols, including ISO 18000-6C and ISO 29143 air-interface protocol for mobile RFID readers [8].

AS3993 provides dense reader mode functionality, which prevents conflicts (i.e. misreading) of tag reading in a multireader application, and supports for transmission coding and decoding, data framing, frequency hopping, and CRC checking. Moreover, improved sensitivity ensures high reading capability. With the high sensitivity feature, end-product designs can easily achieve the required read range even using a simpler and low-cost antenna, thus enabling decrease in total cost [8]. The architecture of the RFID reader IC, AS3993, is shown in Figure 2.

The reader IC is enabled by setting the EN pin of the device to a positive logic level. Communication between the host system (MCU) and the reader device is provided with a four-wire serial peripheral interface (SPI). The MCU is notified to service an IRQ by a logic high level on the IRQ pin. First, as shown in Figure 2, the antenna receives the RF signal into the directional coupler (0910CF15B0100) and the balun (0900BL18B100) divides this unbalanced signal into two balanced signals, then transmits them into the AS3993. Mixers divide these two signals into I and Q modes and then deliver them into the protocol processing unit after amplification, filtering, RSSI sampling, and analog-digital conversion. It is possible to select the Class 1 Gen2 protocol via control signals in the protocol processing unit.

Transmission and reception between the device and transponders is possible in two modes. In normal mode, the baseband data are transferred to the 24-byte FIFO and all signal processing operations (signal shaping, CRC, protocol encoding, adding preamble or frame-sync, and modulation) are done internally. The data are then coded to the modulation pulse level, and coded data are sent to the modulator and amplification level and then finally directed to RFOPX and RFONX pins for transmitting. If only analog functions are required to be used, direct mode is available, which bypasses all the protocol handling support of the reader IC [8].

