Extending the Reading Region of the RFID UHF Gen2 System by HF/UHF Integration

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Abstract—**In this paper we present an architecture of the RFID UHF Gen2 tag which enables an increased reading range based on the integration of the HF harvester with the UHF Gen2 tag. HF harvester charges the circuitry of the UHF tag in a similar way as it works with a battery assisted scheme. In regard to a standard battery-assisted tag, the proposed solution is preferred since: i) the proposed tag, although performs like a battery equipped tag, is still a true passive system, ii) the problem of a limited life period of the battery is overcame, and iii) by simple charging control it is possible to synchronize reader to recognize true tag(s) position at a resolution defined by a dimension of the HF transmitter antenna(s). We present an experimental architecture of the integrated HF/UHF system and the measured results on the typical lab set up to show a benefit in the reading range of the RFID UHF Gen2 tag.**

I. Introduction

RFID technology, based on the wireless communication between readers and tags is the most important tool for objects identification and tracking. Its real-world implantation enables each item identification, thus providing the edge infrastructure of Internet of Things (IoT) concepts. Due to tags battery presence or absence, RFID technology can be divided into: passive, battery assisted passive (BAP) and active RFID technology [1]. In passive RFID, readers both communicate and power tags using same Radio Frequency (RF) waves transmitted by an reader antenna. Passive tags are able to harvest energy from the RF waves to power its circuitry, and respond back to the reader by the smart reflection of the same RF waves. Standards specify frequency usage, relied upon technology application. Both Low Frequency (LF) RFID at 125 and 134 kHz, and High Frequency (HF) RFID at 13.56 MHz are used for near field communication (depending on the size of its antennas, up to 50cm reading distance), while Ultra High Frequencies (UHF) RFID at 860-960 MHz is used for far field applications (up to 10 meters). In BAP RFID, battery is used only for tag circuitry powering. Since the battery is present, tags are optimized for income waves backscattering, rather on energy harvesting. The way how tags communicate with the reader is same as in the passive RFID. Provision of extra power for tags can extend its reading range up to 50 meters. Design study of BAP RFID in more details is well presented in [2]. In active RFID technology, tags are completely active, i.e. they are acting as classical transceivers. Reading range depends on frequency usage as well as the sensitivity of tags receiver, and power level of its transmitter.

The most interesting RFID technology in terms of best price-performance ratio is passive UHF Gen2 RFID [3], where tags price of 0.1 USD and reading range of up to 10 meters enables quick identification of all objects in the area. However, disadvantages in bad response rate in harsh environment, and unreliable communication at higher reading ranges put restrictions in a real-world implementation. In such scenarios tags cannot harvest enough energy to enable fully reliable reader-tag communication. The issue can be solved by using HF tags (due HF waves propagation through non-metal surfaces), but they can be read only in the vicinity of reader. Several paper address the design of a tag which is HF/UHF protocol compatible, like [4] and [5]. In the paper [6] authors present both HF and UHF compatible tag with added sensor functionality which is compliant with standard Gen2 technology. Another feasible solution is adding the battery to tags (BAP) and optimizing tag antenna for wave backscattering. Using BAP reader-tag communication would be more reliable, but in the other hand makes the tag more expensive. Moreover, battery limited lifetime may become an issue regarding the nature of different identification processes. To overcome such issues, work [7] proposes harvesting of GSM energy in order to provide additional power to passive tags. Authors showed which scenarios can be used for such applications. Authors in [8], present scheme to harvest additional power from proper scheduling in Gen2 protocol and use such energy for the amplification of backscattered signal.

However, none of the related works do not consider intentional power radiate on non-interfere frequencies to power low-power devices such as Gen2 tags. In this paper we present pure Gen2 tag, which is additionally powered using HF power harvester. Battery is replaced with energy harvester at HF (13.56 MHz), thus breaking the battery issue for all tags having harvester attached. Harvester has additional capacitor attached for storage of energy, thus making the system energy efficient. Lower frequencies were considered due to electromagnetic (EM) propagation through various barriers in the office environment. Such approach unites positive sides of both pure passive and BAP RFID technology, and allows: i) reliable tag-reader communication, ii) capacitor-charging at the harvester enables energy-efficient way for such application, iii) by simple ON/OFF control of HF transmitter antenna, along with its size one can retrieve tag position.

