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RFID-based sensor for insect detection

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Abstract. Real-time monitoring of insects is an important objective across many life-science disciplines. Here we demonstrate the first of its kind disposable wireless detector, capable of monitoring insect activity. Our solution is based on an indirect indicator, based on sugar consumption by insects. We develop a caramel-based antenna device, linked with an RFID chip. Apart from its nutrition value, caramel is a dielectric material, affecting electromagnetic interactions between waves and matter. Being consumed by insects, changes the electromagnetic properties of the antenna, deactivating the tag. The failure in the readout suggests an active presence of insects in the surrounding. Adding control bits, weather sustainability, and other functions, required for a reliable outdoor operation, will be reported in the future.

Keywords: RFID, insect detection, microwave sensor, agricultural monitoring

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Материалы конференции
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RFID сенсор для детектирования насекомых

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Аннотация. Мониторинг насекомых в режиме реального времени является важной задачей во аспектах естественных наук. В данной работе мы демонстрируем первый в своем роде беспроводной сенсор-расходник, способный отслеживать активность насекомых. Наше решение основано на наблюдениях о потреблении насекомыми частиц сахара, в результате чего разрабатывается антенное устройство на карамельной основе, связанное с RFID-чипом. Помимо своей питательной ценности, карамель является диэлектрическим материалом, влияющим на взаимодействие между электромагнитными волнами и веществом. Поедание карамели насекомыми изменяет геометрию метки и, как следствие, электромагнитные свойства антенны, деактивируя метку. Особенности в показаниях детектора говорят о наличии насекомых в окружающей среде. Также о добавлении управляющих элементов, об устойчивости к погодным условиям и других функциях, необходимых для надежной работы на открытом воздухе, будет сообщено в будущем.

Ключевые слова: RFID, детектор насекомых, СВЧ сенсор, мониторинг в сельском хозяйстве

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Introduction

Real-time monitoring of the distribution, migration, and population of insects provides valuable information in ecology, agriculture, and other life science disciplines. Quite a few methods of detection and monitoring have been developed. These include components, driven by optical, acoustic, acousto-optic, chemical, radiofrequency-based, and other elements [1–6]. The vast majority of the devices are based on active sensing schemes and therefore require power sources. The main fundamental challenge, faced by radiofrequency approaches, is the small size of insects relative to operational wavelengths. For example, the average size of ants is 3.5-5.5 mm, which makes them weakly interact with electromagnetic waves owing to characteristic size mismatch and relatively low average refractive index. A probable solution to this problem is shifting operation frequencies towards the sub-terahertz region. However, the penalty of this approach is high atmospheric decay, making the wireless detection extremely short-range and not practical. Camera-based monitoring is an appealing solution but comes with a penalty if an elevated cost.

Here we propose a sensor, based on mature RFID technology. Capable to accommodate multiple information bits with a capability of a mid-range interrogation (typically, several meters for passive schemes), RFID tags were used to monitor migrations of bees and bumblebees [7, 8]. However, only a limited number of species were labeled to make statistical estimates of the population behavior. Furthermore, this approach is inapplicable to most species, which cannot be RFID-labeled owing to their small size, appearance, and other possible constraints. Pests monitoring is also not possible owing to their rather unexpected appearance.

Our proposed solution is based on an indirect indicator, based on sugar consumption by insects. We develop a caramel-based antenna device, linked with an RFID chip. Apart from its nutrition value, caramel is a dielectric material, affecting electromagnetic interactions between waves and matter. It is well-known that placing a dielectric in the vicinity of an RFID tag can change its resonant frequency, antenna gain, efficiency, and other electromagnetic parameters [9, 10]. Here we use this concept and functionalize a tag with a biodegradable dielectric. Being consumed by insects, changes the electromagnetic properties of the antenna, deactivating the tag. The failure in the readout suggests an active presence of incest in the surrounding. Adding control bits, weather sustainability, and other functions, required for a reliable outdoor operation, will be reported in the future.

