Sensors & Transducers, Vol. 271, Issue 4, December 2025, pp. 1-6

Sensors & Transducers
Published by IFSA Publishing, S. L., 2025
http://www.sensorsportal.com

Development of a High-energy Wiegand Sensor for Energy Harvesting Applications

[1, *] Felix HUENING, [2] Hanno VOLKER, [2] Fabian MAINZ and [2] Jonas WIEGNER
[1] University of Applied Science Aachen, Eupener Strasse 70, 52066 Aachen, Germany
[2] FRABA GmbH, Auf der Hüls 183, 52068 Aachen, Germany
[1] Tel.: 0049 241 6009 51979,
[*] E-mail: huening@fh-aachen.de

Received: 12 September 2025 / Revised:10 Nov. 2025 / Accepted: 12 Dec. 2026 / Published: 30 Dec. 2025

Abstract: In this article we describe the development of an energy-harvesting device based on the Wiegand effect. Wiegand sensors generate voltage pulses in a pickup coil when subject to an external magnetic field due to fast magnetization reversal known as large Barkhausen jump. Theses sensors are used in different applications like position sensors or multi-turn rotary encoders. Standard Wiegand sensors generate about 100 nJ – 150 nJ output energy per pulse, sufficient to supply dedicated small electric circuits. In this article we present a novel sensor based on the Wiegand effect to enable significantly higher output energies. The sensor design is optimized with regard to coil parameters and number of wires within the sensor. Measurements reveal the output characteristics of the output voltage as well as the energy that is supplied to an external circuit. The maximum output energy of about 9 µJ per sensor can be used to drive electric circuits and to realize new energy harvesting applications, e.g., for wireless data transfer.

Keywords: Wiegand sensor, Energy harvesting, Magnetic microwire, Sensor design, Large Barkhausen jump.

---

1. Introduction

With Internet of Things (IoT) and Wireless Sensor Network (WSN) devices on the rise, the simplicity of integration becomes a critical factor for new applications. In 2025, about 20 billion of IoT devices were running worldwide, and for 2030 this number is expected to rise up to 31 billion [1]. The continuous growth of IoT market not only increases productivity and enables new business models, but also generates new requirements on the devices and systems involved. In particular, suitable power supply fitting to the requirements of the application is crucial, in particular when wired power supply is not possible.

A promising approach is the use of wireless data transmission technologies paired with energy harvesting, which completely eliminates the need for a wired connection. The Wiegand effect in bistable magnetic microwires is an energy harvesting technology that is in particular suitable for low-frequency, slow and single-shot excitation [2].

2. Wiegand Effect

The fast reversal of magnetization in magnetic microwires is a well-known effect that can be used in sensor applications [3]. The most dominant and commercially material for sensor applications is Vically (FeCoV) used for so called Wiegand wires, named by John Wiegand who discovered the effect. Based on soft magnetic Vicalloy, Wiegand wires are produced by dedicated mechanical (tension and torsion) and thermal process steps [4]. After the processing the wire shows bistable magnetic behavior with a sharp magnetic hysteresis having two main magnetization directions along the wire axis [5] as depicted in Fig. 1. An external magnetic field can switch the magnetization direction in form of a large Barkhausen jump as can be seen in the hysteresis curve in Fig. 1, where the trigger fields are at about -2 kA/m and +2 kA/m, respectively. Depending on the production process, the magnetic system for excitation, the sensor design and statistics, the trigger field can vary from pulse to pulse slightly for each wire. The large Barkhausen jump induces a voltage pulse in a pickup coil surrounding the Wiegand wire [1]. The large Barkhausen jump and hence the induced voltage pulse is independent of the speed of change of the external field making this kind of sensor suitable for low-frequency or single-shot excitations.

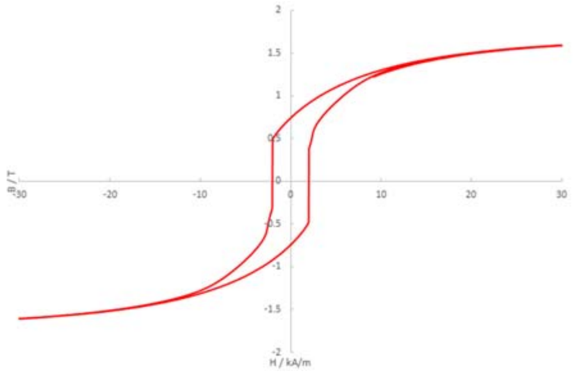

Fig. 1. Hysteresis curve of Wiegand wire, clearly visible are the steps in the hysteresis curve switching the magnetization direction in form of a large Barkhausen jump.

