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Supply Chain Integrity Tilt Sensing RFID Tag

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***Abstract*—A tilt sensing tag is presented with a passive wireless RFID communications link. The tag is designed to reduce its read range when tilted in order to signal and memorize mishandling during transit or storage. The novelty of this design is the incorporation of mechanically altered ground plane separation from the antenna to achieve 2 states of input match, and also the introduction of a pair of sensing pads connected directly to the antenna port to facilitate the tilt detection and the retention of that information. The significance is for supply chain integrity with the realization of low cost wireless sensing tags that can be deployed widely in the monitoring of objects using standard RFID transponder chips, without the need of continuous energy harvesting, on-tag batteries or super capacitors. The results show that, when mounted on a variety of platforms, the tags are able to detect and retain tilt events by signalling states through backscattered power levels. The mechanical structure of the tag is proposed for manufacture by new additive printing techniques.**

***Keywords*—RFID; supply chain; tilt sensor**

I. INTRODUCTION

Items such as pharmaceuticals, military hardware or explosives require specific handling measures and counterfeiting protection to ensure integrity during manufacturing, transportation and storage [1][2][3]. Specifically, tilting may damage products and result in hazards [4]. A low cost method to detect tilt and signal its occurrence wirelessly is therefore attractive. UHF RFID technologies for wireless tracking and security of items are increasingly widely applied [5] and they are being developed to offer sensing. However, while RFID ASICs with input/output ports exist, they are comparatively complex devices requiring power for associated lumped sensors and memory. Meeting the power demand is problematic as batteries increase costs, contain environmentally damaging materials and can be bulky. Alternatively, energy harvesting technologies may be integrated with the sensor, but they must have a sufficiently sustained source of appropriate energy to enable operation and memory storage. Therefore, if a remote sensor is to be a low profile single use device, it is of interest to create totally integrated RFID tags that sense and store the occurrence of various states without the need for on board batteries.

The address these issues a tag is described that provides three distinct read range values which are achieved by altering the value of the match between the tag antenna and the transponder ASIC. These three read range states correspond to an initial very short range, before the tag is mounted when it is addressed individually by a handheld reader; a long range state, when the tag is mounted but has not been tilted; and a mid-range state when the tag is mounted but has been tilted.

II. TAG MECHANICAL STRUCTURE

The tag antenna is printed on the upper surface of an FR4 substrate, Fig. 1.

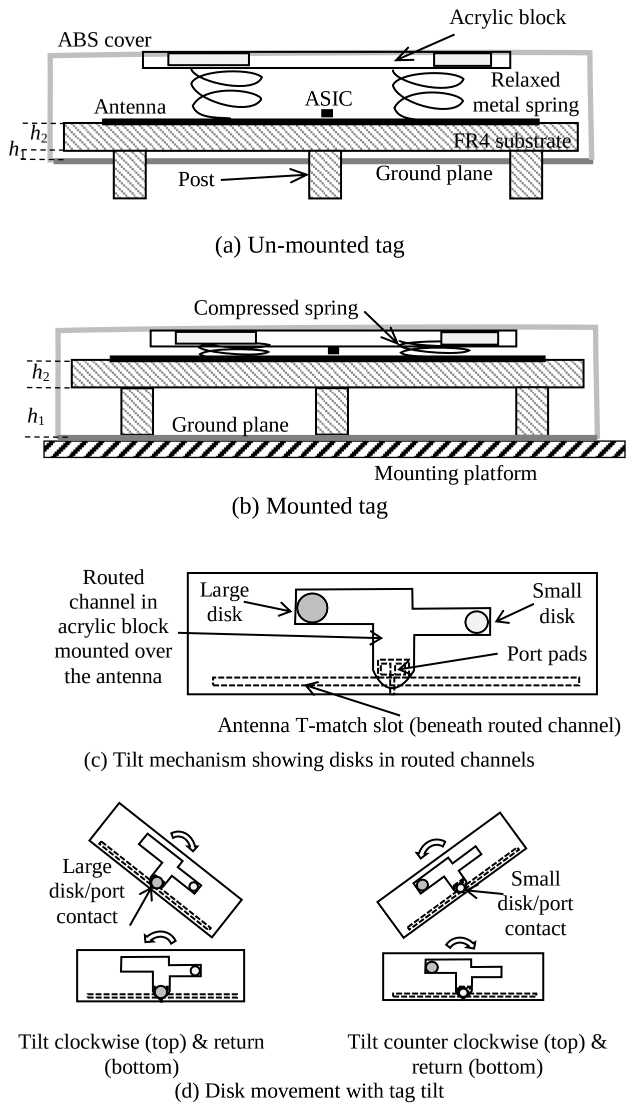

Fig. 1. Passive tag mechanical sensing mechanisms. (a) Tag side view before mounting on surface. Posts protrude from bottom of casing. (b) Tag side view when mounted. Posts pushed into casing. (c) Tilt mechanism plan view showing disks in routed channels. (d) Disk movement with tilt.

The substrate is enclosed in an ABS cover with a conducting ground plane on the inside lower surface. The tag is able to detect that it has been mounted on a surface and that it has been tilted through the mechanisms shown in Figs. 1 (a) and (d).

The advantage of using mechanisms, rather than electronics to facilitate detection is that a state occurrence such as tilting can be memorized with no battery required. The mount detect shown in Figs. 1 (a) and (b) is achieved by changing the antenna-ground plane separation (h_1) which alters the antenna input impedance. The mechanism comprises two metal springs which act to keep the antenna close to the ground plane (h_1 small) before the tag has been mounted. When the tag is mounted on a surface, posts that protrude through the bottom of the casing push the antenna against the springs and increase h_1. The tilt detect in Fig. 1 (c) is achieved through the interaction between a pair of capacitive pads on the antenna port and two conducting polymer coated disks. When the tag is tilted the disks move through routed channels and drop into close proximity with the capacitive pads, Fig. 1 (d). This detunes the antenna in a controlled way.

