An Optically Powered Communication Structure for Integration in Metallic Objects

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Summary: The construction principle and the design of an optically powered RFID-transponder are presented. The transponder can be completely integrated into metallic components, only a small round drilling in the component is necessary. To preserve the stability of the mechanical component, the bore diameter is to be kept small. Thus a carrier frequency of 24 GHz is used for the communication between reader and transponder. This paper gives a brief overview about the antenna design, the optical power supply and the analog and digital circuits which are necessary for the communication. The resulting dimensions of the transponder are approx. 26 mm in length and 8 mm in diameter. The maximum reading range is 0.5m.

Keywords: Identification, Integration.

1. Introduction

Since some years, researches on and applications of self organising processes are growing strongly. This applies to the areas of logistics and autonomous production particularly. Primarily, in a complicated production process the Radio Frequency Identification (RFID) technology [1] is excellently suitable for the electronic identification of a component.

This paper presents a new communication-system that allows the integration of the transponder in metallic objects. A component equipped with this technology can be identified simply and sensor or production data can be transferred wirelessly from the component. The focus of this paper is on the transponder design which is difficult because many antenna structures for example dipole-like antenna suffer from performance losses when they are close to a metallic environment. Hence, optimized antenna structures have to be designed to fit the described problem. A system that fulfils the aforementioned challenges has been developed by the collaborative research centre 653 (CRC653). The transponder presented in this paper consists of a circular waveguide which

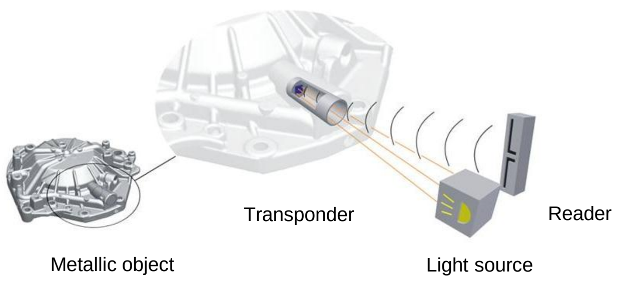

Figure 1. System setup for the optically powered communication structure.

is used as antenna and as waveguide transition between antenna and transponder electronics. The waveguide can be simply produced as a round drill into the metallic object. An existing system works at a centre frequency of 5.8 GHz with a drill diameter of 20 mm [2].

A reduction of the bore diameter down to 8 mm is reached by raising the working frequency to 24 GHz in the newly introduced system. However, the increased path loss at this frequency eliminates a wireless microwave power supply of transponder especially on large distances. Therefore, an alternative power supply has to be added. In this paper, an optical power supply is introduced which makes use of an optical source on the reader side and a photodiode-array on the transponder side. The system setup is depicted in Figure 1.

2. Transponder concept

The design of a transponder that is applicable into metallic objects is a challenging task. Matters are complicated further as the antenna structure has to support the optical energy transfer and the microwave data communication simultaneously.

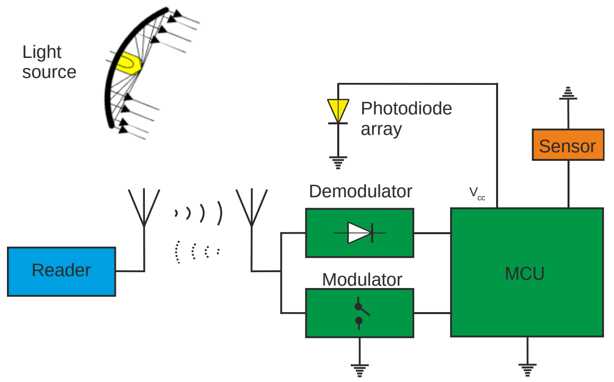

Figure 2. Block diagram of the transponder design.

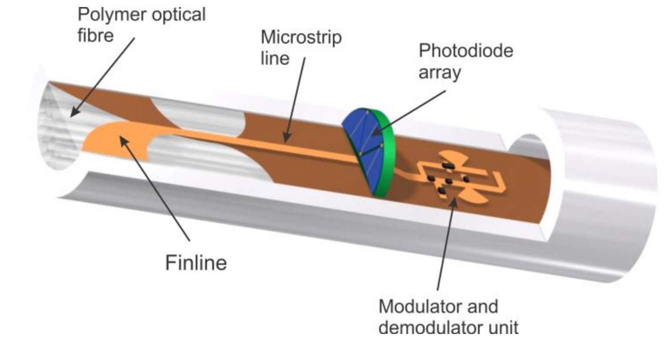

Figure 3. Illustration of the transponder design.