A Wiegand sensor consists of a Wiegand wire surrounded by a pickup coil. At both wire ends, ferrites are used to shield the external magnetic field [6]. Wiegand sensors are used in several applications including position and rotary encoder [7]. Standard Wiegand sensors used in many industrial applications have a size of about 15 mm times 10 mm using a wire of about 250 µm diameter and 10 mm length. The open load voltage reaches about 10 V – 12 V with a width of about 10 µs – 20 µs (Fig. 2). This kind of sensors are able to generate about 100 nJ – 150 nJ of output energy per switching event, sufficient to drive dedicated ultra-low power electronic circuits, e.g., an ASIC and an FRAM for multiturn encoder applications [7]. To power more complex and general applications, significantly higher output energy is needed.

3. Energy Harvesting

Energy harvesting plays a crucial role for many IoT applications. Some prominent methods for energy harvesting include photovoltaic, thermoelectric and RF harvesting [8], but each of them relies on the continuous availability of the corresponding energy form like light or thermal energy as these harvesters are designed and optimized to provide energy continuously.

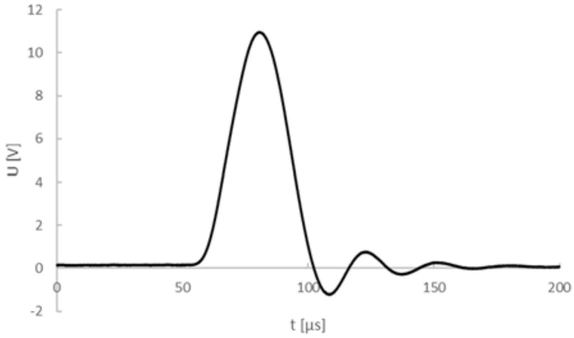

Fig. 2. Typical voltage pulse of a WFS sensor in open load configuration.

Especially when moving parts are involved, induction-based energy harvesters are another well-established approach to harness parts of the motion energy. The drawback of induction-based energy harvesters, according to Faraday's law, is the minimum speed of the moving parts that is needed to generate sufficiently high voltage pulses in a given pickup coil and hence provide sufficient energy output in a given resistive load. Fig. 3 shows the generated energy output of a coil filled with ferromagnetic material. In the zero-speed limit, the energy output approaches zero, even when referred to a single rotation instead of constant time span.

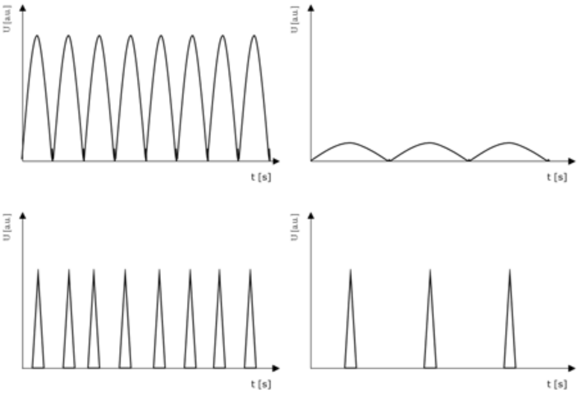

Fig. 3. Output voltage of inductive (top) and Wiegand (bottom) energy harvesters at high (left) and low (right) speed.

To overcome the low-speed problem for inductive harvesters, spring-based solutions can be used to guarantee a sufficiently high speed of the moving part generating the desired energy output. This solution comes to the price of mechanical wear and hence decreased maintainability.

Continuous harvesting systems (e.g., photovoltaic or thermoelectric) are designed to continuously provide an amount of power, that is, albeit low, sufficient to exceed the power consumption of the electric circuit it powers. By using dedicated low power modes of the electronics, like standby or sleep mode of microcontrollers, memory content can be maintained for longer times and allows to perform more energy-intensive operations (like reading out sensors and data processing, storage, or transmission) at least from time to time. These operation modes enable longer runtimes of the system, but nevertheless needs more or less continuous energy harvesting to maintain the minimum voltage level needed even for low-power operations.

By contrast, event-based harvesters like the Wiegand generators can provide a specific amount of energy at one stroke. As depicted in Fig. 3, even in the zero-speed limit it generates the same amount of energy per pulse like at high speeds.