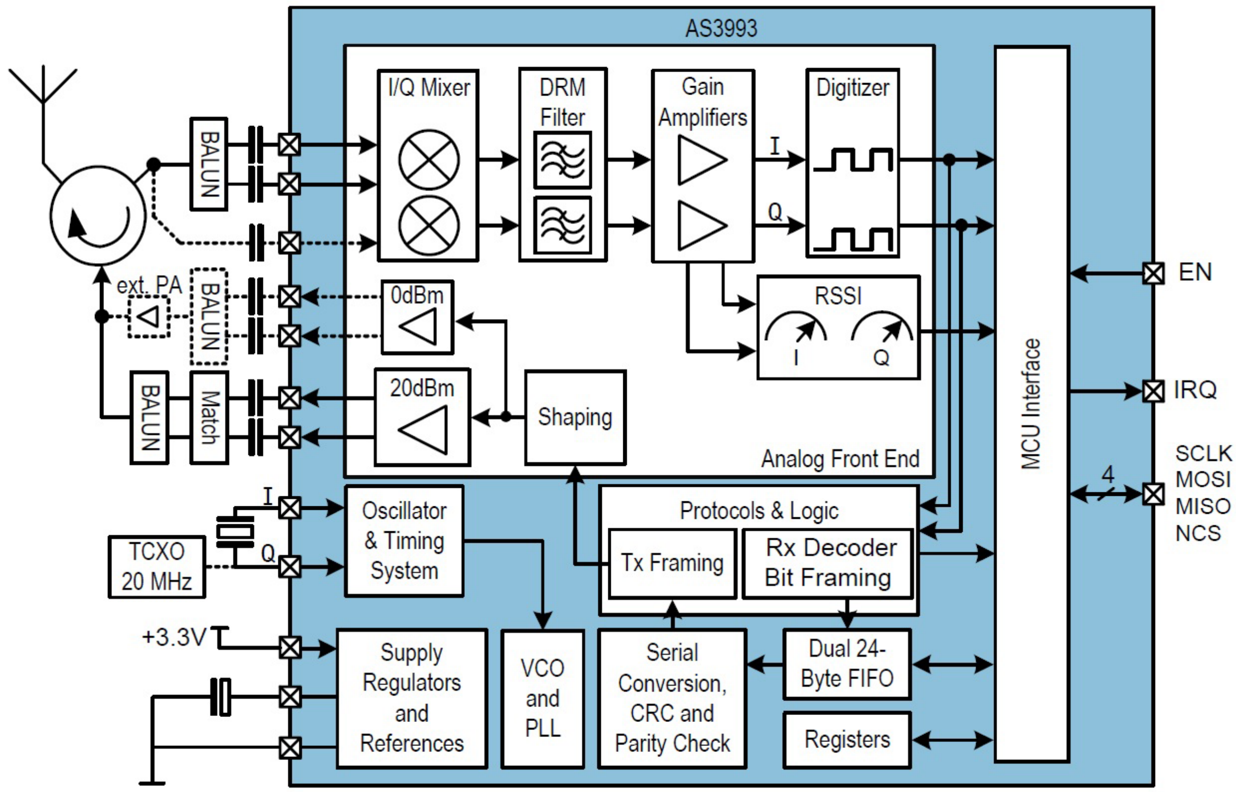

Figure 2. Basic block diagram of AS3993 reader device [8].

A power amplifier, RF2172, is used from RF Micro Devices (RFMD), which is a medium-power, high-efficiency amplifier generally used for mobile systems [9]. It has a 500–2500 MHz operating frequency band providing a gain of up to 28 dB suitable for UHF RFID applications (860–960 MHz). It has a small outline 4 mm *times* 4 mm QFN package. An analog gain control option is available for transmission power optimization while extending the battery life in mobile equipment, which has 100 mW transmit power at the antenna port. The structure of the PA section was designed as shown in Figure 3.

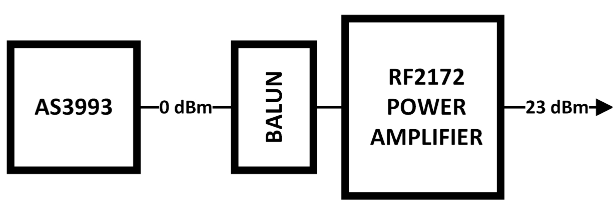

Figure 3. Block diagram of PA section.

The power amplifier is used to amplify the transmitted RF signal from the differential low-power, highly linear output (0 dBm) of the AS3993 reader IC. As shown in Figure 3, RF2172 has 23 dBm output power and provides up to 28 dB variable gain adjusted by control signals from the reader IC. To transform the balanced differential signals (100 Ω) to unbalanced single-ended signal (50 Ω) a balun is used. The signals are carried between RF devices (reader IC – balun – PA) via coplanar waveguides to provide impedance matching for maximum power transmission. As the output pins of the reader IC are internally matched to 50 Ω, all the other RF lines should be matched to 50 Ω as well.

A directional coupler is used in order to prevent the transmit signal leakage into the receiver. It works at 860–960 MHz operating frequency with the feature of 10 dB coupling. This directional coupler also includes a low-pass filter that attenuates the higher order harmonics of the carrier signal. With the use of the directional coupler, 10 dB of the incoming signal via antenna is fed to the balun that is on the receiving side of the reader module. In order to have a good RF isolation performance, not only is a directional coupler used, but also attention is paid to the RF transmission lines while designing the RF board layout and routing. Based on the dielectric constant and height of the used substrate and the gap between the transmission line and copper ground, the widths of the RF transmission lines have been calculated.

3.2. Control unit

PIC24FJ64GB002 was selected as the microcontroller unit, which is a cost-efficient device and has low-power technology from Microchip Technology. It is a high-performance, low-power, applications-oriented, 16-bit processor in a 28-pin SOIC package. The block diagram of the microcontroller is shown in Figure 4.

The MCU is used for data processing and management, communication with the host server and tags, and execution of the commands from the server software. It operates all the protocols for the reader IC via libraries embedded in its flash memory. The communication with the reader IC is provided via SPI. Other communication processes with the host system are carried out by USB interface.

A linear voltage regulator (LDO) is used to reduce 5 V USB voltage, down to 3.3 V that is used for the microcontroller unit and reader IC. On the RF transceiver side, the power amplifier is also supplied through the reader IC by means of 3.3 V delivered from the LDO.

4. Software design

The AS3993 firmware is executable code that is portable for different hardware and editable for the requirements of applications. The most important function of the firmware is to communicate with RFID tags compatible with EPC Class 1 Gen2 protocol. The architecture of software layer is shown in the Figure 5. The main application is executed in the application code layer. The application layer is implemented as a dispatcher that waits for commands from the host (via either USB or UART) and processes commands accordingly. Gen2 protocol handling is performed in the protocol layer. The AS3993 layer includes device-specific procedures of the UHF reader. The communication between the reader IC and microcontroller is provided by platform layer via SPI interface.

