Short Time Fourier Transform (STFT) for Collision Detection in Chipless RFID Systems

Rubayet-E-Azim
Department of Electrical and Computer System Engineering, Monash University Bldg 72, Clayton Campus, Melbourne, VIC 3800, Australia.
rubayet.azim@monash.edu

Nemai Karmakar
Department of Electrical and Computer System Engineering, Monash University Bldg 72, Clayton Campus, Melbourne, VIC 3800, Australia.
nemai.karmakar@monash.edu

Emran Amin
Department of Electrical and Computer System Engineering, Monash University Bldg 72, Clayton Campus, Melbourne, VIC 3800, Australia.
emran.amin@monash.edu

***Abstract*—This method proposes a novel collision detection methodology in chipless RFID system. The tags are interrogated by a impulse radio ultra wideband signal (IR-UWB). The collided backscattered signal received from the interrogation zone is analyzed in time-frequency plane through Short Time Fourier Transform (STFT). From the time-frequency representation, multiple tag IDs can be easily decoded. The simulation results prove the potentiality of the method as an efficient collision detection technique for chipless RFID systems.**

Keywords*—*chipless RFID, collision, IR-UWB, STFT, time-frequency.

I. INTRODUCTION

Radio Frequency Identification (RFID) is a wireless data communication technology that uses Radio Frequency (RF) wave for communication between a reader and a tag. A conventional chip-based RFID system consists mainly of two items: tag with application specific integrated circuit (ASIC) and a reader. Chipless RFID is the low-cost alternative of conventional RFID tags that offers the benefits of RFID systems but with a lower implementation cost. As the main cost comes from the ASIC of RFID tags, this chip has been removed and different electromagnetic properties (frequency response, phase variation, polarization, etc.) are modified to give unique IDs to the chipless tags [1-4]. Being a chipless tag, it doesn't have any on-board mechanism for advanced processing of signals for collision detection and multiple tag identification [5, 6]. Therefore the burden of multiple tag identification lies on the reader part. The reader's post processing unit is modified to perform necessary signal processing algorithms for collision detection and multi-tag identification. This paper proposes a time-frequency analysis based on Short Time Fourier Transform for recovering tag IDs in case of collision. The method has been verified through extensive simulation in CST microwave Studio Suite 2013 and MATLAB. The result proves that STFT can be prominent method to be implemented in chipless RFID reader system for collision detection and tag identification.

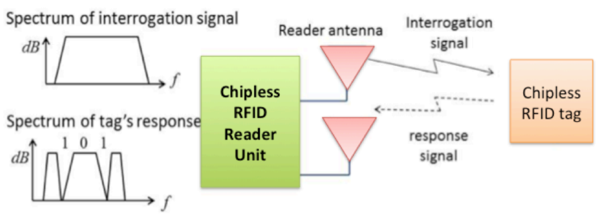


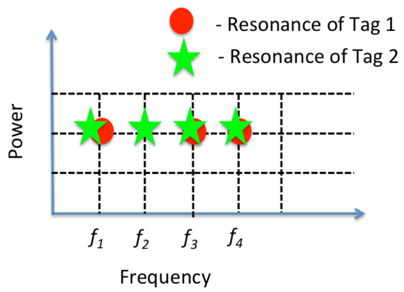
Fig. 1. Operating principle of chipless RFID

II. FREQUENCY-DOMAIN CHIPLESS RFID

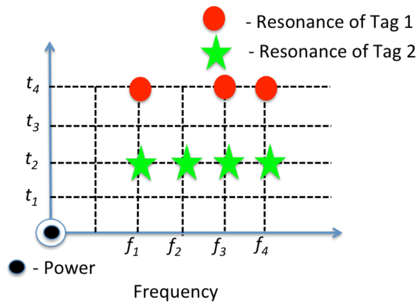
The basic operating method of frequency domain chipless RFD systems is shown in Fig. 1. The reader sends a wideband signal. The signal is backscattered by the tag in which the tag ID is embedded within the resonances at predefined frequencies. However, the interrogation signal can be of two types: (i) frequency modulated continuous wave (FMCW) signal and (ii) ultra wideband impulse signal [7-9]. In our previous work [5, 6], we have discussed two methods of collision detection. But both of the methods are based on FMCW interrogation method where a continuous signal of varying frequency (chirp signal) is send via the reader antenna over a period of time. The impulse method, on the other hand, sends a short duration pulse and therefore the reading is much faster than the continuous wave method. In this paper we are presenting the collision detection using STFT using pulse-based interrogation method.

