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Inkjet-Printed Antennas on Paper: Are they the Ultimate Solution for UHF "Cognitive Intelligence" RFID-Enabled 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.

I.Introduction

Due to increasing demand for automatic identification, RFID's find 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.

II.UHF RFID Antenna

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].

Harsh Environments- Antennas in UHF RFID tags are usually linearly (vertically or horizontally) polarized, as shown in Fig. 1. 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. 2. 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. 3. 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

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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. 4, 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.

III. Inkjet-Printed RFID/Sensors on 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 (~2-3) is close to air's which means electromagnetic power can penetrate easily even if the RFID is embedded in the substrate.

Inkjet-Printed RFID Antenna- Most of the available commercial RFID tags are passive due to cost and fabrication considerations. Passive tags utilize energy from an RFID reader to power up the IC. However, RFID ICs used in passive tags exhibit complex impedance and conjugate impedance matching of the antenna terminals to the IC for maximum power flow becomes a challenge.

The half wavelength tapered width dipole benchmark antenna we decided to fabricate using inkjet-printing was designed to cover the UHF North America RFID freq. band (902MHz→928MHz)with a center frequency of 914MHz. As shown in Fig. 5(b) the two stubs namely: inductive and resistive stubs are responsible for the conjugate matching of the antenna to the reactive and resistive part of the IC respectively. The target Z_{IC} used in this design was Philips EPC 1.19 Gen 2 RFID ASIC IC which exhibits a stable impedance behavior of 16-j350 Ω over the frequency 902MHz→928MHz. Return Loss (RL) plot is shown in Fig. 6(a) with a bandwidth of 905MHz→925MHz defined by a value of RL<-10dB for optimum antenna efficiency and an excellent read range of the RFID tag. The RFID antenna was ink jet printed (Fig. 5(a)) with overall dimensions of: 8.2cm x 4.5cm. The radiation pattern of the antenna is quite similar to that of a classic dipole as shown in Fig. 6(b) which is desirable in most RFID applications. The inkjet printing on-paper approach is very repeatable, allows for features down to 20um and can be easily utilized for other passive functions, such as filters, baluns in single or multilayer (multi-sheet) configurations. Results from on-paper active RF modules including embedded batteries and IC's in addition to the antenna and stubs will be presented at the conference for universal (868-924 MHz) operation.

IV.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. The ultimate goal is to have an all inkjet-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.

V. 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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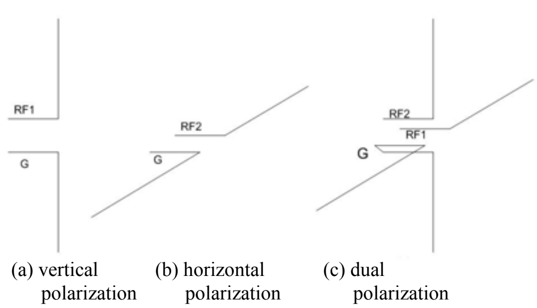


Figure 1. Polarization in RFID antennas.

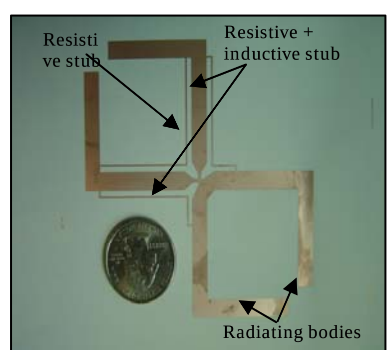


Figure 2. Dual polarization antenna.

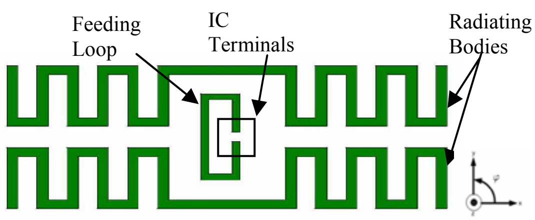


Figure 3. Dual Radiating body configuration

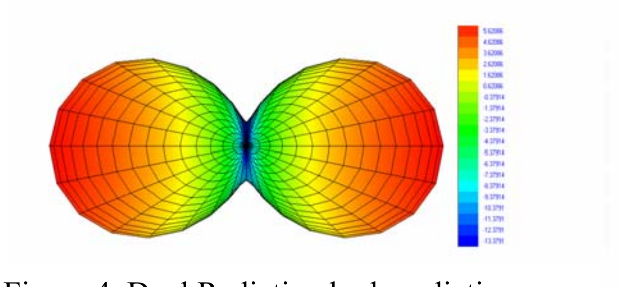
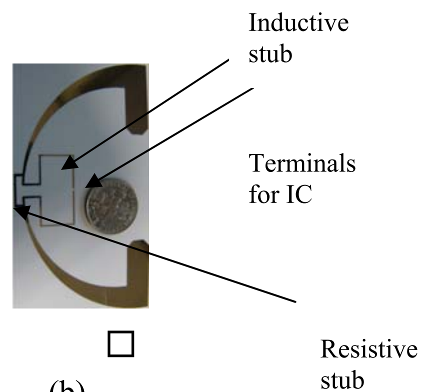


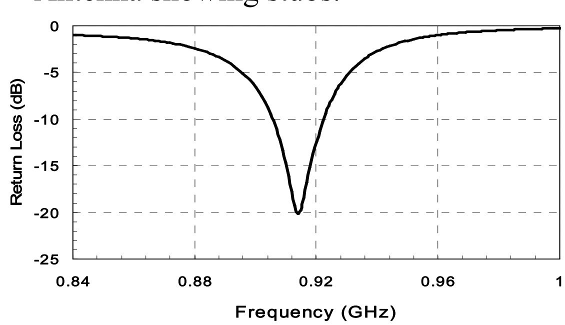
Figure 4. Dual Radiating body radiation pattern (theta=0°, directivity= 5.62 dBi)

(a)

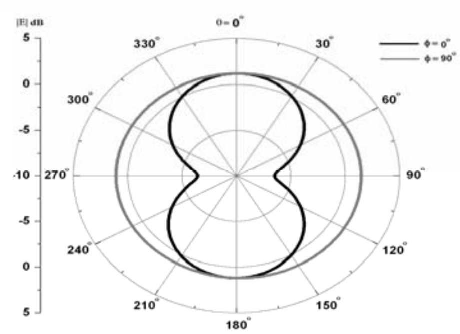


(b)

Figure 5. (a) Photograph of UHF RFID antenna inkjet printed on paper (b) RFID Antenna showing stubs.

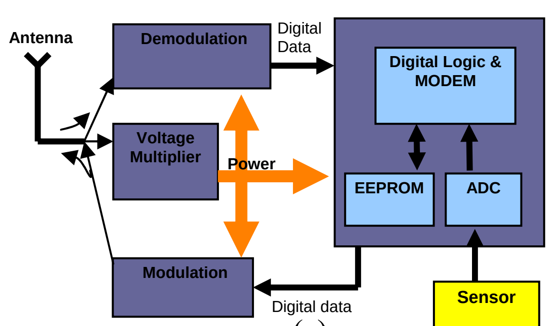


(a)

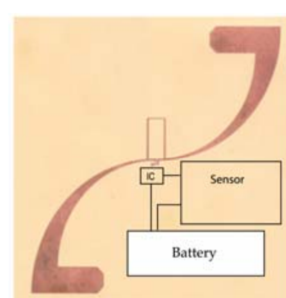


(b)

Figure 6. (a) Return Loss (b) Omni radiation pattern of RFID UHF Antenna.



(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.