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Optimization of Energy Harvesting Systems for RFID Applications

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Abstract**—**To avoid battery assisted tags with limited lifetime batteries, it is proposed here to replace them by energy harvesting systems, able to feed from local environment. This would allow total independence to RFID systems, very interesting for applications where tag removal from its location is not possible. Example is here described for luggage safety in airports, and is easily extendable to similar situation in terms of operation constraints. The idea is to fix RFID tag with energy harvesting system not only to identify luggage but also to supply an embedded microcontroller with a sensor delivering luggage weight making it impossible to add or to remove anything from the luggage during transit phases. The aim is to optimize the harvested energy for such RFID applications, and to study in which limits these applications are theoretically possible. Proposed energy harvester is based on two energy sources: piezoelectricity and electromagnetic waves, so that when the luggage is moving on ground transportation to airline counters, the piezo module supplies the tag and its microcontroller, while the RF module operates during luggage transit thanks to readers located along the way. Tag location on the luggage is analyzed to get best vibrations, as well as harvester better choice for optimizing the energy supply depending on applications and the amount of energy harvested during a period of time. Effects of system parameters (RFID UHF frequencies, limit distance between the tag and the antenna necessary to harvest energy, produced voltage and voltage threshold) are discussed and working conditions for such system are delimited.

Keywords**—**EM waves, Energy Harvesting, Piezoelectric, RFID Tag.

I. Introduction

ONE of the main challenges of this century is to provide everyone with his needs in energy. Thus, the idea to create independent systems able to provide themselves the energy from local environment has been first spreading for applications needing small energy consumption [1]. Radio Frequency Identification systems (RFID tags) were initially simple passive tags, activated through EM waves sent by the reader and received by tag antenna [2]. The system can then answer back its name and some information to the reader. Next a sensor has been added to these tags to deliver information read by an embedded low consumption microcontroller. RFID tags became battery assisted, as they needed a battery to supply the microcontroller and the tag. Nowadays, the main goal is to replace batteries by energy harvesting technologies [3] so that tags become battery-free systems [4]. An energy harvester is able to harvest energy from its environment (e.g. EM waves [5], vibrations [6], piezoelectricity [7], kinetic [8], solar exposure and so on). To meet this demand, it is proposed to optimize energy harvesting systems for RFID applications and to study the limits of these systems depending on applications. Here the analysis concentrates on systems for increasing luggage safety in airports by constant tracking all along the chain from passenger deposit to the counter to collection at destination. Passive tags are already used in some airports for luggage registration. The innovation is to use energy harvesting technology based on two modules: piezoelectric and EM waves harvesters to power a microcontroller and a strength sensor delivering luggage weight. Aside evident safety aspects, such RFID system would also prevent thirty million trunks and suitcases from misguidance and delay every year, as reliability of RFID tag identification is about 99% compared to 85% for current optical reading. Other consequence is immediate identification of luggage parameters easing passenger comfort with this environmental friendly approach.

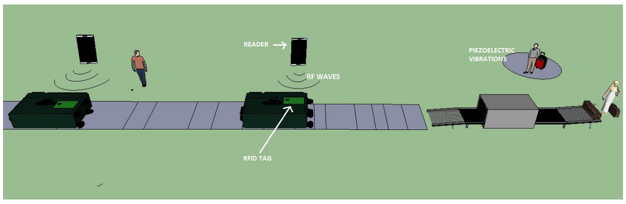

Fig. 1 Luggage Transit in Collector System with Tag Action

II. Equipment

To determine the characteristics for airport application in terms of vibrations and frequency, different systems have been used. First, largest vibration amplitude location is determined by MyVibrometer iPhone application, which gives accelerations along the three directions. Secondly, to calculate luggage resonance frequency, key data for properly simulating piezoelectric system on LT-Spice are obtained from Slam Stick device. Slam Stick is a high-speed ultra portable rechargeable data logger measuring acceleration in the three dimensions (x, y and z).

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Fig. 2 Enocean Slam Stick

The Slam Stick uses a USB Port for configuring, charging and downloading data. Simple configuration software allows tailoring the device to specific needs. Configuration options include adjustable delay time before each measurement, different measurement durations, and a trigger based on a pre-determined acceleration level. Free analysis software allows having a complete vibration characterization and access to the frequency content of this given vibration.

Fig. 3 MyVibrometer Application on the luggage

Fig. 4 Slam Stick USB Key on the Luggage

LTSpice IV software is used here to simulate chosen harvester, namely the LTC 3588-2 and the LTC 3588-1 cards [9] for piezoelectric analysis, and later the LTC 3330 card for both piezoelectric and RF analysis. This directly downloadable Linear Technology software allows simulating and evaluating the harvested average voltage. Other possible harvesters can be analyzed as well from their site. The results for output power delivered by the antenna and harvested voltage for various distances and UHF frequencies in accessible range [860-960 MHz] have been gathered in Excel table, allowing at a glance to evaluate the effects of selected frequency on maximal range for harvesting energy and frequency effects on the flow of information sent to a reader.