The reminder of the paper is organized as follows. In Section II we shortly overview the UHF RFID system and its basic performance. In Section III we desribe the proposed architecture of the HF power assisted UHF Gen2 system as well as details related to the HF system and its integration with the UHF passsive tag. Sections IV presents experimental setup and the measurements results. Finally, Section V provides some concluding remarks.

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II. UHF GEN2 RFID SYSTEM

Typical RFID system is consisted of RFID reader which through its antenna(s) communicates with tags which are in the area of interrogation. In Gen2 reader-tag communication (downlink), tags are using RF power to energize themselves, decode reader commands and prepare data transmission. Power that tags receive on its antenna can be approximately calculated with Free Space Loss (FSL) Friis equation [2]:

$$FSL = -20\log\left(\frac{\lambda}{4\pi d}\right) - (G_{TX} + G_{RX}) \qquad (1)$$

where $\lambda = c/f$ stands for wavelength, G_{TX} stands for transmit antenna gain (reader), G_{RX} is receive antenna gain (tag), while d is the distance between reader and tags. However, real scenarios and depiction of the exact power that tag receives is complex, due to signal multiple reception, channel noise, interference, etc.

In tag-reader communication (uplink), once energized, to transmit data tags are modulating income RF waves (*backscattering*). Reading range limiting factor in passive RFID is downlink, where energy level that tags can harvest from incoming RF waves is low for energy required for tag proper functioning. To overcome such issue, one can consider usage of BAP RFID, where tag circuitry is powered by an external power supply, i.e. battery. Comparison of BAP and passive RFID with uplink and downlink limitations is shown in Figure 1. More details can be found in [9].

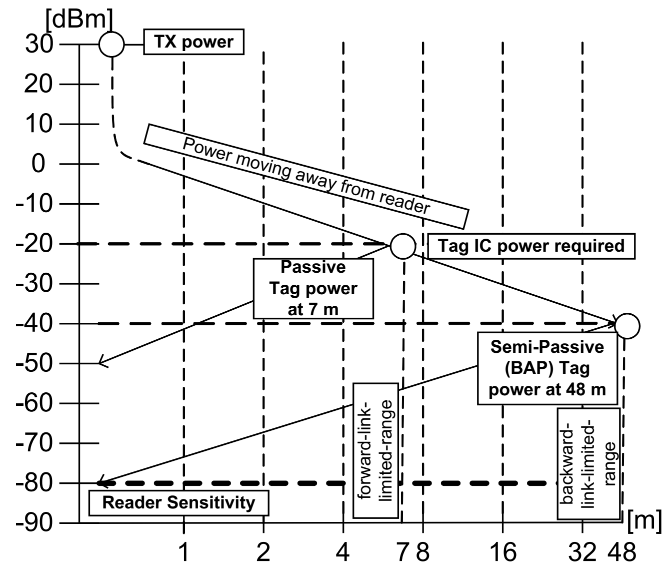

Fig. 1. Downlink and uplink limitations in UHF passive RFID.

III. HF POWER ASSISTED UHF GEN2 TAG

Figure 2. illustrates an inductively coupled near-field HF system which powers the UHF Gen 2 tag improving its readability and possible driving the circuitry of an additionally integrated sensors. The HF magnetic field is generated by the transmitting antenna connected to the RF source. The RF carrier frequency is settled to 13,56 MHz, which is the frequency band available worldwide as an ISM (Industrial, Scientific and Medical) frequency. Other advantages of using 13.56 MHz frequency include: an excellent immunity to environmental noise and electrical interference, minimal shielding effects from adjacent objects and the human body, water's damping effects are relatively small, field penetrates dense materials, freedom from environmental reflections that can plague UHF and microwave systems, cost effective antenna coil manufacturing, low RF power transmission so electromagnetic (EM) regulation compliance cause no problems, no user licenses for usage (ISM band) and possibility of using the systems in industrial and in hazardous environments with potential for explosive substances.

