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RFID sensor systems embedded in concrete – systematical investigation of the transmission characteristics

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Abstract
Long-term completely embedded sensor systems offer innovative possibilities for structural health monitoring of concrete structures. Measuring of relevant parameters, e.g., temperature, humidity, or indication of corrosion can be performed with low energy sensors. This allows to implement passive RFID sensor systems without cable connection and battery, which are power supplied exclusively by the electromagnetic field from the external reader device. To evaluate characteristics and conditions of this concept, a systematical investigation of the transmission characteristics with variation of relevant parameters, as communication frequency, installation depth, type of concrete, moisture content, etc. is currently carried out in an interdisciplinary research project at BAM. First results are presented in this paper.

1 INTRODUCTION

Structural Health Monitoring is needed in scenarios that carry a risk of structural failure due to application and boundary conditions. An actual example in civil engineering are steel reinforced concrete bridges. In Germany, the majority of bridge buildings is significantly older than 30 years, but the heavy goods vehicle traffic increased five-fold during the same period. Since legally relevant and currently applied inspection procedures are based on personal, e.g., visual assessment, it is reasonable to develop, validate, and establish alternative and/or complementary methods based on modern technology.

Completely embedded RFID sensors offer the chance to monitor relevant parameters of structural integrity, which are in the case of reinforced concrete, e.g., temperature, humidity and corrosion [1], [2]. Such systems can be integrated in structural components of new buildings during construction or by subsequent integration at crucial positions of existing buildings. For the latter the method of integration must be solved carefully, to minimize the impact on the structure and to assure representative measurements [3]. Passive RFID systems are operated wirelessly without any internal power supply and offer best requirements for long-term operability and robustness. A decisive factor for such systems is the transmission reliability after structural integration. The installation depth and the concrete moisture content are limiting factors [4].

The presented study systematically investigates the transmission characteristics of concrete embedded RFID sensors. Two similar types of passive RFID sensor systems, each containing a temperature and a humidity sensor, were assembled in research and development activities, just differing in their transmission frequencies of 13.56 MHz (HF) and 868 MHz (UHF). The investigation of their transmission characteristics is carried out with RFID analysis tools that utilize the corresponding frequency ranges 10 to 30 MHz (HF) and 860 to 960 MHz (UHF).

This paper presents the basic design of RFID sensors systems for embedding in concrete and first results from experiments that are performed to compare both RFID systems (HF and UHF) in defined scenarios, particularly embedded in concrete with variation of the installation depth and concrete moisture content. Since experiments are ongoing, the actual focus lies on the HF RFID systems and variation of the installation depth.

2 SYSTEM DESIGN AND OPERATION PRINCIPLE

The system design is implemented at a size of 25 x 25 mm^2. The same basic design was applied for HF and UHF systems (Figure 1). RFID transponders equipped with a microchip and sensor interface form the core of the system. The sensor system features electronic interfaces (E) to connect active and passive external sensors (eS).

Operation principle is, that the RFID antenna absorbs energy from the electromagnetic field, which is applied by an external RFID reader device. The analog frontend (AFE), which is connected to the antenna, transmits the energy through the power management module (PM) to operate the external sensors. The signal input (Sin) is processed by the microchip and communicated through the electromagnetic field via load modulation (HF) or backscattering (UHF).

Figure 1. RFID sensor system (UHF left, HF right)

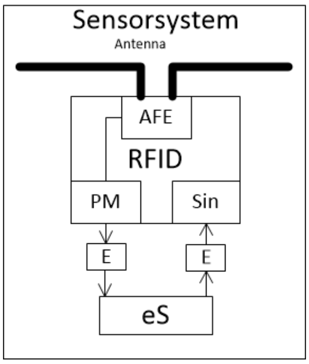

Figure 2. RFID sensor system scheme

Long-term embedding in concrete components requires a very robust design. Besides implementation in passive form (without batteries), an accordingly robust encapsulation which resists durably in the aggressive concrete environment is essential. Investigations are carried out, to identify and optimize suitable materials.

3 INVESTIGATION METHOD AND SET-UP

For systematic investigation of the transmission characteristics an investigation routine was established and operated in analogous manner for each measurement. At constant frequency, an excitation signal is sent with increasing transmission power from 0 to 29 dBm. Once a backscattered signal from the RFID system can be received by the analysis tool, the characteristic parameters are recorded, e.g., the transmitted and backscattered power, and the signal phase. Parameter curves are determined by sequentially repetition of this routine at stepwise varied frequencies (here in 0.01 MHz steps). Additionally, a theoretical transmission range can be calculated from the results. This allows for comprehensive characterization of the systems transmission behavior as a function of frequency.

A number of test specimen were assembled and equipped with RFID systems. Different types of concrete with different moisture characteristics were used. Two specimen were assembled for each concrete type, one equipped with RFID devices, one without, respectively. This gives a reference for, e.g., moisture content and allows for simulation of larger installation depth by placing the second specimen on top of the equipped one.

Figure 3. Test specimen with RFID systems before filling with concrete.

Figure 3 shows an exemplary test specimen. The one in front is equipped with 3 HF RFID sensor systems with different installation depth (antenna in circle form), one UHF RFID sensor system (dipole antenna, second from left), and a Bluetooth low energy system (with battery, second from right). The test specimen have dimensions of 50 x 15 x 10 cm^3. HF systems were positioned with 3, 6 and 9 cm distance to the top surface.

Measurements are performed periodically once or twice every week. The reader device for operating the measurements is always applied at the same fixed positions at the specimen top surface.