III. BACKGROUND THEORY

Time-frequency analysis is a well-known signal processing method in RADAR system. In chipless RFID, tags have their IDs embedded in their resonances. Conventionally the backscattered time-domain signal is converted into frequency domain to analyze the spectrum for resonances. However if more than one tag respond simultaneously, from frequency domain it is almost impossible to identify any information regarding collision and tag IDs. If the tags are separated in time by their responses, time-frequency analysis can be an excellent tool to analyze the backscattered signal for collision and identification. Here we have implemented STFT for collision and tag identification.



(a)



(b)

Fig. 2. (a) Response of two tags in frequency domain and (b) Response of two tags in time-frequency domain

A. Short Time Fourier Transform

STFT is the advanced version of Fourier Transform (FT) that includes both the frequency and time information [10]. It is normally used to analyze signals in which frequency contents vary over time. The time signal data is broken into several overlapping frames using time domain windows and Fourier transform is applied in each of the frames. Thus it preserves both the time and instantaneous frequency information. It is represented as:

$$STFT\{x[n]\}(m,\omega) = \sum_{-\infty}^{\infty} x[n]w[n-m]e^{-j\omega n} \qquad (1.1)$$

Here signal $x[n]$ is windowed using $w[n]$ and Fourier transform is applied in each of the windowed frames.

If two chipless tags in the interrogation zone are separated by a distance and hence their responses are having a time delay, the time-frequency analysis can facilitates to find the individual tag resonances for decoding the tag IDs even if they are colliding. Fig. 2 (a) shows resonances of two chipless tags. As they are having resonances at the same frequency, their resonances overlap each other and make it difficult for the reader to detect collision and tag identification. In Fig. 2 (b), the resonances are shown in time-frequency plane. As the resonances at same frequencies occurring at different time instances, they can be distinguished and hence reader can detect collision as well as collided tag IDs. Therefore, time-frequency analysis facilitates the reader to a great extent in reliable tag reading, collision detection and identification.

B. Compromise between time and frequency resolution

There is a compromise between time and frequency resolution in time-frequency analysis using STFT. A wide window gives good frequency resolution but poor time resolution. A narrow window gives good time resolution but poor frequency resolution. We have to determine an optimum between the two where we can have an acceptable resolution for both time and frequency. This will be further explained in the results section.

IV. Simulation

A simulation environment is created in CST Microwave Studio Suite 2013 with two chipless tags and three transceivers in a circular interrogation zone as shown in Fig. 3. Two Chipless tags have been placed in the interrogation zone. For the ease of analysis, one tag is kept fixed at the center position whereas the other one is moved at several places at a distance of 5 cm to 20 cm from the centered fixed tag. Tag 1 is a 3-bit tag having resonances around 6.5, 8 and 9 GHz. Tag 2 is a 4-bit tag having resonances around 6.5, 7, 8 and 9 GHz. The backscattered signal is received by each set of receivers. Here the purpose of using three transceivers is, the relative distance between tags and receivers varies based on their relative position. The backscattered signal from the interrogation zone received by the receivers are analyzed and the one having higher SNR is used to perform the post processing for collision detection and identification. The post processing is done in MATLAB.