Figure 2 illustrates the schematic of the transponder design. A detailed view of a possible realization is depicted in Figure 3. The transponder consists mainly of four parts the antenna, the photodiode-array, the analogue front end which is positioned behind the photodiode-array on the upper half of the substrate material and the digital front end which is located on the lower half of the substrate material, respectively. This section will describe the four parts briefly. According to the previously introduced challenges the antenna structure has to feature energy supply and data communication at the same time. An antenna structure that is suitable for this task is a circular waveguide which is filled with polymer optical fibres and it is therefore named hybrid waveguide. Due to the fact that most electrical components are designed for a planar integration, the waveguide mode has to be transferred into a planar microstrip mode. For this transition an antipodal finline structure is used [3]. The microstrip line makes the simple integration of electronic components possible and offers the advantage that the electric field concentrates predominantly in the substrate. Hence, the photodiode-array positioned at the end of the polymer optical fibres has only a small influence on the electrical behaviour of the microwave performance. Nevertheless, the photodiode-array has to be embedded inside the circular waveguide to power the digital components of the transponder unit. This photodiode-array consists of six serially connected triangular cells and can deliver several mW of electrical power to the digital circuitry [4], depending on the light source. Since the energy supply of the transponder is the bottle neck of the system, a good illumination of the photodiode-array has to be guaranteed. Thus, all electrical components are placed behind the photodiode-array and do not tarnish it. For the sake of simplicity the principle functionality of the transponder is described only. A transistor is used as switch to modulate the incoming microwave as signal. This modulation type is also known as backscatter modulation. Depending on the state of the transistor the incoming wave is absorbed or reflected representing a logical $'\mathbf{0}'$ or $'\mathbf{1}'$, respectively. Hence, the modulator enables the transponder to transfer information out of the metallic object to the reader. It is also necessary that the reader can transfer commands or data to the transponder. Therefore, the transponder has an amplitude demodulator which is an envelope detector.

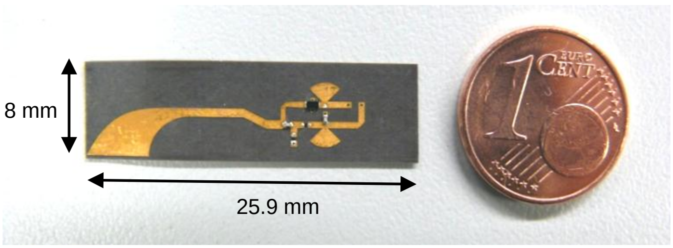

Figure 4. Realized transponder.

The whole transponder components listed before are connected to a microcontroller unit (MCU). The MCU analyzes the incoming demodulated signals and controls the modulator. The power to the MCU is supplied by the photodiode-array. Due to the flexibility of the digital part other electrical components like sensors or a memory can be connected to the MCU.

3. Practical evaluation of the transponder

The layout of the presented transponder design is fabricated using the etching method. As the radiofrequency performance is mainly determined by the fabrication accuracy, it has to be mentioned that by this method structures can be realized with an accuracy of 10 µm [5] which is sufficient for guaranteed microwave behaviour. The realized transponder for the integration in metallic objects is shown in Figure 4. As can be seen, the overall size of the structure is 25.9 mm x 8 mm. The digital components are not yet directly connected to the layout. The analogue front end has the dimensions of 5.7 mm x 6 mm. Due to the high carrier frequency most analog components have dimensions of a few hundred microns. Thus, the handling is complicated. Hence, a special positioning and fabrication unit has been developed. The depicted design is feasible for integration in a metallic object. For testing purposes, a metallic cylinder with a diameter of 20 mm made of brass is used as metallic object. For the evaluation of the transponder a reader is also needed. The measurement setup consisting of the reader and the transponder is shown in Figure 5. For the sake of simplicity the digital components for the modulation and demodulation on the reader and an the transponder side are not shown. Microcontrollers are used for the control of the communication besides the analogous microwave circuits. Hereby, the 24 GHz signal source of the reader can be switched on and off by the MCU at the reader side resulting in an on-off- keying modulation, respectively. This leads to a modulated electromagnetic wave with a carrier frequency of 24 GHz which is transmitted via the air interface to the transponder. Inside of the transponder an envelope detector is used for demodulation of the incoming data stream. The demodulated signal is interpreted by the MCU on the transponder side.