4 RESULTS AND DISCUSSION

Figure 4 displays typical results for the HF RFID systems. The transmitted power represents the minimal power transmitted by the reader device, which is required to receive a response signal from the RFID transponder. Lowest values are achieved at frequencies between 13.45 and 13.55 MHz. The installation depth of 13 cm is simulated by using a second specimen on top, as described in section 3. The corresponding response signal is close to the power limit of 30 dBm and can be assumed as the maximal possible installation depth for the applied boundary conditions (system and antenna design, type of concrete, moisture content, etc.)

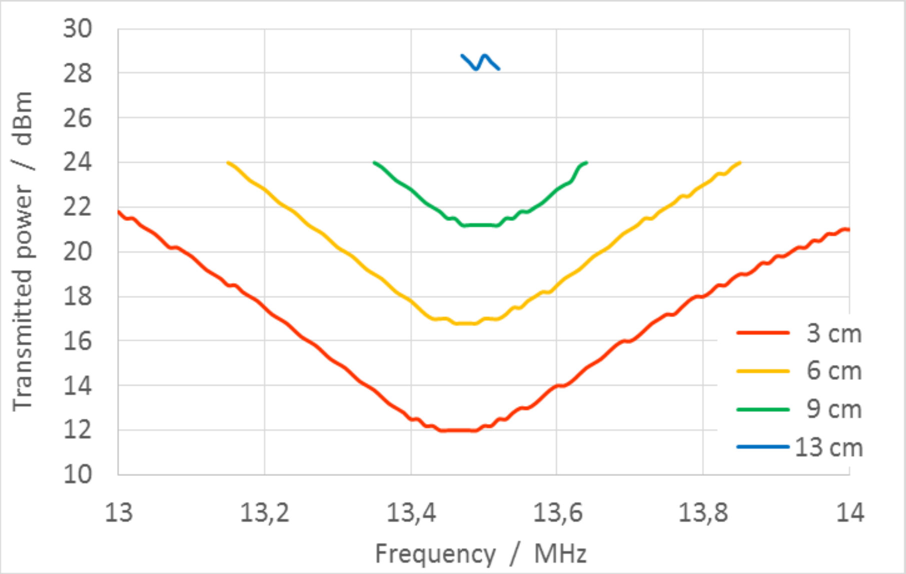

Figure 4. Exemplary results of HF measurements for RFID systems at different installation depth.

All results of the HF measurements have very good reproducibility for immediately repeated measurements and high similarity for RFID systems at the same installation depth, so far (3 weeks after assembly), quite independently from the concrete type and date of measurement. A tendency to slightly decreasing power values can be recognized, presumably indicating a correlation to decreasing moisture contents.

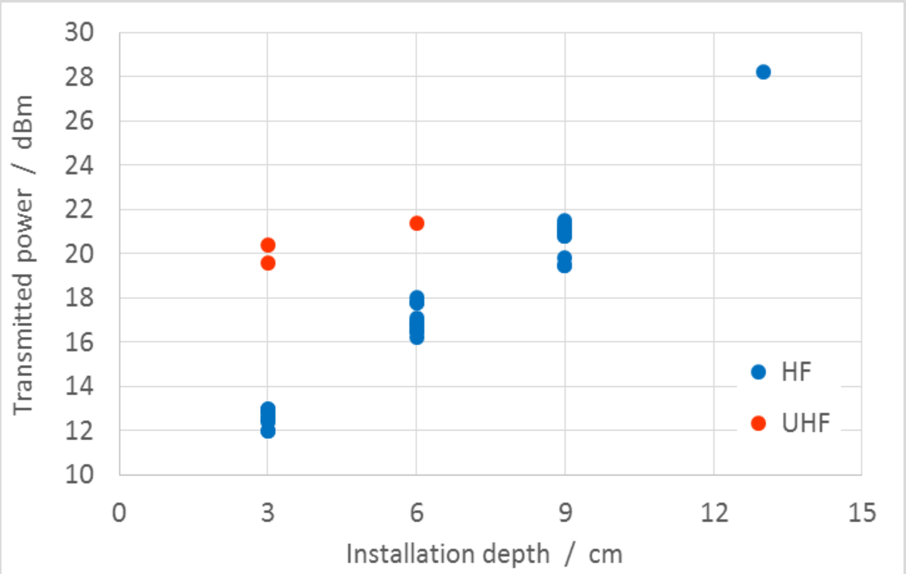

Figure 5. Comparison between results of HF and UHF measurements.

A comparison between results of HF and UHF measurements is displayed in Figure 5. The minimal required transmitted power at optimal frequency is plotted over the installation depth for measurements at all types of concrete and from all dates, so far completed. HF results show a linear relation between required power and installation depth. Since UHF measurements are still under optimization regarding the orientation of the antenna and positioning of the reader, results have to be interpreted carefully. For RFID systems close to the surface (3 or 6 cm installation depth), the HF communication seems to require less power, whereas UHF results seem to indicate a weaker increase of required power for increasing installation depth. However, to ensure this findings, more reliable measuring results are needed.

5 CONCLUSIONS AND OUTLOOK

The paper presents a systematical approach to evaluate the potential of RFID-Sensor-Systems for embedding in concrete structures. To implement systems for long-term operation, which can be a couple of decades, a number of challenges has to be investigated. Beside resistant and long term reliable components and encapsulation, as well as a simple and robust design, the reliable communication to an external reader device under different ambient conditions must be ensured. The presented investigation method and first measuring results provide a promising approach. For a comprehensive study of relevant parameters, further measurements are necessary and currently running.

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