The transfer of HF energy is based on the vicinity of inductive coupling. In near-field inductive coupling, the transmitting antenna loop and the small receiving coil windings establish a loosely connected "space transformer" resulting in power transfer across relatively short distances that are comparable to the actual physical dimensions of the transmitting antenna loop. Such coupling is deemed to be predominately magnetic if the physical dimensions of the transmitting loop are small compared to the system's operating wavelength. Magnetic flux linkage and thus energy exchange occurs between the two resonant coil windings having the small but finite coefficient of coupling between them. The efficiency of power transfer between the transmitting and receiving antennas is proportional to the operating frequency, the number of coil turns, the area enclosed by the receiving small antenna, the angle of the two coils relative to each other, and the distance between the two coils.

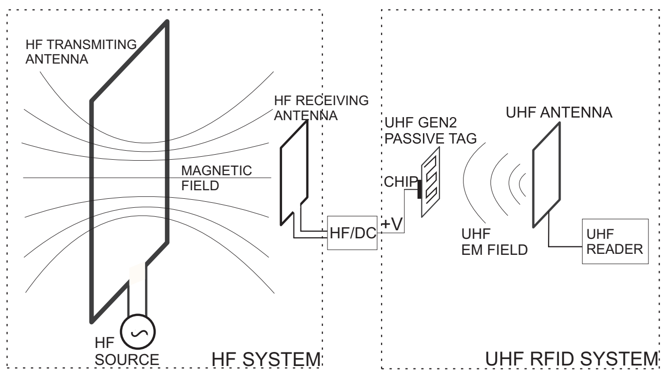

Fig. 2. HF power assisted RFID UHF system.

Maximum power transfer occurs when the two coupled coils are placed or aligned at the same plane. As the label is rotated with respect to the transmit coil, the coupling is reduced by the cosine of the angle of rotation. However, due to the inverse cube law, inductively coupled systems are relatively immune to antennas misorientation, so a significant aberration from optimum alignment will result in only a modest reduction in a transferred energy. As a resonant application, the receiving antenna can be vulnerable to environmental detuning effects that may cause a reduction in power transfer distance. The quality factor Q defines how well the resonating circuit absorbs power over its relatively narrow resonance band. In the power

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transfer applications, the Q value demanded is preferred to be relatively high. More detailed description of the design of the HF system and its integration with the UHF Gen2 passive tag is given in the following subsections.

A. HF System

The HF system is composed of the large transmitting loop antenna and the small receiving antenna (Figure 3). The transmitting loop antenna is connected to the function generator whose output is amplified to obtain 30 dBm (1W) RF power. Small receiving loop antenna charges UHF Gen2 Tag. The alternating magnetic field excited by the powered loop antenna induces a voltage in the inlay of the receiving antenna. The induced voltage can be increased by enlarging the dimensions of the receiving antenna collecting more magnetic flux, or by increasing of a number of turns in a spiral antenna design. The transmitting loop antenna with dimensions (1050 $\times$ 605) mm is, as suggested in [10], constructed from 50 mm wide copper tape. Corners of the antenna are soldered at $45°$ with minimum overlap of the tape to avoid parasitic capacitive coupling. The main loop is cut at the top centre to form 12 mm gap. Across the gap capacitance is added in order to tune a loop naturally resonant at $f_{res} = 13.56$ MHz. In resonance holds $f_{res} = 1/(2\pi\sqrt{LC})$, and with known inductance L, the capacitance follows from $C = 1/((2\pi f_{res})^2 L)$.

At this point calculated inductance of the transmitting loop antenna is 2.05 μH which for resonance requires capacitance of 63.5 pF [11]. A variable capacitor with range from 5.5 to 65 pF is used for fine tuning to resonance. Across the gap 10 kΩ, 1 W resistor is added to reduce the quality factor Q of the antenna. To achieve optimum performance 3.63m RG58 (1/4 wavelength) coax. cable is used to connect antenna to transmitter. To match the loop antenna to 50 Ω we used ”T” matching to main loop using 12 mm wide cooper tape. Coax. cable is split into screen and core and soldered to the matching arms. This type of matching is ’balanced’ as both screen and centre core of the coax cable are tapped. Small loop antenna of dimension (150 $\times$ 100) mm is designed using artwork for the board. Matching components are two 10 kΩ, 1 W resistors to reduce the quality factor Q to 27 and 120 pF, 180 pF and variable 2.5 pF to 7 pF capacitors for the resonant frequency adjustment. They are connected in parallel between core and antenna and between screen and antenna. Between screen and antenna are also added 22 pF and 10 pF capacitors to match antenna to 50 Ω.