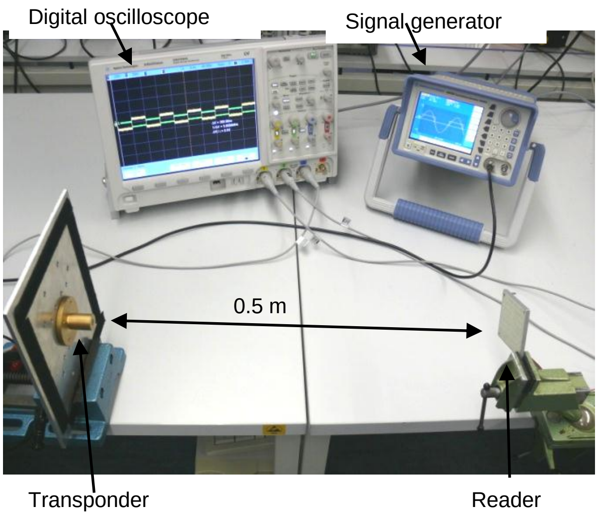

Figure 5. Measurement setup to evaluate the transponder.

After the reader has sent the request, it transmits a continuous wave at 24 GHz. Depending on the transmitted information from the reader, the transponder starts to send the requested data back to the reader. This is done by backscatter modulation. Therefore, the MCU on the transponder side controls the modulator. The down conversion of the backscattered electromagnatic wave received by the reader to the baseband is accomplished by an IQ-mixer. The low frequency baseband signal can be analysed by an analog to digital converter (AD-converter) or in the laboratory by an oscillosope. A complete comunication between the reader and the transponder is illustrated in Figure 6. This example shows the request of the reader for the temperature value of the transponder which has a duration of approx. 200 µs and the response of the transponder containing the temperature in the time span of 800-1100 µs. The delay between the end of the request and the beginning of the answer is introduced due to processing time of the MCU at transponder side. Depending on the requested task, the processing time varies e.g. the response to a serial number is faster than the response to the request of a temperature sensor value because the sensor data must be recorded first using an A/D-converter. Regarding the described setup, an working communication link over a distance of up to 0.5 m can be achieved.

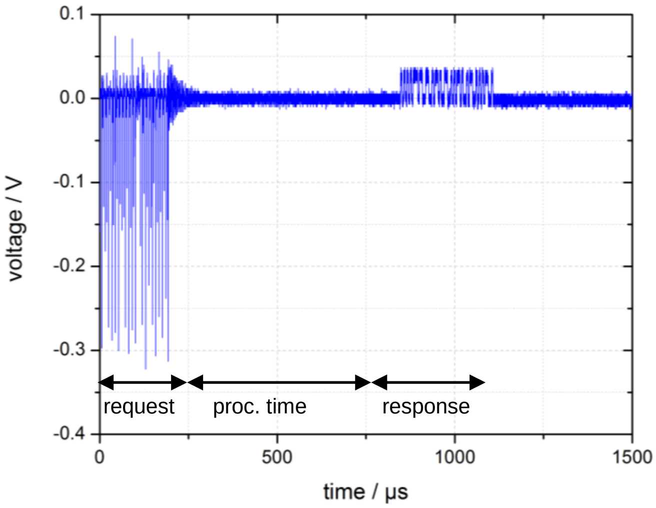

Figure 6. Communication procedure between reader and transponder.

4. Summary

This paper presents an optically powered transponder design for integration in metallic objects. The antenna of the transponder is the aperture of a circular waveguide. Furthermore, a transition between the waveguide and a microstrip line which is optimized for the presented concept of the hybrid waveguide is described. It consists of an antipodal finline structure which converts the waveguide mode into a planar mode which is more suitable for integration with the analogue transponder components. The basic concepts of the analog and digital front end are explained. Finally, a measurement setup of the transponder with a reader unit is shown. Hereby, the principle behaviour of the setup is explained and it is shown that the setup is able to communicate over a distance of approx. 0.5 m. The overall dimensions of the optically powered transponder are 8 mm in diameter and approx. 26 mm in length.

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