

Development of Bolus Sensor for Cattle Rumen Monitoring

Carsten Brockmann, Alexander Gäbler, Usha Tamanna Yeasmin, Sriram Charan Pasupuleti, Phillip Arnold, Uwe Maaß, Ivan Ndip, Fraunhofer Institut für Zuverlässigkeit und Mikrointegration (IZM), Cottbus, Germany
carsten.brockmann@izm.fraunhofer.de

Abstract

In order monitor the well-being of cows in grazing land scenario a rumen bolus monitoring system has been developed. It contains sensors for pH-, temperature and motion and is deployed inside the cow's rumen. The data is transmitted wirelessly from the bolus in the cow's rumen to anchor nodes using the LoRa protocol. The paper describes design of the sensor-, front-end-, wireless transceiver and power management electronic sub-systems as well as the integration into a bio-compatible housing along with the battery and an omni-directional antenna.

1 Introduction

Animal welfare is important for high-quality dairy products. Innovative technical systems that monitor the health of animals continuously can support farmers by determining the need for food or medication, detecting acute diseases and optimization of fertilization. There are already sensor systems for cows available for intracorporal application (Bolus sensors ([1], [2]) measuring activity and rumen secretion parameters. However, there is a lack of localization and real-time data connectivity to mobile networks (e.g. 5G).

In the framework of the project iCampus Smart Livestock Farming a networked multi-sensor system based on Bolus sensors that are deployed in the cow's rumen whose information is used for the early detection of abnormalities in the digestive tract and vital parameters, thus enabling targeted and species-appropriate treatment.

The Bolus features the following innovative technical solutions: Ultra-low power consumption, pH, temperature and motion measurement and wireless communication for system integration into a biocompatible Bolus-housing. This also inherits an optimized and miniaturized sub gigahertz antenna with omnidirectional gain which overcomes the challenges of attenuation and detuning inside the rumen. The Bolus transmits the sensor data wirelessly out of the cow rumen to distributed anchor nodes which allow a high coverage of even large pastures.

2 System Design

The monitoring system is designed for farmland animal keeping of cows on extended meadows where the cows can range freely. The autonomous bolus sensor system is deployed in the Rumen stomach of the cows. It transmits the sensor data wirelessly to anchor nodes distributed over the farmland using the LoRa ([3]) protocol. All anchor nodes are interconnected via a WiFi mesh network which is also used to upload the data to a server using a specialized 5G anchor node with additional 5G mobile network connectivity.

It is expected that the bolus monitoring system is operational for several years necessitating low-power system design. The rumen environment contains a high level of water creating high attenuation for radio signals especially at

higher frequencies. To minimize the attenuation the LoRa standard operating at 433 MHz was chosen for the wireless link to the anchor nodes. In order to minimize the overall power budget a flexible wireless mesh network architecture was chosen allowing for topology optimization depending on the position of the cows.

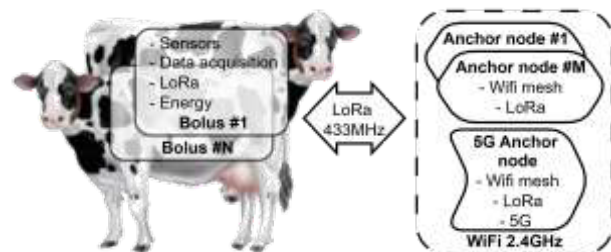


Figure 1 Smart Livestock system overview

3 Bolus Design

3.1 Bolus Construction

The sensor system is integrated into a cylindrical plastic housing fabricated of biocompatible and water-resistant Poly-oxy-methylene (POM) material. The lower part of the bolus contains the battery with a flex-PCB antenna wrapped around while the upper part contains the sensor front-end PCB (cf. Figure 2).

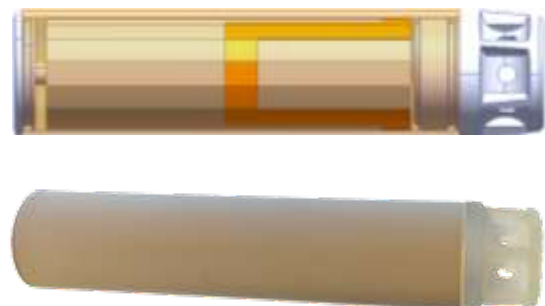


Figure 2 CAD design of bolus sensor (top) and fabricated bolus housing (bottom)

Table 1 gives the bolus outer dimension.

