EFFECTS OF TEMPERATURE AND HUMIDITY ON UHF RFID PERFORMANCE

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ABSTRACT

Radio Frequency IDentification (RFID) technology is contributing to increased manufacturing efficiency, improved supply chain operations, and enhanced logistics. The characteristic associated with RFID technology is currently being exploited by several industries for sensing applications as an alternative to current power inefficient wireless approaches in both fields of structural health monitoring and environmental monitoring. Many environmental challenges continue to persist impeding substantial growth and accelerated implementation of the technology in these fields. This work presents an investigation of the performance of a passive Ultra-High-Frequency (UHF) RFID based system under changing environmental conditions to facilitate increased technology exploitation. The investigation addresses the impact of temperature and humidity variations on the system response (e.g. changes in resonant frequency). Experimental results demonstrate a linear relationship between passive UHF RFID tags’ resonant frequency and temperature at relative humidity (RH) of 50\% and 80\%. No significant change in the resonant frequency was observed as result of humidity variation at temperature ranging from 20\textdegree C to 80\textdegree C. Results suggest that the frequency and return loss are independent of each other and are good indicators for temperature and humidity monitoring.

Keywords: RFID, radio frequency, UHF, humidity, temperature, sensing
INTRODUCTION

Radio Frequency technology has served as an identification technology for more than 50 years. After the development of Ultra-High-Frequency (UHF) radio frequency identification (RFID) technology by IBM in 1990’s, and after the RFID system was adopted by many large companies and organizations in early 2000’s, the RFID technology has attracted much attention from several sectors of the industry. RFID tags can be made in different sizes and shapes and can be adhered or secured to several items with different degree of complexity. Over the years, the cost of each tag has been reduced to about 10-15 cents per tag, for large quantities of labeling tags [1]. The technology further offers indirect and no line-of-sight detection of tagged articles with simultaneous multiple tags detection, hence reducing check-in and check-out time in stores, airports, hospitals and improving asset management efficiency. After the adoption of this technology by several big early adapters, such as United State Department of Defence (DoD) and Wal-mart [2], the technology is now widely used in asset tracking and management among other applications.

The simplicity and low cost associated with the implementation of RFID technology extends its potential to other areas, including passive wireless sensing and wireless power transmission. Near field wireless power transmission has been realized and utilized to charge cellular phone batteries [3]. The application of RFID technology has also been extended into new areas beyond the supply chain, from tracking the movement of goods to monitoring their health state while in transit [4-7]. With selective coatings, High-Frequency (HF) RFID tags can be used to detect a variety of contaminates in the environment through the monitoring of changes in the tags’ resonant frequency [8] or its capacitance [9]. On the other hand, UHF passive tags are still considered as transponders for other sensors for the purpose of wireless communication [10].

This work’s focus is to assess the potential use of UHF passive RFID tags for humidity and temperature sensing. Our previous work [11-12] showed that position, distance, orientation and power variation has affects on the tag’s readability and detectability.

EXPERIMENT

Experimental Setup

One thin (paper like) 915 MHz UHF tag (98.2 x 12.3 mm) and one 840~960 MHz flat antenna (220 x 220 x 30 mm) were used [6] (Fig. 1) in this experimental assessment. An ESPEC (ESX-3CA) environmental chamber was used for humidity and temperature control, and an Anristu network analyzer (VNA-MS2026C) was used for data collection and analysis (Fig. 1(a)). Inside the environmental chamber (Fig. 1(b)), the antenna was placed at a fixed 10 cm away from the tag. The antenna was connected to the network analyzer which was placed outside the environmental chamber. The environmental chamber’s operating conditions are shown in Fig.2.
Experimental Measurements

In this performance assessment work the tag-antenna system was subjected to a varying temperature and humidity environment. In the temperature variation experiment, the relative humidity (RH) was fixed, independently, at 50% and 80%, while the temperature increased from 20°C to 80°C at increments of 10°C. Similarly, at the same humidity levels, the temperature was ramped down at the same increments of 10°C from 80°C to 20°C. To assess the repeatability of the results the tests were repeated twice. In the humidity variation experiment, the temperature was fixed, independently, at 50°C and 80°C, while the RH varied from 20% to 80% and from 80% to 20% at increments of 10%. Similar to the temperature experiments, and to assess the repeatability of the results the tests were repeated twice.

