Examining Food Quality via RFID Tag Array

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***Abstract* – Radio-frequency identification (RFID) tags are widely used in the food supply chain where they can be used to hold identification data of tagged objects. They can also be used to provide information related to the quality and safety of the tagged object. This can be achieved by analyzing the RF signals emitted by the tag which couples with the tagged objects, and hence can be used to acquire useful information related to the safety and quality of that object. This paper investigates the correlation between the radiated signals from the tags and the quality characteristics of the tagged objects. It focuses on analyzing the mutual coupling between the tags in an array, in particular, of orthogonal polarization configuration, which shows that more information can be extracted by an array of tags compared to the use of a single RFID tag emitter.**

I. INTRODUCTION

The existing food quality inspection relies heavily on expensive food labs and most of them are using food samples to perform electrochemical tests [1]. These testing methods are not on-time, requiring direct contact, and not meeting the need for real-time monitoring, especially during the COVID-19 pandemic, where contactless and real-time response has become increasingly important.

Dielectric properties of foods are important in determining the interaction of microwaves with food, hence they can be used to assess quality. The dielectric constant is the ability of a material to store microwave energy, the dielectric loss factor is the ability of a material to dissipate microwave energy. Dielectric properties depend on the composition of the material, its moisture content, in addition to its temperature and quality. Comprehensive reviews on dielectric properties of a wide variety of foods are presented in [2][3].

Food is largely composed of carbohydrate, fiber, fat, moisture, protein, and salt. The physical-chemical changes of the foods take place in different stages of the life cycle and influence the dielectric properties. Raweendranath and Mathew (1995) suggested that dielectric behavior of water at 2.685 GHz can be an effective method for detecting pollutants in water [4]. In [5] the feasibility of a microwave sensor for water activity measurements was investigated.

RFID stickers have been widely used in industry. These battery-free stickers attached to objects can be triggered by RFID readers and respond with identifiers. In addition to identification information in the responding signals from the RFID tags, the change of radio frequency characteristics of the signal emitted from the tag caused by the materials attached to it can be utilized to extract quality information of the materials by analyzing the spectrum of the received signal in the analogue level. The quality features of the objects have a direct correlation relationship with the dielectric properties of the materials, and hence, the altered signal can be examined for feature extraction [6]. The backscattered transponder signals from passive ultra-high frequency (UHF) RFID tags have been used for localization in [7].

The weak coupling between the RFID tags and the material in their immediate vicinity is the key mechanism governing the change of the RF characteristics of the emitted signal from the tags. The material which are in the near field reactive region of the tag antenna and can be simply treated as an extra dielectric substrate on the radiation antenna. Near field microwave scattering techniques have been utilized to characterize the materials [8]. In [9], the resonant frequency of the UHF RFID tag inside the bottle of sports drink was detuned from 960 MHz to 890 MHz.

This paper propose a methodology to use an array of RFID tags to extract the quality and safety information of the tagged material. The array of tags has been proposed to compensate the insufficient information where a single tag provides and flexible array configuration can be implemented to cope with different materials. An experiment has been conducted to verify the concept proposed and the preliminary results indicate that RFID tag array can be useful to extract more information from the tagged object.

II. THE CONCEPT DESIGN

In order to understand the role of the weak coupling between the RFID tags and the material in changing the spectrum of the signals emitted from the RFIDs, one dipole antenna for the RFID chip has been designed and analyzed. The UHF RFID antenna design is shown in Fig. 1, its input impedance characteristic has been studied closely in three scenarios. 1) RFID tag in the open air and on the surface of an object. 2) RFID tags are arranged in perpendicular on surface, 3) RFID tags are in parallel, and they are attached to the same

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surface. The second and third scenarios are shown in Fig. 2. The RIFD tags are arranged perpendicular and parallel to each other respectively.

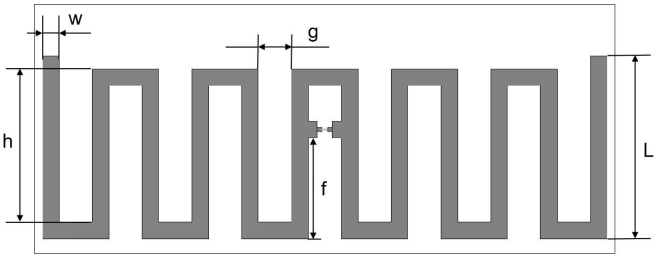
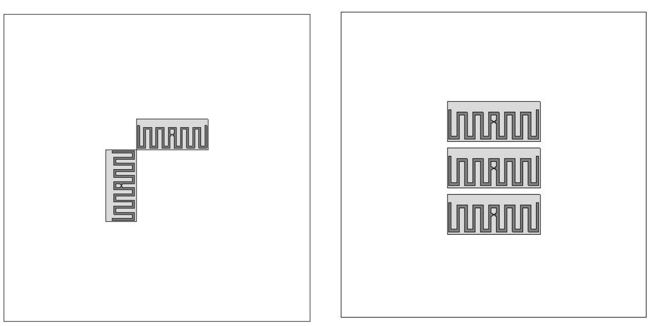


Figure 1. The RFID antenna designed for the investigation.