Parameter	Value
Length	120 mm
Wall thickness	2,0 mm
Diameter	35 mm

Table 1 Bolus dimensions

3.2 Bolus Sensor Front-end PCB

The Bolus contains pH-, temperature- and motion-sensors connected to a low-power microcontroller with an integrated wireless transceiver (STM32W) implementing the LoRa protocol.

The electronics are realized using SMD technology on the front-end PCB. The antenna is connected externally to the front-end PCB using miniaturized coaxial RF connectors. Figure 3 shows the fabricated front-end PCB for set-up of the sensor system outside the bolus sensor.

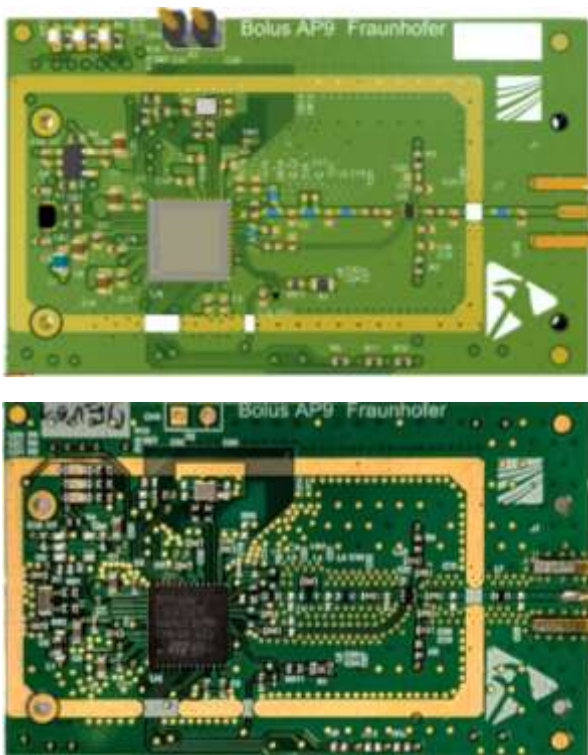


Figure 3 Bolus sensor front-end PCB. Top: layout, bottom: fabricated front-end PCB

3.3 Power Management

The Bolus is powered by a battery with a capacity of 19Ah. In order to meet the lifetime demands, the sensor system is operating intermittently.

4 Conformal Antenna Design

To transmit the collected data from bolus sensor to anchor node, the bolus application requires antenna which can be placed inside the bolus. For this bolus application, a flexible conformal meander antenna is designed on flexible substrate (dielectric constant $\epsilon_r = 3.4$, and $\tan \delta = 0.002$) shown in Figure 4 so that it can be wrapped inside the bolus.

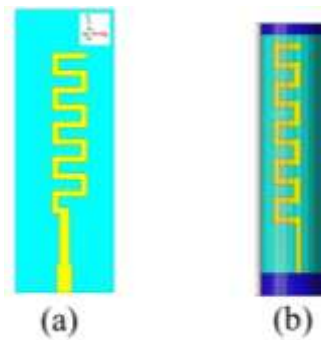


Figure 4 (a) Planar meander antenna (b) antenna wrapped inside bolus

The electromagnetic properties of the antenna strongly depend on the surrounding environments, causes impedance detuning and results in the loss of total efficiency. This antenna is designed based on considering the environment where the antenna will be embedded and place work to validate the antenna performance in terms of impedance matching and radiation. As this sensor bolus will be placed in the livestock rumen, the antenna is simulated inside a spherical homogeneous phantom of 150 mm radius and the cow rumen equivalent material properties (dielectric constant $\epsilon_r = 61$, and conductivity $\sigma = 1.77$ S/m). This phantom helps to evaluate antenna performance specially the radiation pattern in the livestock body. Moreover, to realize the impact of the bolus electronics and battery, the bolus is filled with material with $\epsilon_r = 3.2$, and $\tan \delta = 0.037$. In the antenna simulation, the thickness of the bolus is 0.2 mm, radius of the cylindrical bolus is 15 mm and length 110 mm, the material of the bolus is POM with $\epsilon_r = 3.8$, and $\tan \delta = 0.0015$ are considered.

