Screw tightening monitoring with RFID passive tag

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***Abstract*—The specific application of monitoring the tightening status of critical screws, e.g., screws for metallic structures which require high reliability, is herein discussed. A solution based on radio frequency identification (RFID) passive tag devices is proposed, and the design of a simple tag for metallic surfaces which allows for detecting the screw relaxing is presented. A tag prototype is manufactured on a 0.5 mm thick FR4 substrate of size 40 mm × 40 mm based on the commercial tag chip Impinj Monza R6 for working within the ultra-high frequency (UHF) FCC band 920.5-924.5 MHz, and measurement results reveal that the screw status can be detected up to a range of 2.5 m.**

I. INTRODUCTION

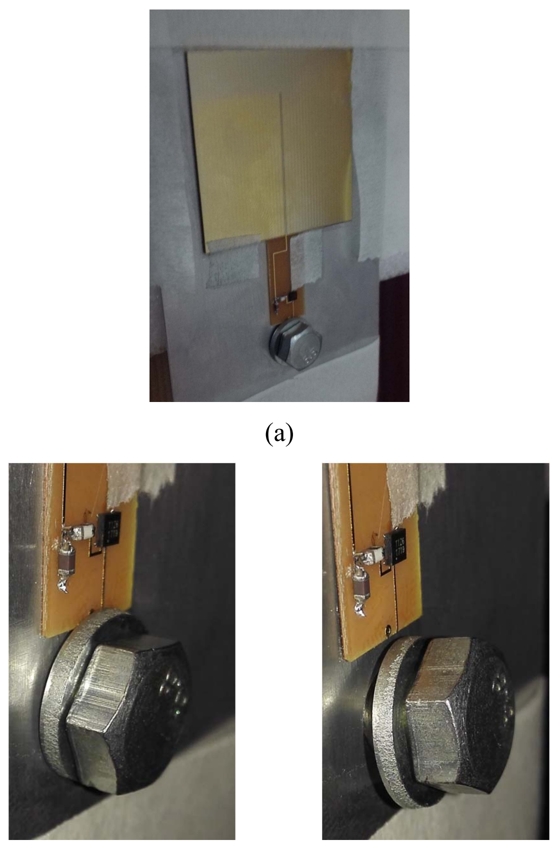
The Internet-of-Things (IoT) scenario in which a multitude of objects or people possess the ability to communicate and transfer data over a network is attracting the interest of many research centers as well as private companies. Among the possible applications for this all-connected network [1], continuous monitoring of sensor status is surely important.

A special application is considered in this work. Passive radio frequency identification (RFID) tags are used to monitor the tightening status of critical screws, e.g., screws for metallic structures which require high reliability and to be safe. To this end, a planar inverted-F antenna (PIFA) [2] based tag is designed to be applied on metallic surfaces and, exploiting an open-close contact mechanism easily implementable with the metallic screw, and an impedance matching network for an Impinj Monza R6 tag chip, the tightening status of the screw can be monitored by verifying the possibility or not to communicate with the tag. The tag antenna is designed on a 0.5 mm thick FR4 substrate with size 40 mm × 40 mm, whereas the impedance matching network, the tag chip, and the open-close contact mechanism reside on a 20 mm × 10 mm substrate protrusion. Applying the tag on a 100 mm × 60 mm aluminum surface, a read range larger than 2.5 m is measured when the screw is well tightened, whereas it is found that the tag cannot communicate when the screw is relaxed (read range is lower than 0.3 m).

II. DESIGN OF TAG WITH TIGHTENING MONITORING MECHANISM

The manufactured tag device is shown in Fig. 1 (a), which has a similar structure as [3]. A PIFA occupies the whole 40 mm × 40 mm dielectric surface, except for a central fissure used to feed the antenna. A feed line of length l_{inset} and width w_f protrudes into the PIFA surface. Feed line parameters are optimized to have a Z_0=100 Ω antenna input impedance.

The screw tightening status identification mechanism is implemented with a simple open-close contact. In fact, as it can be observed in Fig. 1 (b), when the screw head is tightened, it determines a short-circuit between a microstrip line and a short via. On the other hand, when the screw is relaxed as in Fig. 1 (c), the microstrip line is opened, causing a completely different electrical configuration. It should be noted that, when the screw cannot be tightened over the tag substrate, the tag can be placed close to the screw, and a conductive glue drop can be used to electrically connect the screw to the couple microstrip line/short



(a) (b) (c)

Fig. 1. (a) The manufactured passive tag for the screw tightening monitoring. (b) Tightened and (c) relaxed screw.

via. When the screw relaxes, the drop will fall down yielding an "open circuit" status.