The system is not able to communicate with the host system via USB and UART simultaneously. In the designed system, it is optional to select USB or UART in the firmware. Within the main.c file, timer initialization is the first step for starting the program; then USB descriptors, UART, and AS3993 chip registers are taken into the operation process; and then a self-test is performed for the tags to check whether they are in the field. If tags are recognized in the field, the application commands procedure examines the operational tasks. The application commands procedure operates the relative functions with the data embedded in the USB/UART packets sent by the host system as shown in Figure 6.

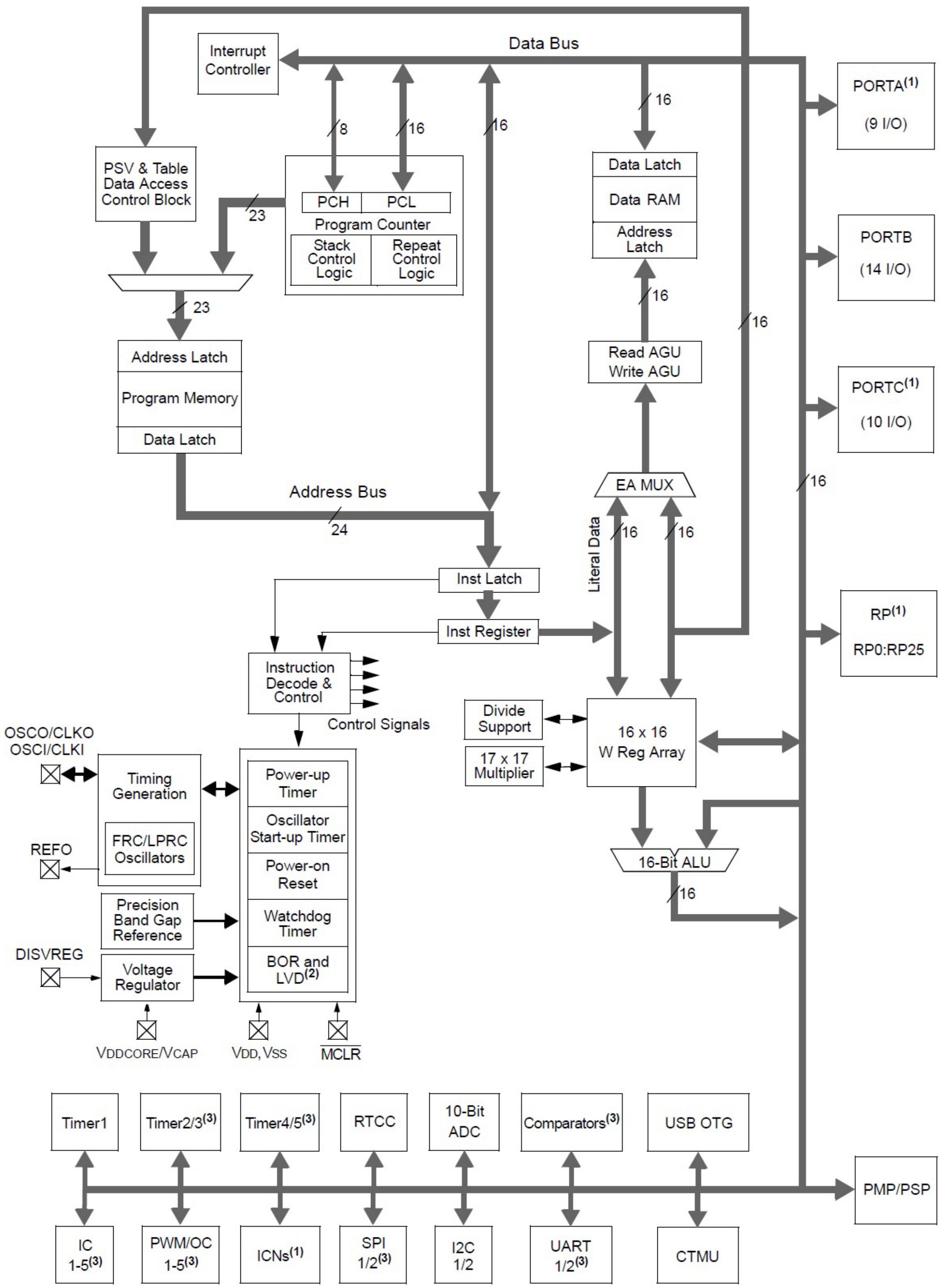

Figure 4. Block diagram of PIC24FJ64GB002 MCU [10].