Geometry and design

The basic structure of the proposed RFID sensor is PCB meander whose configuration and parameters is shown in Fig. 1 and summarized in Table 1. The proposed design is printed on 1 mm FR-4 substrate with 36 μm copper metal layer. Chosen geometry of tag reduced overall size (40 x 40 mm^2) related to UHF RFID wavelength (370–330 mm) and increase thickness homogeneity of caramel layer during manual crafting. Other geometric characteristics is shown in Table 1. Lumped port with 20 ohm impedance replaces IC chip. Dielectric properties of caramel are $\varepsilon = 3$ (without dispersion) and $\mathrm{tg}\delta = 0$ (in the model loss in caramel is neglected). Numerical simulation of sensor shows its high sensitivity to caramel layer thickness as a resonant structure.

Table 1

Dimensions of RFID tag

L_1	L_2	w_1	w_2
36.5	32.5	3.4	1.4

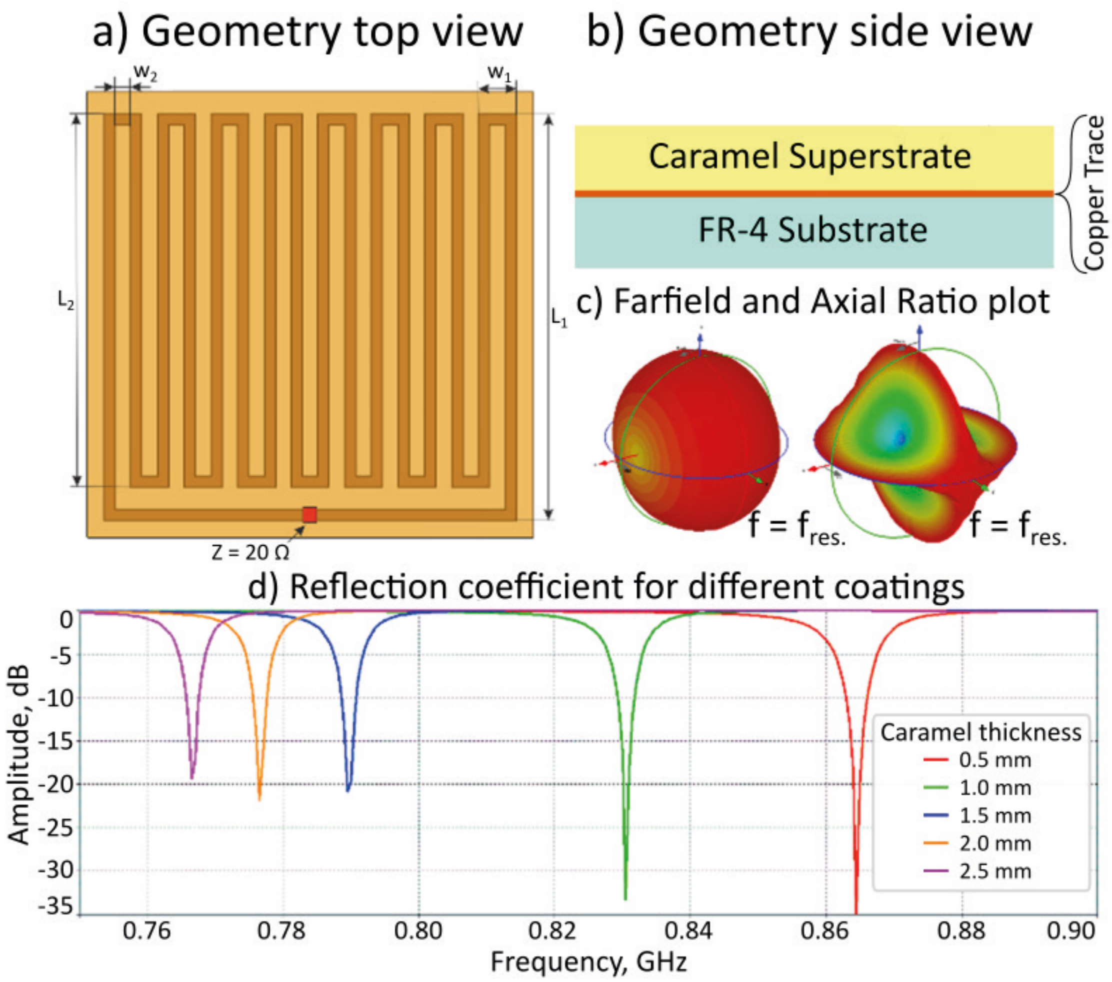

Fig. 1. Proposed design of sensor with tag geometry of tag in top view (*a*) and side view (*b*) Properties of model sensor: far-field and axial ratio 3D plots on resonant frequency of tag (*c*), influence of caramel layer thickness on tag resonance position (*d*)