Complete antenna simulation considering environment

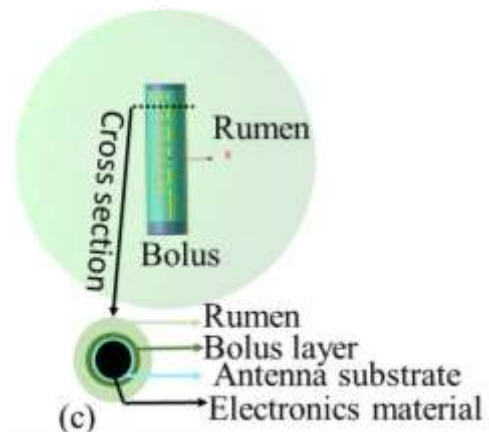


Figure 5 Antenna simulation considering environment

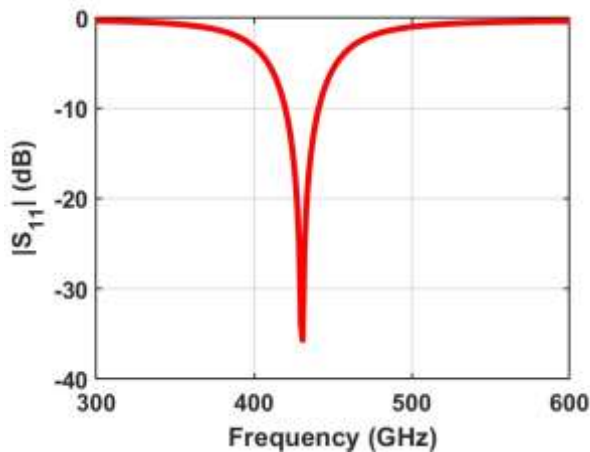


Figure 6 Reflection coefficient (S_{11} in dB)

Figure 6 shows the simulation results of reflection coefficient (S_{11}) in dB for meander antenna array (Fig. 2(c)). The S_{11} curve shows a pronounced resonance at approximately 433 MHz, where S_{11} reaches a minimum value of about -21.6 dB. This deep notch in the reflection coefficient signifies strong impedance matching at the resonance frequency, with minimal reflected power and efficient power transfer into the structure. The achieved impedance bandwidth, defined by the -10 dB reflection criterion, is approximately 20 MHz, which exceeds the required bandwidth for the intended application.

In addition, the designed antenna exhibits an omnidirectional radiation pattern in 3D shown in Figure 7 with a simulated peak gain of -38 dBi. Despite the low gain, this radiation characteristic is sufficient to meet the required data transmission rate for the targeted short-range communication scenario.

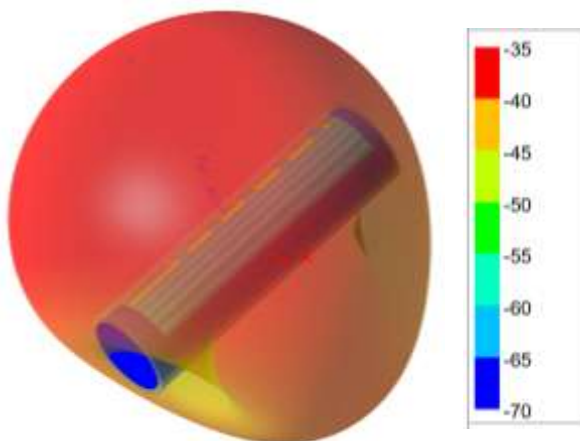


Figure 7 3D radiation pattern of antenna gain

5 Acknowledgement

The work was funded by the Germany research agency (BMFTR) in the framework of the project “iCampus 2 Smart Livestock”.

6 References

- [1] Smaxtec System, <https://smaxtec.com/de/>
- [2] Dropostix System, <https://www.dropostix.com/de/produkt/>
- [3] LoRa alliance <https://lora-alliance.org/>