Integration of Sensors and Inkjet-Printed RFID Tags on Paper-based Substrates for UHF "Cognitive Intelligence" Applications

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Abstract- In this paper, an overview of novel design and integration approaches for improved performance UHF Radio Frequency Identification (RFID) tags with embedded power source and sensing capability is presented. Ultra-low-cost organic substrates, such as paper, with inkjet-printing capability are investigated for the UHF frequency band. The proposed technology could potentially revolutionize sensor nodes and RFID tags for various applications such as security, logistics, automotive and pharmaceutical.

Introduction

Due to increasing demand for automatic identification, RFID finds countless applications in different areas including retail level management, item level tracking, access control, animal tracking, vehicle security, and electronic toll collection. At the same time and driven by several "cognitive-intelligence" applications such as: item-level tracking of temperature sensitive products, pharmaceutical logistics, transport and storage of medical products or bio-sensing applications, a demand for inexpensive, low-power-consumption and durable wireless nodes with sensing capabilities has also increased tremendously. In this paper, a brief outline of novel approaches to integrate RFID electronic components, namely antenna, power source, and IC with sensors in/on organic substrates such for UHF frequencies is depicted. Antenna design guidelines, material characterization, sensor and power source integration are also included.

UHF RFID Antenna Design and Application

The UHF RFID band ranges from 860 MHz to 955 MHz. A half wavelength antenna is typically used in RFID applications due to its omnidirectionality enabling the tags' communication with the RFID reader in any orientation and for a variety of environments [1]. The fundamental topology of an integrated UHF RFID is demonstrated in Fig. 1.

Bandwidth- The dimensions of the antenna shown in Fig. 1 (3" x 3") allow for an integrated battery and/or sensor on the top and bottom of the antenna structure. The matching network (double inductive feed and shorting stub) modifies the antenna's impedance to match any IC impedance value hence allowing an optimum power transfer from IC to antenna. It has to be noted that the antenna has to be compact with efficiency close to 100%. The tapering of the two arms allows for a higher bandwidth than typical dipole antenna configurations. The simulation and the measurement results are shown in Fig. 2, demonstrating very good agreement and verifying the efficient operation of the antenna in both European and North American bands.

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Harsh Environments- Antennas in UHF RFID tags are usually linearly (vertically or horizontally) polarized, as shown in Fig. 3. However in harsh environments (presence of metals and/or liquids) the transmitted/received electromagnetic waves undergo polarization changes. This causes a transmission loss or blockage of communication with the RFID reader. The proposed solution is a dual antenna configuration with two identical antennas in dimensions and shape bodies, such as the one shown in Fig. 4. This configuration can greatly minimize this effect of polarization changes and also account for any misalignment of the tag (with respect to the reader antenna) that might cause a null in its radiation pattern and deteriorate the communication quality. This is especially critical in extreme "rugged" industrial and/or urban environments.

Directivity- The design of a highly directive RFID antenna is an effective method to increase the read range of a tag for manufacturing applications, such as boxes, palettes or items placed on conveyor belts (known position of tag). However, the radiation pattern of most RFID antennas is constrained by their intrinsic dipole nature (omnidirectional) with limited directivity (~2 dBi). A new topology, named dual-body configuration is presented in Fig. 5. Two meander-line arms are placed on each side of the feeding loop. In this case, the current directions are opposite along the arms and the radiation patterns cancel out each other in most of the directions. Thus, in this inductively coupled RFID antenna [2], the radiated energy is focused directionally in a dumbbell shape as shown in Fig. 6, and a high directivity of 5.62dBi is observed. In general, a highly increased effective range is expected to achieve with RFID antennas in such a configuration.