In both humidity and temperature tests, the environmental chamber was considered as an enclosure having metal sidewalls. The adverse effects of metal on radio frequency propagation are well known and are presented in the open literature [13-14]. To discern the metal effect and to project a more realistic environment, additional data was taken with the environmental chamber door open, at the above presented conditions. The door was...
kept open for few seconds at each test point. For example, after taking data at 50°C and 50% RH, the door of the chamber was opened, for few seconds, to allow for signal propagation and data collection for the particular condition. This process reduces the interaction of the conductive enclosure on the RF signal propagation.

RESULTS AND DISCUSSION

In this investigation, analysis has mainly focused on the passive UHF RFID tags’ resonant frequency variation as a result of environmental changes. Selected tag’s frequency characteristics (Fig. 3) were monitored. These characteristics include resonant frequency, imaginary impedance valley and peak frequency and real impedance peak frequency. The resonant frequency is denoted by $f_o$ (Fig. 3(a)), the valley and peak frequencies of the imaginary impedance are denoted by $F_1$ valley and $F_1$ peak (Fig. 3(b)); whereas, the peak frequency of the real impedance measurement is denoted by $F_2$ peak.

![Fig. 3](image-url)

Fig. 3: Frequency measurements; (a) tag’s resonant frequency; (b) valley and peak frequency of the imaginary impedance measurement; (c) peak frequency of the real impedance measurement.

Temperature Variation Effects

In varying the temperature while holding the RH constant, a change in the resonant frequency of the RFID tag was observed, as shown in Fig. 4. In both cases where the environmental chamber door was open and closed, and at 80% RH, a linear relationship was obtained between the resonant frequency and the temperature.

In the experimental setup where the door of the environmental chamber was closed, and at 80% RH, the frequency decreased from 912.727 MHz to 909.425 MHz with a rate (slope of the trend line) of 55.05 kHz/°C while the temperature increased from 20°C to 80°C (Fig. 4(a)); when the door was open, the decrease of frequency was more pronounced and varied from 912.927 MHz to 907.524 MHz with a rate of 90.05 kHz/°C (Fig. 4(b)). The rate of frequency decrease is higher when the chamber door was open. This is a result of the effect of the metal enclosure on the UHF response. Although the heat transfer from the chamber to its outside, when the door was opened, might have certain effect on the frequency shift, the heat loss would result in lower temperature indicative of lesser resonant frequency shift. Additionally, the rate of decrease between the temperature ramp up and down for both closed and open chamber door, is found to be
57.1 kHz/°C and 82.8 kHz/°C respectively. This difference between temperature ramp up and down is believed to be due humidity variation. This difference is practically insignificant in the open door case. It is noted that the rates of increase or decrease are obtained as an averages between the ramp up and ramp down.

At 50% RH, similar frequency decreases were also observed (Fig. 4(c)). A rate of decrease of 25.5 kHz/°C for closed chamber door and of 25.8 kHz/°C for open chamber door, were obtained, respectively. Similar to the 80% RH case, the higher rate of decrease is associated with the open door configuration, indicating the similar effects of the metallic enclosure on the RF signal propagation. Additionally, at this lower level of humidity, the rate of change was slower than at higher humidity levels. Such higher frequency variation at higher humidity level is also observed in the humidity experiment (next section). This change can be attributed to the change of antenna properties, including both resistance and capacitance. Larger variation on temperature may result higher change on the antenna resistance and capacitance, which could alter the resonant frequency further away from its nominal value.

Fig. 4: The resonant frequency shift as a result of temperature variation; (a) chamber door closed (at 80% RH); (b) chamber door open (at 80% RH); (c) comparison between 50% RH and 80% RH.
Humidity Variation Effects

In varying the humidity while holding the temperature constant, a change in the resonant frequency of the RFID tag was observed, as shown in Fig. 5. In both cases where the environmental chamber door was open and closed, and at 80°C, a linear relationship was obtained between the resonant frequency and relative humidity. In this experiment, both the humidity ramp up and down are provided at 80°C but only the ramp up was recorded at 50°C, unlike the case of temperature variation where both temperature ramp up and down were provided for both cases in Fig. 4.