Of course, they can also be operated in a mode of periodic excitation, but if the system is designed accordingly, this single amount of energy will be sufficient to perform an operation (such as reading a Hall [9], even if no power is provided in between the events, i.e., at the beginning of the operation all capacitors are discharged and all information is available from non-volatile memories only. Therefore, the energy generated by the event-based harvester has to be sufficient to power up the complete system from scratch, like charging capacitors, power up the circuit and perform all required operations.

In the following, a proof-of-concept system powered from Wiegand generators and using off-the-shelf components is designed to be operated in such a pulsed, or "one-shot", mode and to not only acquire, but also transmit the data wirelessly. As one of many possible applications, the system is then integrated in a physical demonstrator.

4. New Sensor Design

The output energy of Wiegand sensors can be increased by increasing the amount of bistable magnetic material, either by increasing the wire diameter or length. The length of the wire is limited by the maximum size of the pickup coil and complete sensor, limiting the increase of bistable material and hence output energy increase. Wires with bigger diameter can increase the output energy slightly. In Fig. 4, the output energy is depicted for three different wire diameters. Measurement of the output energy was done using a standard WFS sensor [10] and a 1.6 kΩ load resistor. The output energy was measured for a large number of pulses for five wires of each diameter, yielding the distribution of the output energy with the minimum, average and maximum output energy that can be obtained from a sensor. Clearly visible is a rather big distribution of the output energy for each wire individually, but similar for all wires with the same diameter. This distribution with a maximum at the average value is due to the small variation of the trigger field of each wire and small variations of the magnetic excitation, e.g., by external disturbances Also, the increase of output energy with increasing wire diameter is visible. As the maximum wire diameter is limited to about 400 µm – 450 µm due to the mechanical production process of the wire, the increase in output energy is also limited and not sufficient to power more complex electronic systems.

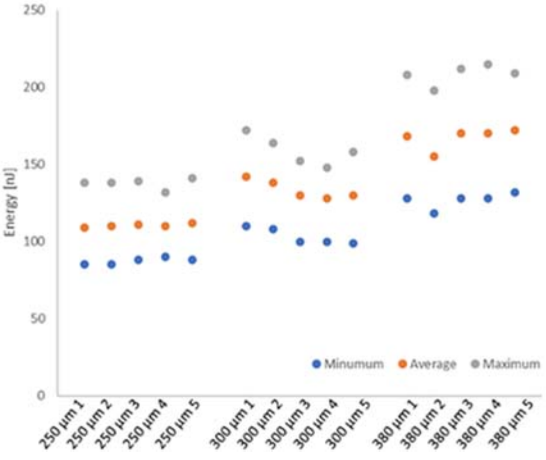

Fig. 4. Output energy of Wiegand sensors with different wire diameters.

Another option to increase the amount of bistable magnetic material in the system is to use multiple wires in a system. Magnetic multiwire systems have already proven to be able to increase the output pulse shape [11]. Therefore, we use this approach to design a Wiegand sensor with higher output energy.

The design of the sensor is a compromise between its size and the amount of Wiegand wires the sensor can hold. The final application, including the size and shape of the magnetic system to drive the Wiegand effect, determines the maximum size of the sensor. In addition, the size of the pickup coil and the number of windings plays a crucial role to maximize the output energy. The final sensor uses a pickup coil with 8000 windings, a length of 21 mm and an inner and outer diameter of 2.2 mm and 7.5 mm respectively (Fig. 5). Up to 40 wires with diameter of 250 µm can be inserted into the pickup coil. Big ferrites at both ends of the coil shield the external magnetic field at the wire ends.

As can be seen in Fig. 4, even single wires show a variation of the output energy. In case of multi-wire systems, the surrounding wires and their magnetic state influence the switching behavior of the wires even stronger. The geometric arrangement of the wires causes different magnetic fields for each wire, as all wires are magnetic. This field of the surrounding wires is individually different for all wires, in particular, the parallel magnetization of the wires is energetically unfavorable compared to an antiparallel magnetization. As a result, the external magnetic field that triggers the reversal of the magnetization, is different for each wire. Instead of a single voltage pulse like in standard Wiegand sensors with just one wire, pulse trains are observed for multiwire systems. Using a multiwire system is able to increase the output energy significantly at the expense of single-shot triggering.

Fig. 5. High energy Wiegand sensor compared to standard WFS sensor.