RFID/Sensors Embedded in/on Organic Substrates: Paper

Paper is considered one of the best candidates for organic substrates for RFID/sensing applications. In terms of mass production and increased demand, this makes paper the lowest cost material made. Paper also has low surface profile with appropriate coating. This is very crucial since fast printing processes, such as conductive paste inkjet-printing, can be used instead of metal etching techniques. In addition, paper is compatible with circuit printing by direct write methodologies. This is one of the biggest advantages since active tags require additional modules like sensors and batteries to be mounted on or embedded in. A fast process like inkjet-printing can be used efficiently to print these modules on or in the paper substrate. Paper can also host nanoscale additives (i.e. fire-retardant textiles) and can be hydrophobic. Most importantly, its dielectric constant is close to air's which means electromagnetic power can penetrate easily even if the RFID is embedded in the substrate. Dielectric constant and loss tangent can be effectively accurately measured up to 40 GHz by using methods such as: microstrip ring resonator, cavity resonators and parallel plate resonators [3].

Integration with IC, Sensor and Power Source

Recent developments in sensors, such as pressure sensors fabricated on Liquid

Crystal Polymer (LCP) [4], unfold a new field of opportunities in the organic sensor field. Additionally, development of organic thin-film transistor (OTFT) sensors opens up new possibilities in compact sensing systems. Such scenario leaves space for a conception of a mass production and integration process which will eventually reduce cost and enable a large-scale implementation RFID/sensors tags.

One of the major concerns of active RFID is the limited lifetime of the battery. The cost of replacing batteries in the tags can be relatively high. Among the power reservoir technologies investigated over the last years, rechargeable lithium thin film batteries seem to be the most suitable solution to be embedded in organic substrates due to their small thickness (less than 100 um). Such batteries have rechargeable capabilities which overcome short lifetime limitations, thus making them extremely useful for the drive of the sensors in active and semi-passive RFID/sensors tags. In order to meet the ultra low cost demand for passive, semi-passive, and active RFID tags, a simple manufacturing process, such as conductive inkjet-printing technology on organic substrates, is proposed. The ultimate goal is to have an all printed RFID tag (antenna, IC, battery, and sensor) on a low-cost environmental friendly paper. An integrated organic prototype with block diagram is illustrated in Fig. 7.

Conclusion

In this paper, we proposed the integration of sensors with UHF RFID tags utilizing inkjet-printing techniques in/on organic substrates, such as paper, that will enable the low cost and large-scale implementation of RFID-enabled semi-autonomous sensors for “cognitive-intelligence” applications. Additionally, the use of embedded rechargeable thin film batteries will increase the tag’s lifetime. The three suggested antenna structures may fit any type of application (worldwide frequency coverage, harsh environments, and enhanced directivity) in UHF/RF bands, which will enable a high read range with high data rate transfer.

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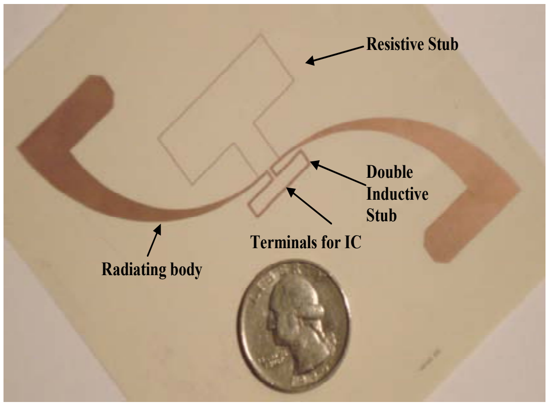


Figure 1. Typical RFID tag architecture.

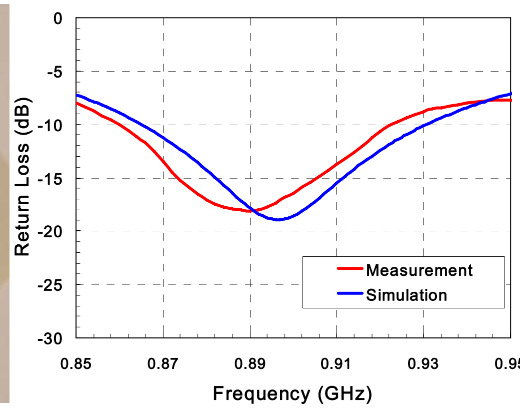


Figure 2. Return loss of RFID tag shown in Fig. 1.