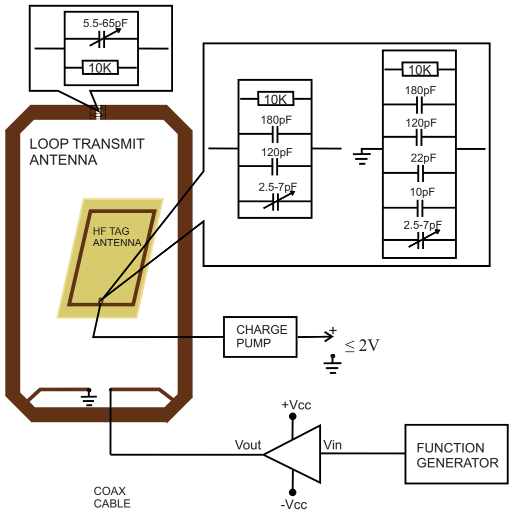

Fig. 3. HF system architecture.

IV. HF/UHF INTEGRATION

Figure 4 shows the HF/UHF system architecture. Integration of the HF receiving antenna and the UHF tag is realized by the HF harvester circuitry. HF harvester is developed to assist the powering of the UHF tag. To test the proposed approach, tag’s battery was replaced by the HF harvester. Harvester consists of receiving antenna, 3 stages Villard multiplier and output capacitor (for storage of harvested energy). Villard voltage multiplier uses BAT85 Schottky diodes and 2.2 nF capacitors (design is depicted in Figure 5). Schottky diodes are used because of their high speed and low forward voltage-drop. Output of the multiplier is connected to the BestCap AVX 10 mF supercapacitor (C7) for energy storage. A 3.3V Zener diode BZX85 (D7) is used for high voltage protection of the supercapacitor and RFID tag circuitry. Supercapacitor is an element, whose power-handling capacity is far better than normal batteries power-handling capacity. It is able to produce high peak currents and at the same time it can store large amounts of energy. Such energy can be used as a tag power supply in the cases HF system is off or is not present. Added capacitor actually increases the price of proposed system, however the system can work with cheaper capacitor of lesser capacity maintaining the system cheap.

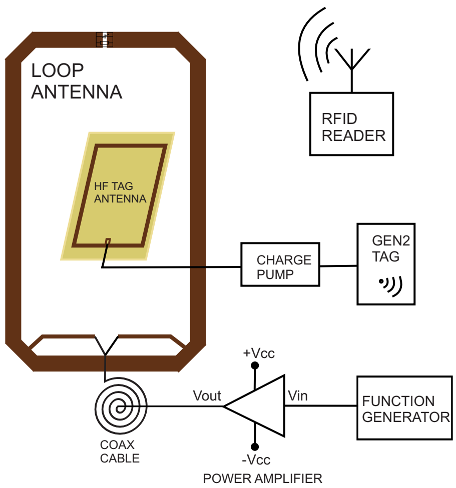

Fig. 4. HF/UHF system architecture

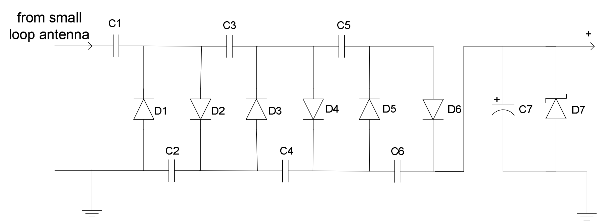

Fig. 5. Scheme of the charge pump (Villard voltage multiplier).