Results and Discussion

Measurements of the passive RFID tag were based on the near-field response. For this purpose, a special magnetic probe, sensitive to electrodynamics structures, was numerically simulated (Fig. 2) and fabricated (Fig. 3,*a*). Its own first eigenmode is much higher in frequency (Fig. 4, orange circle) than the expected resonance of the tag, thus there was no coupling between them. The distance between the sensor and the magnetic probe is 2 mm.

The probe diameter is 40 mm, feeder length 110 mm and gap size 4.5 mm. Special labels were applied on its top (Fig. 3,*b*) to simplify the placement of the tag (Fig. 3,*c*).

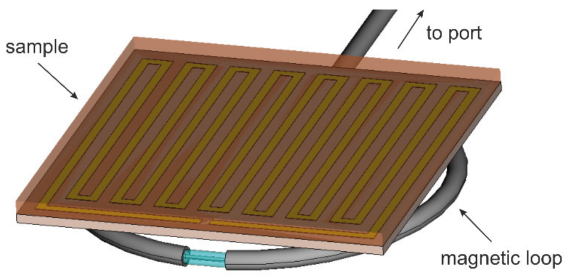

Fig. 2. Sensor model taking into account the influence of the magnetic loop

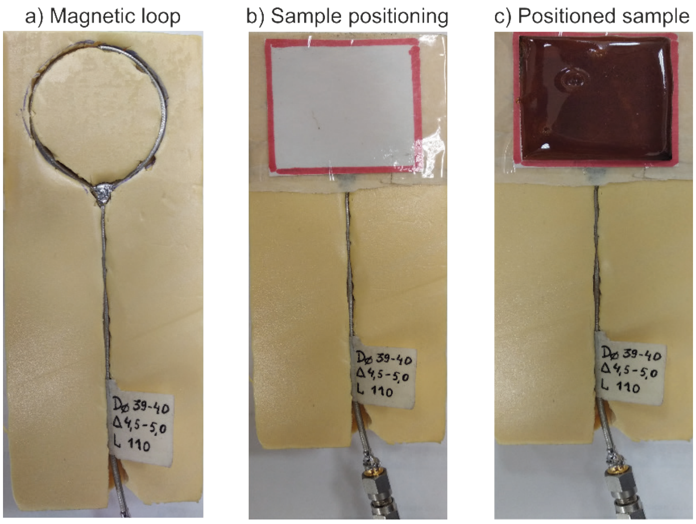

Fig. 3. Measurement setup: standalone probe on a stand (*a*), probe with a sample positioning mark (b) and probe with a positioned sample (*c*)