An Impinj Monza R6 tag chip [4] is considered for this design. This tag exhibits an equivalent complex impedance Z_{chip}=16.3-j139.5 Ω at the frequency of interest, different from the PIFA impedance. For this reason, a simple LC matching network is used to minimize the tag return loss at the tag chip input when the screw is well tightened (close circuit). The equivalent circuit in Fig. 2 is considered for the impedance matching.

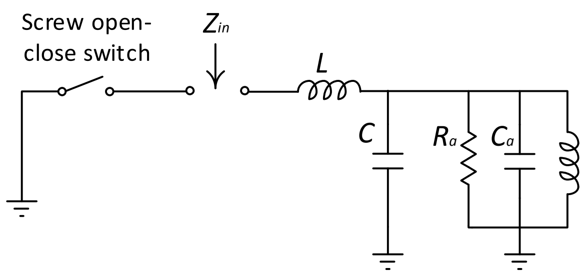


Fig. 2: Impedance matching equivalent circuit

The matching network inductor and capacitor values are determined as

$$L = \frac{\sqrt{R_c(Z_0 - R_c)} - X_c}{2\pi f}$$

$$C = \frac{1}{2\pi f Z_0}\sqrt{\frac{Z_0 - R_c}{R_c}}$$

where R_c and X_c are the tag chip resistance and reactance, respectively, and Z_0 is the antenna input impedance at the resonance. It should be noted that the microstrip line which goes toward the screw contact behaves as another inductance, and, for this reason, the final value of L will be lower than the one calculated with the above equation. Furthermore, the microstrip line length is determined in order to both maximize the quantity

$$|S_{11}| = \left|\frac{Z_{in} - Z_{chip}^*}{Z_{in} + Z_{chip}}\right|$$

when the screw contact is open, and minimize the above S_{11} when the screw contact is close. Final values of L and C are L=20 nH and C=3.3 pF.

III. Measurement Results

The tag is manufactured as shown in Fig. 1 (a), and the read range is measured with a commercial reader with P_{eirp}=30 dBm. An aluminum surface of size 100 mm x 60 mm is applied behind the tag to emulate a real application environment.

Read range is calculated according to [5]

$$d = \frac{\lambda_0}{4\pi}\sqrt{\frac{P_{eirp}}{P_{th}} G_{tag}(1 - |S_{11}|^2)}$$

where P_{th} is the tag chip sensitivity (-20 dBm), whereas G_{tag} is the tag antenna gain (simulated value is 0.16 in linear scale). Fig. 3 depicts simulated and measured read range when the screw is well-tightened (contact) and when the screw is relaxed (no contact). As it can be seen, when the screw is well-tightened, the read range is larger than 2.5 m. When the screw is relaxed, the tag is not reachable (a minimum distance of 0.3 m is tested).

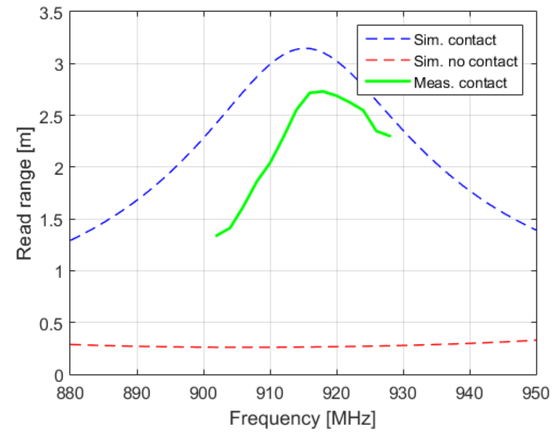


Fig. 3. Simulated and measured read range for well-tightened and relaxed screw.

Simulation and measurement results are in good agreement, even if a little difference in the maximum read range is visible, probably due to non-perfect tag chip soldering operation which have caused a tag chip impedance variation.

IV. Conclusion

This paper discusses the design of a passive RFID tag for the detection of relaxed screw. The detection mechanism, based on a simple open-close contact determined by the screw status, is investigated and modeled to be included in the tag device design process. When the screw is relaxed, it is found that the tag is not reachable (a minimum distance of 0.3 m is tested). On the other hand, when the screw is well-tightened, the measured read range is larger than 2.5 m in the 920.5-924.5 MHz band.

Acknowledgment

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