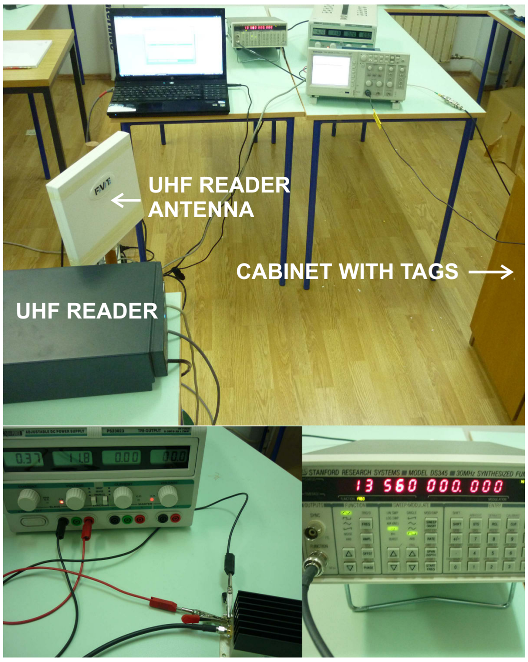

Fig. 6. Experimental Lab measurement setup

V. Experimental Lab Set-Up and Measurement

In order to demonstrate that the powered UHF tag assures better reading performance than passive tag we performed some measurements in a lab environment as shown in Figure 6. The transmitting HF loop antenna was fixed at the back side of the cabinet with shelves filled by 21 books (Figs. 7 and 8) each equipped by UHF tags: 18 pure passive Gen2 tags, two BAP tags and one powered by the HF harvester.

The RFID UHF system includes the Intermec IF5 reader with output power of up to 30 dBm, the UHF reader patch antenna with 6 dBi gain and passive Gen2 tags. Reader's antenna was located in front of the cabinet with possibility of in-line moving from 1m to 5m referenced to the back side of the cabinet (see Figure 8). The transmitting HF loop antenna was powered by 30 dBm RF signal via amplifier (MPA-10-40) connected to the function generator with output level of 0.14V at frequency 13.56 MHz.

We performed two measurements scenarios, where in the first one the HF source was set off, and in the second one the HF source was set on. Both scenarios have included the measurement at the UHF reader output power set to 23 dBm (200 mW) and 26 dBm (400 mW). Measurements included tags readings at distances beginning at 1 m away from the cabinet back and repeated at steps of 1 m away up to maximum distance of 5 m (see Figure 8).

The measured results are summarized in Figure 9. In the first scenario (HF source was set off) and UHF reader output set to 23 dBm, reader has read only about 20 % tags, at 2 m distance reader has read only about 15 % tags, and at distances 3 m, and 4 m, the percentage of tag reading was fixed to 10 %. Based on the registered IDs of the tags by the reader it is clear that two battery-assisted tags were read in the whole region up to 4 m, but only two passive tags among the others 19 IDs were read randomly at 1 m distance. In an another measurement

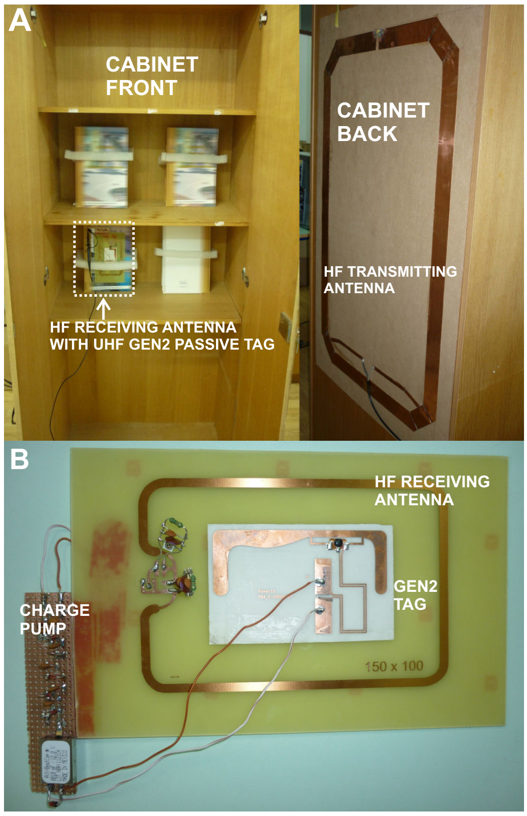

Fig. 7. Integrated HF/UHF circuitry.