III. Model

Proposed energy-harvesting system thus combines piezo and RF sources. The aim of the study is to define the domain within which an application can work with this double source system.

A. Piezo Harvester

To simulate piezo harvester behavior (the Linear Technology device for piezo/DC conversion LTC-3588-2), most efficient frequency of luggage vibrations and best sensor location are first determined by testing various IPhone positions on the luggage when launching MyVibrometer application. Best position found is up front on the luggage see Fig. 4, and resonance frequency is determined with Slam Stick. After recording fluctuations for 30 seconds moving around to simulate real luggage rolling, amplitude vs frequency is obtained by reading Slam Stick on a PC, see Fig. 5. It is mainly observed that vibrations are mostly concentrated along Z axis (the only one visible on Fig. 5). Depending on rolling surface nature, vibrations may be different, but overall curve after several experiments looks the same in general and leads to resonance frequency range [100-110 Hz], which has been taken to delimitate the analysis, see insert in Fig. 5.

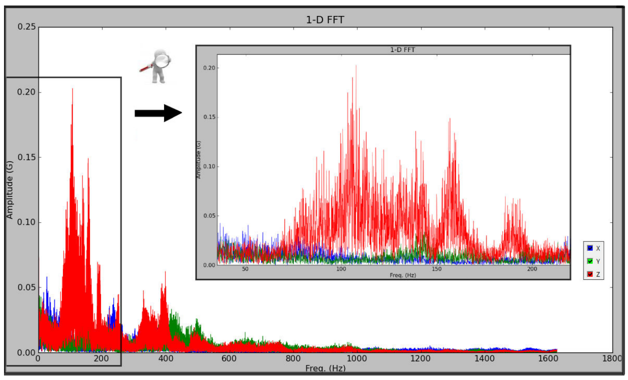

Fig. 5 Amplitude vs Frequency on Slam Stick Viewer Software

B. RF Harvester

The second part concerns the RF module. Most European RFID applications are located in Ultra High Frequencies range [860-960 MHz]. Focusing on this range for the RF module, one needs to find the available power, which can be harvested with half-wave antenna. To process to energy harvesting on RFID tag located on the luggage, the range of the signal emitted by such antenna is calculated, and conditions for EM wave propagation to the luggage are discussed, see Fig. 5. It is seen that the higher is signal RF frequency, the smaller is its range. In the frequency choice adapted to present application, and to reduce antenna number, better choice corresponds to lower limit frequency close to 860 MHz For all UHF frequencies in selected range, harvested voltage has been calculated for distances between 0 and 5.5 meters representing maximum signal detectable range at 860 MHz see Fig. 7.

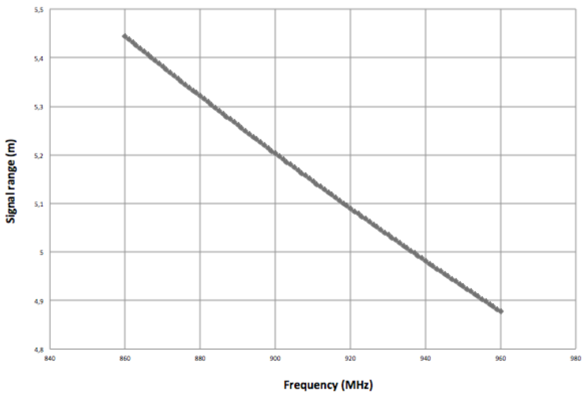

Fig. 6 Signal vs Frequency

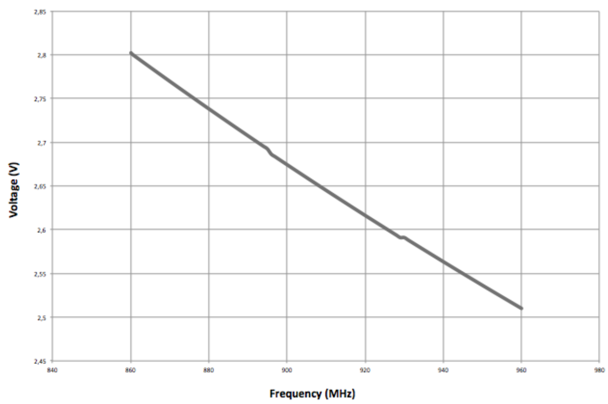

Fig. 7 Harvested Voltage vs RF Frequency

IV. Results and Performance Evaluation

A. Piezo Harvester

Calculations are performed for LTC 3588-1 and LTC 3588-2 cards, with resonance frequency in [100-110 Hz] corresponding to luggage resonance frequency, and for duration time of 30 seconds estimated for luggage rolling as for experience with Slam Stick in Part III. *A*. Results are displayed on Fig. 8 below.