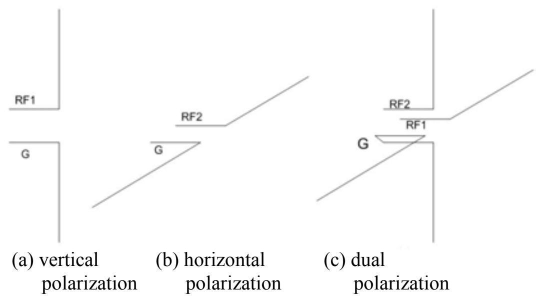


Figure 3. Polarization in RFID antennas.

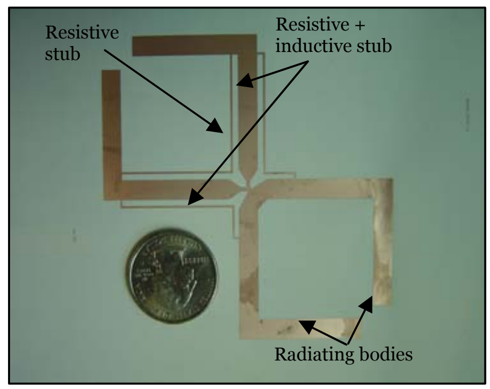


Figure 4. Dual polarization antenna.

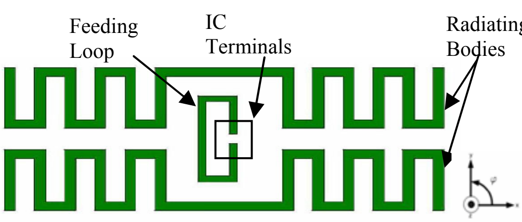


Figure 5. Dual Radiating body configuration

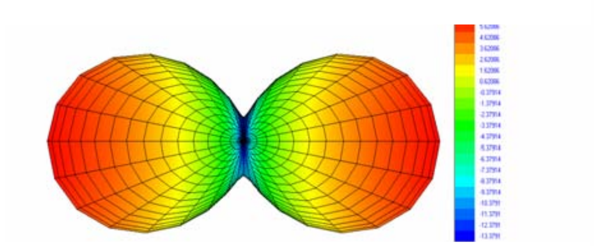
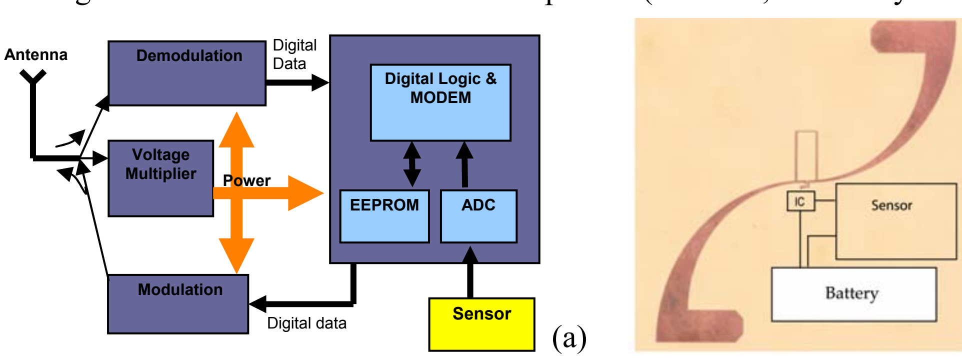


Figure 6. Dual Radiating body radiation pattern (theta=0°, directivity= 5.62 dBi)



(a) (b)

Figure 7. (a) Block diagram of RFID/Sensors tag (b) Suggested outline of integrated S-shaped antenna with IC, sensor and embedded battery.