TABLE I
RFID ANTENNA DESIGN PARAMETERS

Parameter	Value(mm)	Note
h	18.4	height
w	2	width
g	4	gap
f	12.125	feet point
L	22	height of edge

In the Fig. 2 (b) the separation distance between the centres of the tags is 35mm, the size of the object the tags attached to is 230mm × 230mm, the thickness of the object is 5mm in the investigation, and the relative dielectric constant of the material is assumed 15.



(a) (b)

Figure 2. The RFID tag array configurations.

The input impedance of a single RFID tag case is shown in Fig. 3, which is obtained by observing the reflection coefficient of the antenna. It shows that the material the tag being attached to has changed the resonant state of the tag antenna. In the open air, the antenna is resonant at 920MHz, but when the tag antenna is attached to the surface of the object, two resonances appear at 564MHz and 905MHz. However, this information is insufficient to differentiate materials in a good accuracy as the interaction between the RFID tag and the material in the near field is limited. Therefore an array of RFID tags has been proposed, where the mutual coupling between the tags are mainly altered by the material properties. Quality change of the material will be reflected by the signals simultaneously emitted from the tags in the array. More information can be extracted by arranging different configurations of the RFID tag arrays.

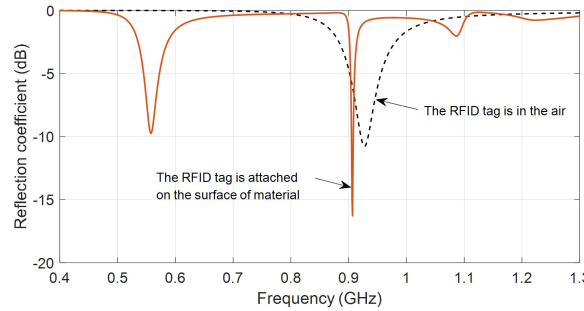
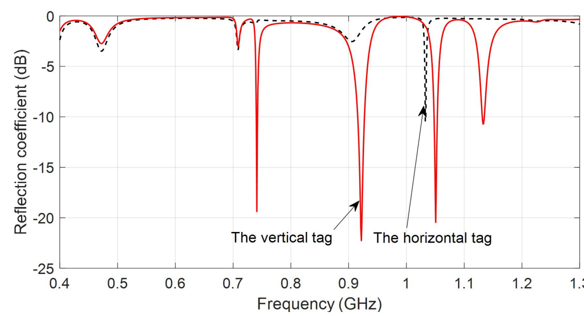
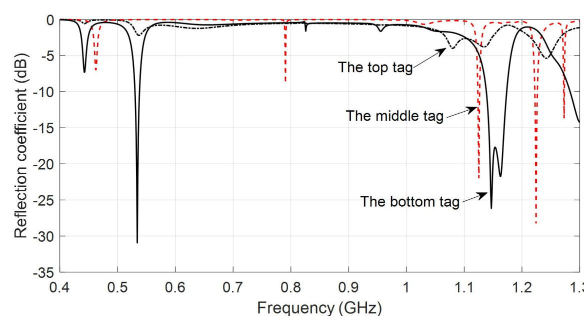


Figure 3. The single RFID antenna case.

As expected, the input impedance of the antennas in the RFID tag array are more complex. When the two RFID tags are arranged in perpendicular to each other as shown in Fig. 2 (a), five clear resonant frequencies can be observed from the two tags, this is shown in Fig. 4 (a); when three RFID tags are arranged in parallel to each other as shown in Fig. 2 (b), more spectrum information can be extracted from RF signals emitted by the three RFID antennas, this is shown in Fig. 4 (b).



(a)



(b)

Figure 4. The RFID tag array, (a) two RFID tags are perpendicular; (b) three RFID tags are in parallel.

III. THE RESULTS

In order to verify the concept proposed in this paper, two RFID stickers have been attached to a plastic drink bottle and measurements have been performed. This is shown in Fig. 5. The two RFID tags were arranged perpendicular to each other.