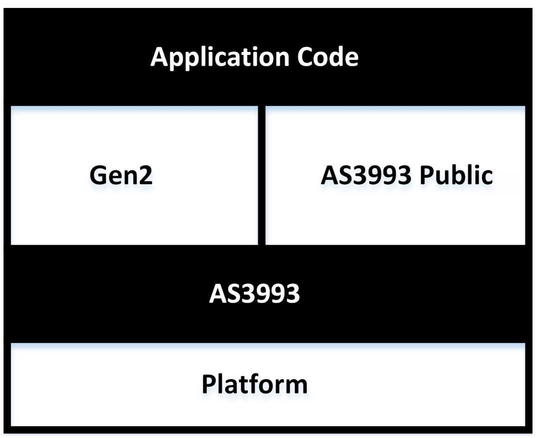

Figure 5. Architecture of software block.

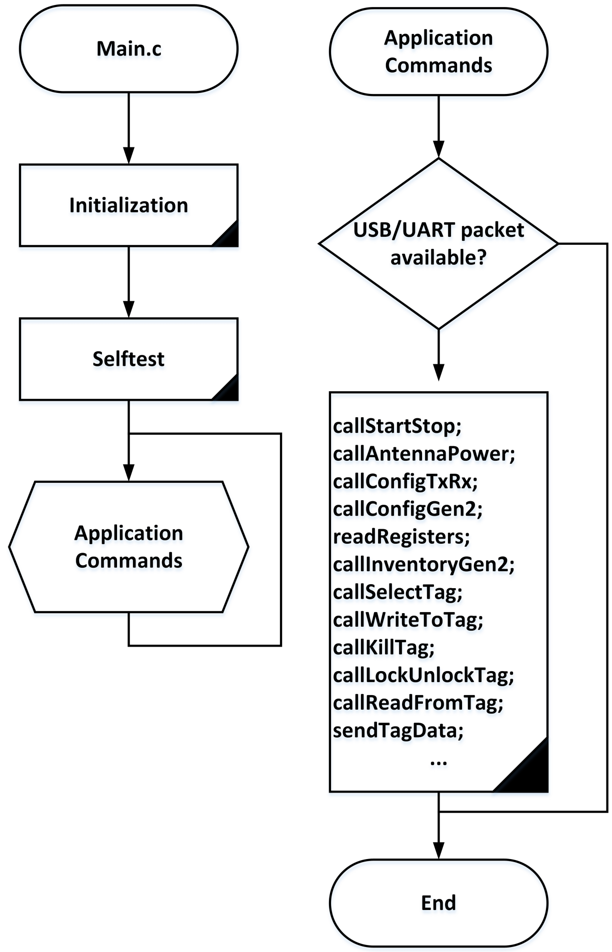

Figure 6. Flowchart of the software design.

Three basic operations providing the communication between the reader and tags are as follows:

- "Select" for the operation to choose tags for inventory and access.
- "Inventory" for the operation to identify tags.
- "Access" for the operation to communicate with tags.

5. Measurement results and discussion

Output power of the UHF RFID reader module has been measured. It is clear from Figure 7 that the output power of the module is nearly 20 dBm. The set value in the chip (i.e. ideal output power) is 23 dBm, but due to losses in the measurement setup (i.e. RF cables, attenuator, SMA adaptor), which are in the range of 2 dB, the output power is lower. Moreover, RF transmission lines and the components used after PA section also result in a loss of an additional 1 dB. As a result, the total loss is around 3 dB.

For the measurement of the output power, a spectrum analyzer from Agilent, E4402B, with a 20 dB attenuator is used. The measurement setup of the module is shown in Figure 8.

The presented UHF RFID reader module is compared with recently published modules and single-chip readers in the Table in terms of output power, power consumption, and size.