5. Measurements

The measurements of the output characteristic were performed in a Helmholtz coil setup to generate the external field of 20 mT maximum with a low frequency of 500 mHz to minimize inductive effects. Output power was measured using a 1.6 kΩ load resistor. To demonstrate the effect of mutual interference between the wires, Fig. 6 shows the output voltage of a sensor with five wires with a diameter of 300 µm. Due to the mutual interference, the output characteristics is a pulse train, and it takes about 15 ms – 25 ms for all wires to reverse the magnetization. Sometimes, two wires flip at the same time and the output pulses coincide, resulting in higher output pulses. In the insets of the diagrams in Fig. 6, the total output energy of a pulse train is given, for the sensor with five wires it is about 2 µJ, slightly lower in case of five pulses and slightly higher in case of 4 pulses, indicating that a synchronized reversal of magnetization of the wires is better with regard to maximum output power.

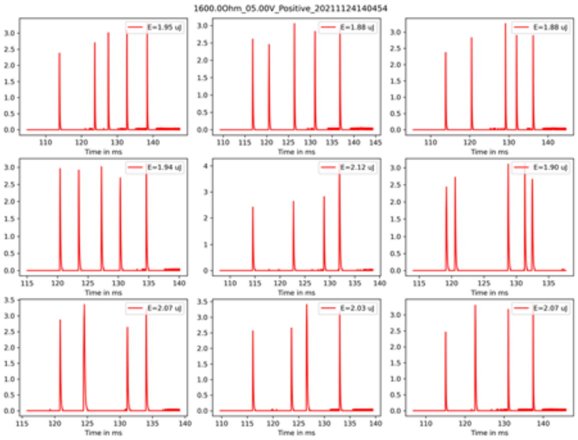

Fig. 6. Nine measurements of output voltage across the load resistor for a sensor with five wires.

Fig. 7 depicts a measurement of the output voltage of the high energy Wiegand sensor with 35 wires with 300 µm diameter. The magnetization reversal in the wires occurs at different external field strength, as the wires have different trigger field strengths and influence each other. This behavior leads again to characteristic pulse trains, in this example with 25 pulses. Again, some wires flip at the same time. Summing up the energy of the pulses gives the total output energy per trigger event of the sensor, about 9 µJ as shown in Fig. 7.

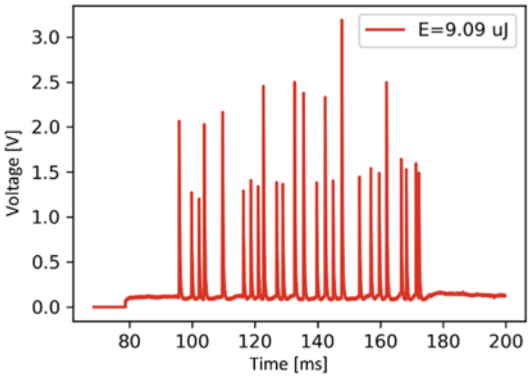

Fig. 7. Pulse train of a high energy Wiegand sensor with 35 wires.

To analyze the output energy in more details, experiments were performed using different wire diameters of 300 µm, 380 µm and 430 µm and varying the number of wires. The wires were cut in a standard procedure without any dedicated selection process with regard to output energy. The high energy Wiegand sensor can hold up to 40 wires with 300 µm diameter, 24 wires with 380 µm and 18 wires of 430 µm. As expected, the output energy increases with increasing number of wires as depicted in Fig. 8.

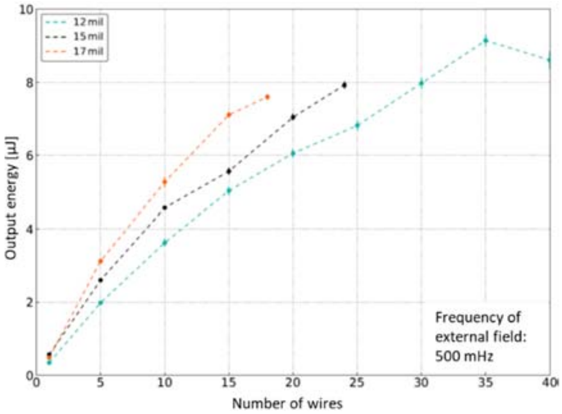

Fig. 8. Output energy of the high energy Wiegand sensor using 300 µm, 380 µm, 430 µm.

Due to the mutual influence of the wires, the output energy does not increase linearly with the number of wires. For the two systems with larger wire diameters the maximum output energy is about 8 µJ, whereas the system with the smallest wire diameter reaches about 9 µJ due to higher filling factor. Repeated measurements reveal a minimum output energy of 8.7 µJ and a maximum output energy of 9.9 µJ for 35 wires of 300 µm diameter. The output energy is still small compared to energy harvesting techniques like photovoltaic, thermoelectric, inductive or piezoelectric [12], but these techniques require a continuous excitation to generate higher energy output. The Wiegand power sensor, on the other hand, only needs a one-time excitation by a small change in the external field.