First, the bottle was kept empty, the spectrum of the signals emitted from the two tags were monitored via the spectrum analyzer N9918A with the resolution bandwidth of 100kHz; Then the bottle was filled with water, the responded signals from the two RFID tags were analyzed again, a distinct difference is observed for the bottle with full of water compared to the case of an empty bottle. The reader is in the close range of the drinking bottle. Two RFID tags have been attached on the outside of the bottle and they are perpendicular to each other. The spectrum observed from the local environment is shown in Fig. 6, the signal from the reader is clearly the strongest.

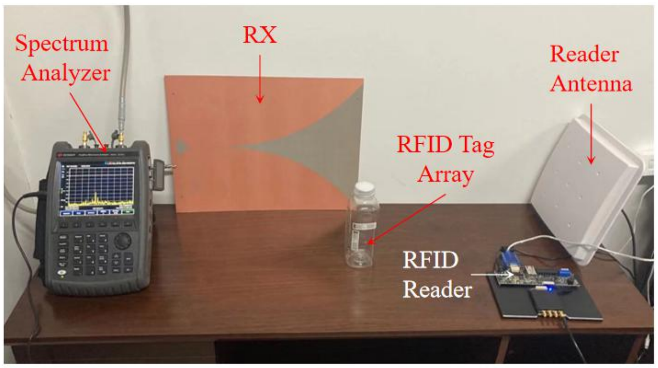


Figure 5. The experiment setup.

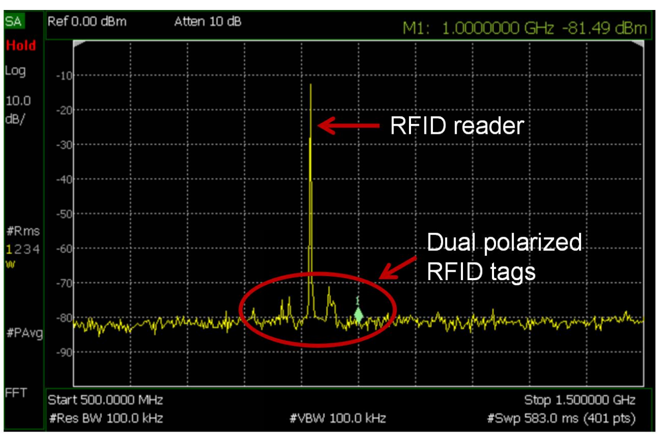


Figure 6. The response on the spectrum analyzer from the two perpendicular tags and the RFID reader.

The RF signals emitted from the two RFID tags were extracted while the tag reader was in the waiting mode, this is shown in Fig. 7. A clear extra peak was observed when the bottle is filled with water. Two RFID tags simultaneously emitted a wider range of spectrum and they can be recorded and used to catalogue different materials in a database, hence for food quality monitoring. The spectrum profiles can be looked up in a real-time monitoring system when the database is sufficiently large and stored into a table. Of course the catalogue information dependents on the RFID tag array configuration, even tailor-made tags can be designed to cope with different material monitoring needs.

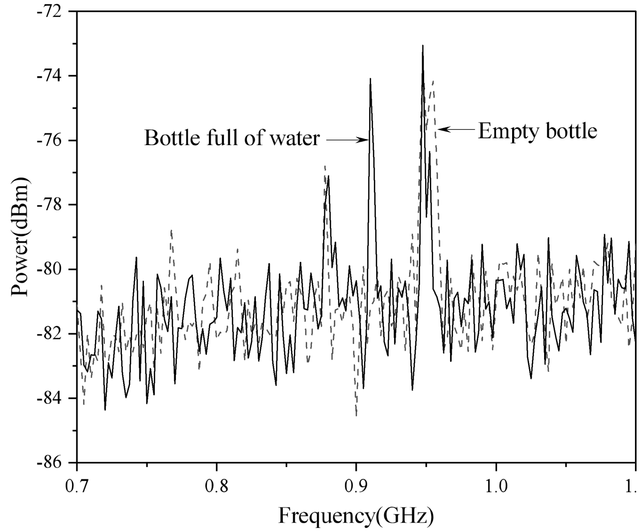


Figure 7. The emitted signals from two RFID tags of dual polarization.

IV. The Conclusion

The paper concludes that the RFID tag array can extract more information about the tagged material compared to a single RFID tag case. The mutual coupling between the RFID tags has been predominantly changed by the material in the near field and this characteristic can be used to monitor the quality and states of the tagged material. The RFID array can be arranged into different configurations for a better inspection accuracy.

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