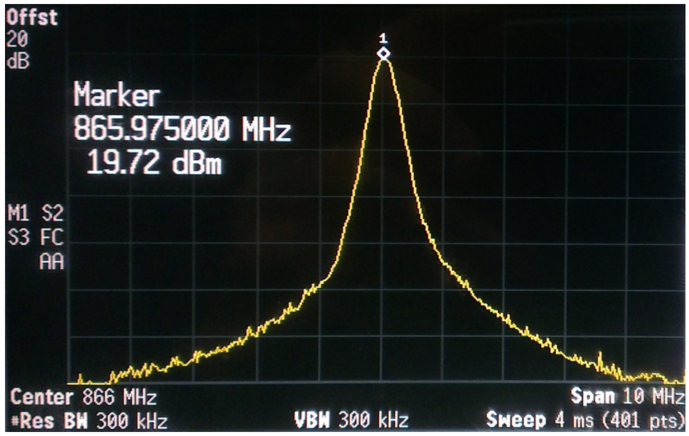

Figure 7. Measurement result of the output power of the module.

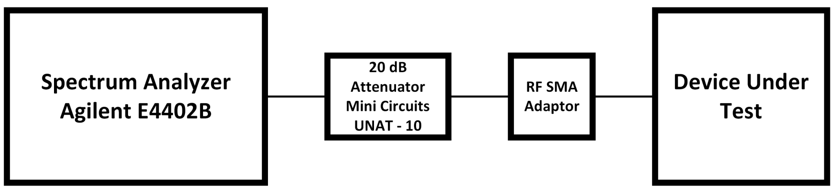

Figure 8. The measurement setup.

Table. Comparison chart of modules and single-chip readers presented in the literature.

Work in:	Output power (dBm)	Power cons. of IC (mW)	Size (mm)
[3]	27.5	<7500 (whole system)	90 *times* 55 *times* 10
[4]	20	-	90 *times* 35 *times* 50
[5]	21	471	-
[6]	7.4	116,18	-
[7]	20	135	-
This work	23	780 (whole system)	66 *times* 53 *times* 30

Before the design process, various products from multiple manufacturers were examined. It was investigated that especially directional couplers and filters are crucial parts for such designs. It was decided to use a directional coupler integrated with a low-pass filter for proper and low-cost system implementation. The used directional coupler has the advantage of noise reduction feature with signal isolation (integrated LPF). Other critical component is the RF power amplifier. It should meet the design requirements for desired power level. As this module is designed for short-range applications, the selected PA is a medium-power, high-efficiency component. For proper operation, the biasing of the PA is really important. Biasing voltages are supplied through the reader IC via voltage regulator. The prototype of the designed UHF RFID reader module indicating the RF and MCU parts is shown in Figure 9. This circuit is on a 2-layer, FR4 substrate.

6. Conclusions

In this paper, a new low-power, low-cost UHF RFID reader module based on AS3993 for short-range applications was designed, fabricated, and characterized. According to the authors' knowledge, this work is the first implementation of AS3993 for short-range UHF RFID applications. The design of the UHF RFID reader module has the advantages of a high level of integration, low-power technology, small outline size, and reliability as well

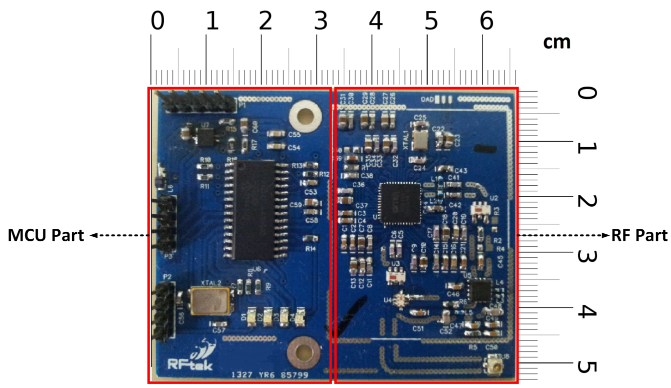

Figure 9. Prototype of the UHF RFID reader module (66 *times* 53 mm).

as low cost with reduced component complexity. By the selection of peripheral components, a reader with pretty low loss and power consumption has been achieved. It also has the feature of firmware selected communication via USB or UART. The system works at the UHF band (860–960 MHz) and is compatible with EPC Class 1 Gen2 ISO 18000-6C protocol. The measurement result indicates that the set output power value in the chip is achieved quite successfully. This UHF RFID reader module can be easily integrated to any development process for applications.

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