6. Application

The significantly increased output of the high energy Wiegand sensor can be used to power more complex electric circuits. Several prototypes of the sensor were built to drive electric circuits build from standard components without dedicated ASICs. As the energy is distributed across several pulses, a storage element like a capacitor has to be used to integrate the energy and to power the electric circuit. Fig. 9 shows the energy harvesting circuit for the Wiegand harvester. As the harvester generates pulses of positive and negative polarity, depending on the direction of magnetization reversal, a full bridge rectifier is used to rectify the output voltage and to charge a capacitor.

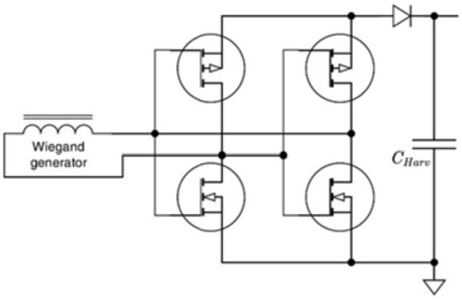

Fig. 9. Energy harvesting circuit.

As demonstrated in a previous paper [13], this type of sensor can be used to drive a wireless IoT node consisting of a microcontroller, sensors and an UWB transceiver IC. As the system should be started and operated in pulsed mode from power off state without any energy stored in the capacitors, the Wiegand generator has to provide sufficient energy to startup all logical components, sample a sensor value and transmit this value via UWB wireless transmission. Therefore, two Wiegand harvesters with corresponding rectifiers, like depicted in Fig. 10, are used in the current demonstrator.

A block diagram of the application circuit is shown in Fig. 11. A Low Dropout Voltage Regulator (LDO) is used to generate the 1.8 V needed for application circuit. In addition, the application circuit contains a low-power MCU (STM32L0) with fast and energy-efficient start-up, a low-power SR1000 UWB transceiver IC (SPARK Microsystems) and a fast-starting 32 kHz oscillator needed for the SR1000. Special care was taken to initialize and configure all components in power optimized modes to reduce the power consumption as much as possible, including dedicated drivers for the SR1000 to minimize the start-up time and need for calibration and configuration. For the communication between MCU and SR1000 SPI is used.

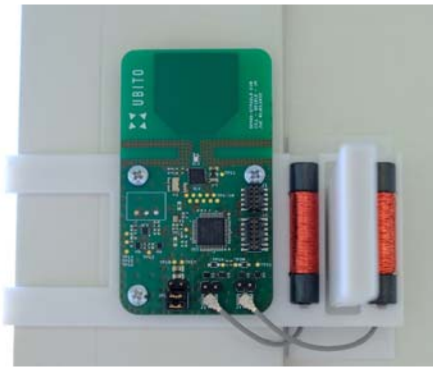

Fig. 10. Demonstrator including two Wiegand power sensors and the application circuit board.

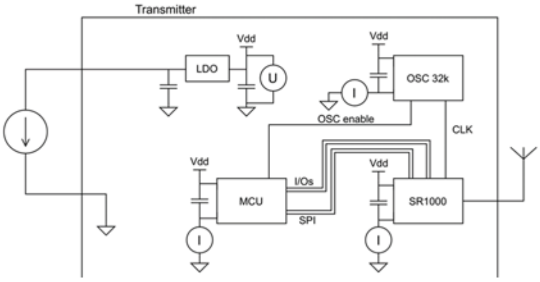

Fig. 11. Block diagram of the application circuit. The voltage source on the left represents the energy harvesting circuit shown in Fig. 9.

The energy consumption of the circuit was done by measuring the power supply voltage and the current of the application during operation, like depicted in Fig. 12. The capacitor of the circuit is charged by the Wiegand energy harvester starting at marking (a) in Fig. 12. After the power supply of the circuit (V_{DD}) reaches 1.8 V, the MCU starts up at the default frequency of 2 MHz (b). The MCU waits for the SR1000 to finish its start-up procedure before switching to 4 MHz, enabling the 32 kHz oscillator and configuring the SR1000 (c). The configuration includes the configuration of the general behavior, a static calibration, configuration of the transmission protocol and parameters. During the configuration, the SR1000 can stay in deep sleep mode, again minimizing power consumption. In the next step, the MCU samples its internal temperature sensor and the reference voltage by the internal ADC to calculate the silicon chip temperature. It sends the sensor data of the internal temperature sensor via SPI to the SR1000 and enters MCU standby mode afterwards, as it needs to wait for the SR1000 to finish the wireless data transmission (d). After the data are sent via UWB by the SR1000 (e), it generates an interrupt to wake up the MCU again to disable the 32 kHz oscillator and the SR1000. Due to optimization of operation, the operation time from start-up of the MCU (b) to end of wireless data transmission (e) is just 5 ms.