Comparison between LTC3588-1 and LTC3588-2 over 30s period				
Energy harvester	LTC3588-1		LTC3588-2	
Frequency (Hz)	100	110	100	110
Time before harvesting energy (s)	0.13	0.13	0.33	0.33
Time before harvesting over 1.8V (s)	0.42	0.42	0.4	0.4
Maximum voltage harvested (V)	1.83	1.85	3.52	3.51
Harvesting time over 1.8V (s)	31.9	31.9	30.7	30.7
Total harvesting time (s)	39.4	39.3	37.4	37.3
Average of the voltage harvested (V)	1.55	1.56	2.95	2.96

Fig. 8 LTC3588-2 Piezo Harvester with Resonance Frequency 105Hz on 30s Time Period

As today low consumption micro-controllers can work under 1.8V, this voltage will be taken as the reference value to determine the time over which higher voltage can be harvested. Knowing this time allows knowing for how long embedded microcontroller can work to communicate luggage information. On Fig. 8, it is clearly seen that frequency difference effect between 100 and 110 Hz is negligible. So the question only reduces to compare pros and cons for the two LTC piezo harvester generations. From Fig. 8, LTC 3588-1 card allows harvesting over 1.8V during 1.2s more than LTC 3588-2 one. But for average voltage, LTC 3588-1 card is under required 1.8V. On the other hand, LTC 3588-2 card, due to maximum 3.52V harvested voltage, develops average 2.96V harvested voltage during 37.6s. This means that it is still possible to harvest energy during 7.6s while the luggage has stopped to move.

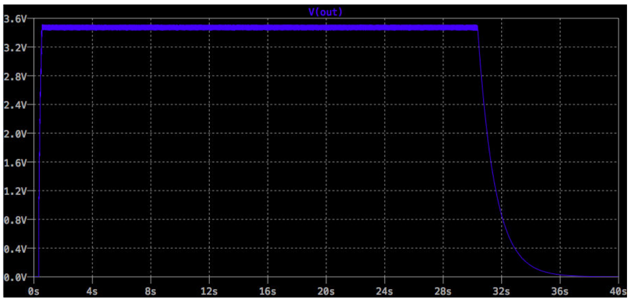

Fig. 9 Emitted piezo vibration at 105Hz vs Time

Considering XLP microcontrollers family with 5 MIPS (Million Instruction Per Second) CPU speed, and knowing 2.96V average voltage is available for 37.6 s, it can be concluded that LTC 3588-2 card is largely able to provide the embedded microcontroller with the energy and the time interval it needs to decode information received from the sensor and to send it back to the readers. Indeed, for considered RFID application, this time interval of 37.6s is already large enough to allow the reader to communicate with the tag fixed on the luggage (between 10 and 20ms for reset, answer to request, read and write the data) and to make the microcontroller work at the same time (a few seconds depending on applications). Consequently, the LTC 3588-2 card is better adapted to make an embedded low consumption microcontroller and its sensor for considered application.

B. RF Harvester

As seen from Fig. 6, 2.5 and 2.8 V can be harvested for application to a luggage on a conveyor belt submitted to RF wave from a half-wave antenna on one side. The voltage can even be doubled if the antenna feeds the tag from both sides. Putting many antennae (approximately every 10 meters depending on used frequency) along the conveyor belt, energy can be harvested without interruption all along the way and feed the microcontroller during the whole time. Besides, the XLP microcontroller family works down to 1.8V with active current down to 30µA/MHz In present case, it means a power of 46mW is required to make chosen embedded microcontroller work under 860 MHz and up to 52 mW under 960 MHz According to available data, the half wave antenna emits a power up to 500mW, 10 times higher than needed, which also contributes to ascertain that proposed system is theoretically viable.

V. Conclusion

Thanks to improvements in terms of low consumption microcontroller, RFID applications powered by energy harvesting systems have a real future, as a large already available technical parametric range has been seen to be adequate for applications. Piezoelectric harvesting systems are allowing harvest sufficient energy for supplying systems with adapted needs. Even if harvested energy is quite low, it is still admissible for many applications. UHF frequencies, in the range of which RFID applications are mostly used in Europe, affect significantly the utilization domain of application. On general grounds the problem of energy self-containment, discussed here on the example of luggage tag identification, deals with two antagonistic effects: for communication flux, the higher is the working frequency, the better is the microcontroller bits flow rate but, for power flux, the closer the antennae have to be located, which implies less harvested energy and higher cost. Corresponding trade-off fixes the limits of RFID applications, and determines how they should be optimized to make any application to work. However, today technological advance provides a large range of components satisfying actual constraints of interesting applications. In particular, extension to networked harvesting systems [10] will be discussed elsewhere.

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