III. TAG ANTENNA

The tag antenna shown in Fig. 2 is a wide half wave dipole of dimensions L_1 and W_1 on an FR4 substrate (relative permittivity $\varepsilon_r = 4$, height $h_2 = 1$ mm). A conducting ground plane of width W and length L is attached to the casing base and is separated from the antenna by $h_1 + h_2$ and provides some isolation between the tag and the mounting surface, Fig. 2 (b). The coplanar fed dipole differs from other embedded T-matched RFID antenna designs such as those in [10] owing to its multilayer substrate and incorporated sensing pads. The T-match connection surrounds a slot of width S and length L_2 and the coplanar feed lines are of width W_2. Fig. 2 (c) shows the ASIC connected across the feed gap together with the two sensing pads that are inset into the antenna.

As well as providing isolation between the antenna and the mounting surface, the ground plane creates different matched states by switching between two discrete h_1 separations from the antenna. A related concept was considered in [11] where an electromagnetic band gap (EBG) material was tuned by mechanically moving an underlying ground plane with a screw thread mechanism. However, it was noted that although the mechanical approach may be more economical than electronic tuning, exact control of the air gap height was challenging. In this work we overcome this problem by exploiting a distinct separation state based approach to avoid inaccuracies.

In [12] it is shown that the total voltage at a half wave dipole feed point reduces with ground plane separation h causing the input resistance to fall from around 100 Ω to 0 Ω for h between 0.3λ and 0λ respectively and radiation efficiency reduces significantly. Fig. 3 gives simulated resonance frequency and total efficiency for the antenna in Fig. 2 for h_1 between 0.1 and 1000 mm, with optimal efficiency occurring at 5 mm. Therefore, the mount detection mechanism was designed to switch h_1 from 0.5 to 5.0 mm with the tag reading at short range in the first case and at much longer distances in the second case when it has been mounted on a platform.

The entire tag structure was simulated with CST MWS ® and tuned to 915 MHz. It was determined that the metal springs did not affect the resonance frequency. The tuned dimensions are given in Table I. After tuning the tag dimensions, the port resistance does not change significantly across the American RFID band (905-928 MHz), while the reactance changes by about 100 Ω. Tag total efficiency in Fig. 5 is shown to peak at -0.8 dB at resonance. The antenna patch width W_1 was adjusted to achieve this maximum efficiency.

TABLE I. TILT SENSING TAG DIMENSIONS

Parameter	(mm)
Ground plane length, L	155
Ground plane width, W	42
Dipole patch length, L_1	134
Dipole patch width, W_1	35
Slot length, L_2	100
Slot width, S	3
Feed line width, W_2	3
Pad length, L_3	3.5
Pad length, W_3	3.5
Pad recess length, L_4	10
Pad recess width, W_4	4
Air gap height, h_1	0.5, 5
FR4 substrate height, h_2	1

IV. TILT SENSING BY IMPEDANCE MISMATCH

Tilt detection is achieved by the sensing pads shown in Fig. 2 (c). The pads are open circuit when the tag is untilted, however, when tilted beyond a certain angle, a metallic disk with a thin polymer coating makes capacitive contact with the sensing pads. When the disk is absent, the tag is tuned for maximum power transfer (longest read range). When tilted, the capacitive loading of the metallic disk detunes the tag and reduces the read range by 30%.

V. MEASURED RESULTS

A tag was fabricated and tested in the initial, mounted (untilted) and mounted (tilted) states, Fig. 9. The read range d

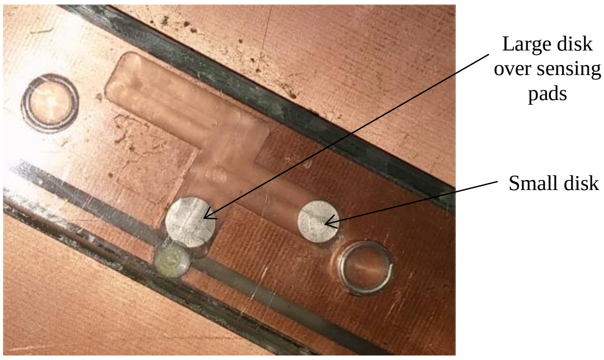

Fig. 9. Prototype tag in tilted state

was measured in a laboratory using Voyantic equipment [18] where system losses were quantified with a known benchmark tag. At 915 MHz the measured *d* for the unmounted, and mounted on metal untilted & tilted states were 1.1, 20.3 and 7.4 m respectively. When tilted, *d* decreased by 63% compared to the untilted state and this demonstrates good discrimination between the states. Tilting the tag caused it to detune by less than 10 MHz, but before mounting, the resonance frequency was 70 MHz lower causing *d* to be about 1 m as would be required when the tags are mounted and interrogated by a handheld reader.

VI. Conclusion

A rugged cased tag is described for tilt sensing on platforms during transportation and storage. The principle of impedance detuning by moving disks allows for mishandling of tagged objects to be detected and stored passively. As an application scenario, at the tag deployment stage prior to being mounted, the tag offers only short range communication for unambiguous inventory logging. After mounting, the maximum tag read range is achieved, and this range is reduced by 30% if the mounting platform is tilted beyond a predefined angle. The tags could be manufactured by conventional machining, but are proposed for construction with new fabrication processes such as additive manufacture.

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