![Fig. 5: Resonant frequency shift due to humidity variation; (a) comparison between two cases (open and close) at 80°C; (b) comparison between 50°C and 80°C.](image)

In the experimental setup where the door of the environmental chamber was closed, and at 80°C, the frequency increased from 906.529MHz to 908.279MHz, for variations in humidity from 20% RH to 80%RH at intervals of 10% RH (Fig. 5(a)), with a variation rate of 12.1 kHz/RH. Whereas, in the case of open chamber door, the variation of frequency was increased from 907.126MHz to 908.627MHz (Fig. 5(a)) with a variation rate of 0.08 kHz/RH. The rate of frequency increase is higher when the chamber door was closed. This is a result of the effect of the metal enclosure on the UHF response as well as heat transfer. This difference is practically insignificant in the open door case believed to be due to reflection and deflection of water vapor at higher relative humidity level beside the metal effect caused by the chamber itself. The added reflection and deflection generally introduces phase shift to the original signal, and such phase shift can be both positive and negative, which could cause the resonant frequency shift either way. As a result, more frequency variation was observed when the chamber was closed. The gap between the two trend lines may be explained by heat transfer loss, identified earlier. The higher the humidity level, the more humidity and frequency loss would be expected when the door is open. Given the fact, the trend lines R² values are low for both closed and open door cases, 0.106 and 0.00001 respectively, these trend lines are not conclusive.

At 50°C, similar frequency behavior was also observed (Fig. 5(b)). A rate of increase of 12.2 kHz/°C for closed chamber door and a rate of decrease of 9.7 kHz/°C for open chamber door, were obtained, respectively. Similar to the 80°C, the similar rate of increase is associated with the open door configuration, indicating the similar effects of
the metallic enclosure and humidity impact on the RF signal propagation and showing the
repeatability of the experiment. Additionally, the constant displacement of approximately
0.88 MHz also confirmed the frequency shift due to temperature variation (previous
section). Although based on Fig. 4(a), the expectation of the displacement would be about
1.5 MHz, such difference could be caused by humidity variation, which is 2.75MHz. It is
observed that, at both 50°C and 80°C, the change in frequency shift between the closed
and open door configurations, increased as the humidity increased. This increase took
place at similar rates but opposite direction. If the average of the frequency shift for both
open and closed configurations, for both 50°C and 80°C, is obtained, no change of the
frequency shift would be observed with increase in humidity.

![Graphs](image.png)

**Fig. 6:** The peak and valley frequency shift as a result of temperature variation; (a) close
case at 80% RH; (b) open case at 80% RH; (c) close case at 50% RH; (d) open case at
50% RH

In addition to the use of the UHF RFID resonant frequency, for the assessment of the
impact of temperature and humidity variations on the tags response, characteristics such
as impedance valley and peak frequency were also used. Fig. 6 and Fig. 7 present the
valley frequency (F1 valley), peak frequency (F1 peak) of imaginary impedance and peak
frequency (F2 peak) for real impedance at different temperature and humidity variations, respectively. These experimental conditions, for obtaining the variations in frequency, are identical to those employed in the above two sections.

Fig. 6 illustrates distinctly the rate of increase of F1 valley, F1 peak and F2 peak frequencies as function of temperature increase in both, open and close door configurations and for both high and low humidity, 80% RH and 50% RH, respectively. It is observed that the rate of increase, with temperature increase was lower for open door configuration for both cases of RH. However, as seen in Fig 4.c, a higher rate of decrease was observed for the open door configuration. At this stage of the research, it is not clear why as the temperature increased the resonant frequency shifts decreased, while the F1 valley, F1 peak and F2 peak frequencies increased. The difference between the frequencies at 80% RH and 50% RH was not as pronounced in Fig 6 as was in Fig 4.c. Additionally, Fig. 7 illustrates an insignificant change in F1 valley, F1 peak and F2 peak frequencies as the relative humidity increased from 20% to 80% for both open and closed door configuration and for both 80°C and 50°C. If the average of open and closed door
configurations is taken in the case of Fig. 5, similar conclusions can be drawn about the insignificance change in the resonant frequency shifts.

**CONCLUSION**

An investigation on the impact of temperature and humidity variations on a passive UHF RFID system response was conducted. UHF RFID characteristics such as resonant frequency and impedance frequency were used to assess such impact at different temperatures (20°C to 80°C) and relative humidity (20% to 80%) in closed and open environments.

Experimental results demonstrate a linear relationship between passive UHF RFID tags’ frequency (resonant and impedance) and temperature at different levels of humidity. Additionally, as the relative humidity increased, at different levels of temperature, an insignificant change in frequency (resonant and impedance) is observed, indicating the lack of influence of humidity on the tag’s response. The linear relationship between frequency and temperature could be used as a temperature indicator.

Further investigations will focus on understanding the mechanism behind the decrease of resonant frequency and the increase of impedance frequency as a function of temperature.

**REFERENCE**