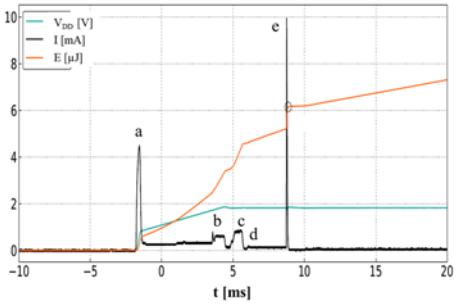

Fig. 12. Measured voltage and current and calculated energy during operation of the application.

7. Conclusion

Energy harvesting using Wiegand sensors enable new fields of applications. We demonstrated a new Wiegand sensor design using multiple Wiegand wires to increase the output energy significantly compared to standard Wiegand sensors. Using this approach, the amount of energy is sufficient to drive more complex electric circuits. The new Wiegand power sensor is able to generate a sufficient amount of energy to supply an application circuit for the wireless transmission of sensor data. To increase the output energy even more is difficult as it is a trade of between the size of the sensor and the output energy.

Acknowledgements

The authors thank Andreas Backes and Biji Balakrishnan for excellent sample preparation and helpful discussions.

References

[1]. Statista, IoT connected devices worldwide, https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/

[2]. F. Xue, C. Yang, Z. Song, Y. Takemura, Induced pulse voltage and hysteresis loss during magnetization reversal of Wiegand wire, *Journal of the Magnetic Society of Japan*, Vol. 48, Issue 1, 2024, pp. 1-4.

[3]. V. Zhukova, P. Corte-León, M. Ipatov, J. M. Blanco, et al., Development of magnetic microwires for magnetic sensor applications, *Sensors*, Vol. 19, Issue 21, 2019, 4767.

[4]. F. Huening, A. Backes, Direct observation of large Barkhausen jump in thin Vicalloy wires, *IEEE Magnetics Letters*, Vol. 11, 2020, 2500104.

[5]. L. Jiang, C. Yang, Z. Song, Y. Takemura, Magnetic structure of Wiegand wire analyzed by first-order reversal curves, *Materials*, Vol. 15, Issue 19, 2022, 6951.

[6]. C.-C. Lin, Y.-C. Tseng, T.-S. Chin, A review of the self-powered Wiegand sensor and its applications, *Magnetochemistry*, Vol. 8, Issue 10, 2022, 128.

[7]. S. Saggini, F. Ongaro, L. Corradini, A. Affanni, Low-power energy harvesting solutions for Wiegand transducers, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 3, Issue 3, 2015, pp. 766-779.

[8]. S. Maurya, P. Sumam, R. Maringati, A review of energy harvesting techniques for WSN, in *Proceedings of the Eighth International Conference on Wireless Communication and Sensor Networks (WCSN'12)*, 2012, pp. 123-127.

[9]. Y. Takemura, N. Fujinaga, A. Takebuchi, T. Yamada, Batteryless Hall sensor operated by energy harvesting from a single Wiegand pulse, *IEEE Transactions on Magnetics*, Vol. 53, Issue 11, 2017, 6100206.

[10]. POSITAL FRABA, Wiegand sensors, https://www.posital.com/en/wiegand-sensors

[11]. A. Matsushita, Y. Takemura, Power generating device using compound magnetic wire, Journal of Applied Physics, Vol. 87, Issue 9, 2000, pp. 6307-6309.

[12]. B. Pozo, J. I. Garate, J. Á. Araujo, S. Ferreiro, Energy harvesting technologies and equivalent electronic structural models – review, *Electronics*, Vol. 8, Issue 5, 2019, 486.

[13]. J. Wiegner, H. Volker, F. Mainz, A. Backes, et al., Energy analysis of a wireless sensor node powered by a Wiegand sensor, *Journal of Sensors and Sensor Systems*, Vol. 12, Issue 1, 2023, pp. 85-92.