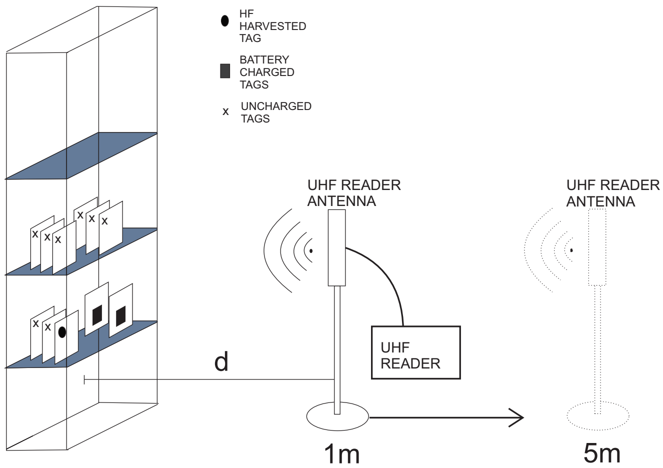

Fig. 8. Measurement setup.

when the UHF reader power was doubled (set to 26 dBm) in the same scenario with HF power off, a bit better reading was obtained, but again at the distance over 2 m only 10 % tags was read up to 4 m. We can conclude that the obtained results in the first measurement scenario verify that battery-assistance assures noticeable increasing of the reading distance for RFID UHF system. In the second scenario when HF power was on, and UHF reader output power was set to 23 dBm, reader has read only about 20 % tags up to 2 m distance, and only about 15 % tags at distance up to 4 m. Based on the registered IDs of the tags by the reader it is clear that two battery-assisted tags and the HF assisted tag were read in the whole region

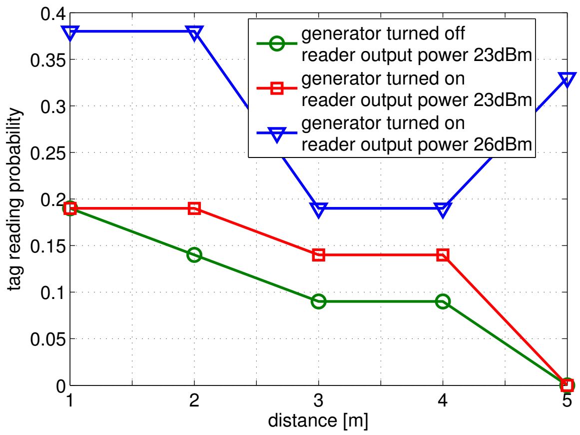

Fig. 9. Probability of tag readings at distances from 1m to 5 m for scenarios i) HF source is set off and ii) HF source is set on. It is important to notice that HF powered tag (once the HF source is on) is performing equivalently to BAP tag.

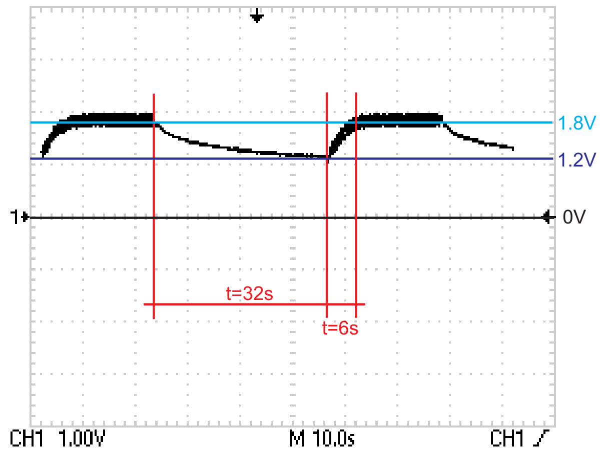

Fig. 10. Output voltage of the storage capacitor during charging/uncharging periods.

up to 4 m. When the UHF reader power was doubled (set to 26 dBm) in the same scenario with HF power on, noticeable better reading was obtained, but again at the distance over 2 m only 10 % tags was read. From the obtained results, it can be concluded that the second measurement scenario verifies HF-assistance in power harvesting which supplies the UHF tag with DC voltage. HF powered tag works equivalently as with the battery one assuring a noticeable increasing the reading distance for Gen2 RFID system.