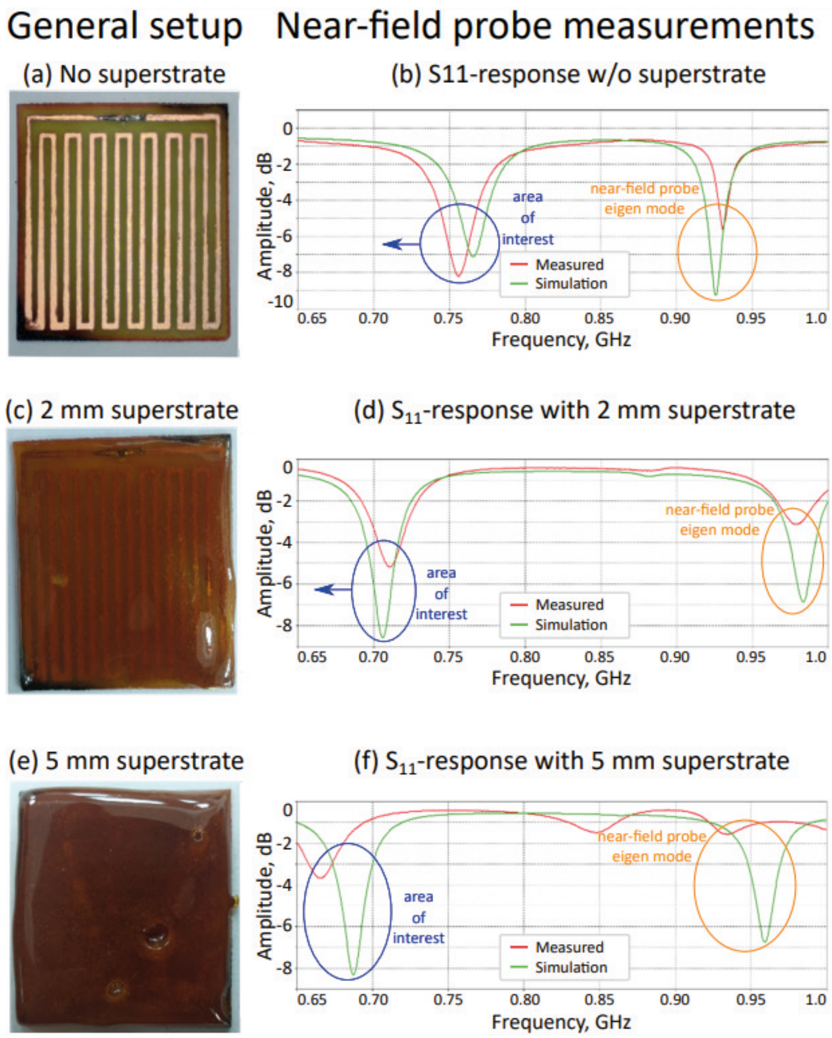

Fig. 4. Manufactured RFID tags without caramel superstrate (*a*), with 2 mm (*c*) and 5 mm of caramel thickness (*e*) and their *S* parameters (*b*, *d* and *f*, respectively)

Three samples were analyzed numerically, manufactured and then measured (near-field measurements of S_{11} parameters via magnetic loop). The first of them does not have caramel layer, the second is covered with only 2 mm thickness superstrate and the third one has 5 mm thickness overlayer. Fig. 4, *b*, *d*, *f* illustrates the positioning dynamics of the RFID tag resonance (blue circle) depending on the changing thickness of the caramel coating. It is noticeable that, according to the expectations and to the numerical experiment (Fig. 4, *b*, *d*, *f*), green curve), the greater the superstrate thickness, the lower the resonance frequency, while the eigen frequency of the probe still lies much higher and does not affect the structure.

The results show general convergence between the numerical simulation data and experimental data. While the convergence remains high at small coating thickness (Fig. 4 (d)), for large thickness (Fig. 4,*f*), the uniformity of the layer starts to play a leading role, which can cause additional discrepancy.

At the same time, it is important to note that in this frequency range, a caramel covered tag can not have a second resonance, as long as it retains the original geometry of the metal. Therefore, when describing the interaction of insects with the tag, even allowing for an uneven coating it with caramel at an arbitrary moment in time, it is possible to describe the superstrate using an effective dielectric permittivity index. Thus, keeping the fact that the RFID reader's channel bandwidth is quite narrow (about 20 MHz), it can be concluded that the label maintains the ability to enter or exit this range when the coating thickness changes. At the same time, due to the continuity and unambiguity of the impact of insects on the caramel, such an event as described will occur only once and will immediately activate the detector.

In continuation of this study it is required to measure dielectric characteristics of caramel and obtain precise convergence of model and experiments. The current task is to make additional samples and increase the homogeneity of caramel thickness.

Conclusion

The relationship with caramel covering layer thickness and resonant frequency of structure was shown. In addition, the possibility of using caramel covering RFID tag for insect detection was demonstrated.

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