It is also interesting to discuss dynamical features of the harvesting system depicted in the Figure 5. The used storage capacitor is quite large (10 mF) so that the charging time is relatively long. This charging time can be considered as a handicap of the system depending on applications, but on the other hand, in case of a harvesting it can be considered as an advantage because, owing to a large stored energy, harvester can power the UHF tag relatively long after the HF source was set off. To explore this effect we have powered the HF system in an intermittent on/off way in order to keep the capacitor output voltage between 1V and 1.8V which is required for driving the UHF tag like a battery. As shown in the Figure 10, the charging time amounts about 6s and the discharging time during off period amounts about 32s. This means that we need to spent only about 20 % of HF energy for functioning of the system with the same performance.

VI. Conclusion

In this work we have developed an integrated HF/UHF RFID system which improves performance of the UHF Gen2 system by increasing the tag reading range. The system integration is based on the HF harvester which powers the UHF Gen2 tag thus making that such truly passive tag works as an BAP tag. In regard to a standard BAP tag, the proposed solution is preferred since it overcomes the problem of a battery limited life period. We presented an experimental architecture of the integrated HF/UHF system and showed through measured results an expected benefit in the reading range, which is equivalent to that of the BAP tag.

Note that this paper presents only proof of concept in the design of HF powered Gen2 tag. The technology study on its detailed design is left for the future work.

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References

[1] D. D. Dobkin, *The RF in RFID*. Burlington, USA: Elsevier, 2008.

[2] W. Che, Y. Yang, C. Xu, N. Yan, X. Tan, Q. Li, H. Min, and J. Tan, “Analysis, Design and Implementation of Semi-Passive Gen2 Tag,” in *2009 IEEE International Conference on RFID*, Orlando, USA, April 2009, pp. 15–19.

[3] EPCglobalInc, “Class1 generation 2 uhf air interface protocol standard ”gen 2”, v1.2.0,” EPCglobal, Tech. Rep., October 2008.

[4] P. Iliev, P. Le Thuc, C. Luxey, and R. Staraj, “Dual-band hf-uhf rfid tag antenna,” *Electronics Letters*, vol. 45, no. 9, pp. 439–441, 23.

[5] L. Mayer and A. Scholtz, “A dual-band hf / uhf antenna for rfid tags,” in *Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th*, Sept., pp. 1–5.

[6] H. Reinisch, M. Wiessflecker, S. Gruber, H. Unterassinger, G. Hofer, M. Klamminger, W. Pribyl, and G. Holweg, “A multifrequency passive sensing tag with on-chip temperature sensor and off-chip sensor interface using epc hf and uhf rfid technology,” *Solid-State Circuits, IEEE Journal of*, vol. 46, no. 12, pp. 3075–3088, Dec.

[7] M. Russo, P. Solic, and M. Stella, “Probabilistic modeling of harvested gsm energy and its application in extending uhf rfid tags reading range,” *Journal of Electromagnetic Waves and Applications*, vol. 27, no. 4, pp. 473–484, 2013. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/09205071.2013.753659

[8] F. Iannello, O. Simeone, and U. Spagnolini, “Energy Management Policies for Passive RFID Sensors with RF-Energy Harvesting ,” in *IEEE International Conference on Communications (ICC 2010), 2010*, Cape Town, South African Republic, May 23-27 2010, pp. 1–6.

[9] P. Šolić, J. Radić, and N. Rožić, “Software defined radio based implementation of rfid tag in next generation mobiles,” *IEEE Transactions on Consumer Electronics*, vol. 58, no. 3, pp. 1051–1055, 2012.

[10] T. Instruments, “Hf antenna cookbook - technical application report,” Texas Instruments, Tech. Rep. 11-08-26-001, October 2004.

[11] Microchip, “microid 125 khz rfid system design guide,” Microchip Technology Inc., Tech. Rep. DS51115F, October 2004.

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