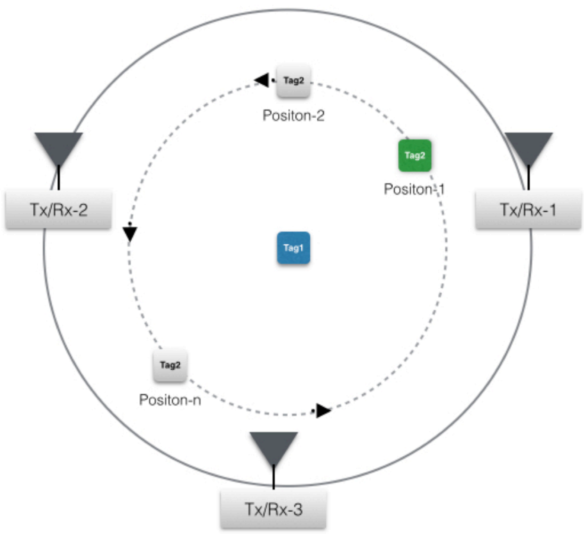


Fig. 3. Simulation set-up in CST Microwave Studio Suite 2013

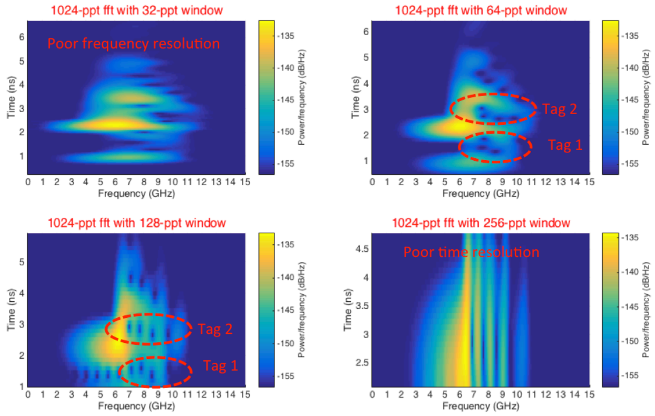


Fig. 4. Spectrogram with 1024-point FFT

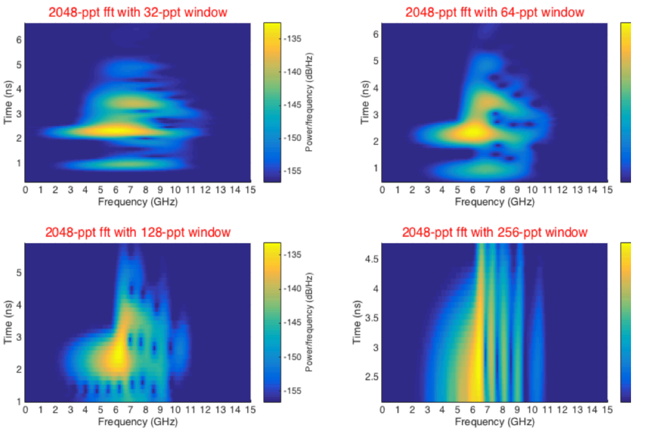


Fig. 5. Spectrogram with 2048-point FFT

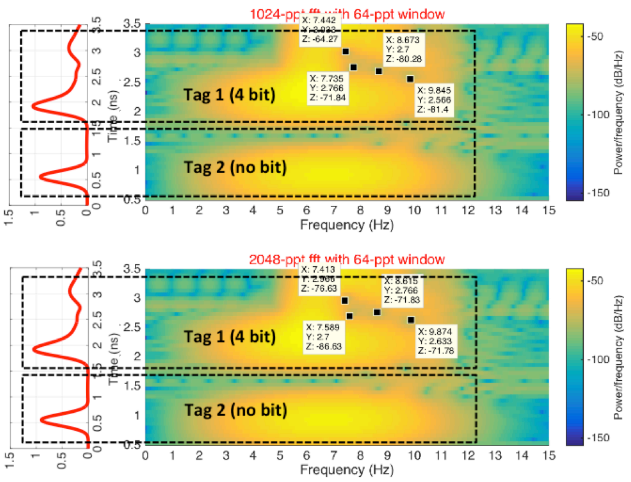


Fig. 6. Spectrogram of two tags with no bit and four bit

V. Results

The received signals are post-processed in MATLAB for time-frequency analysis for tag identification. Two sets of analysis has been performed with 1024 and 2048-point FFT. Each set has been analyzed for different window lengths for obtainging the optimum point between time and frequecy resolution. In Fig.4, STFT for four different window lengths has been presented, they are 32, 64, 128 and 256 points window. As we can see for 64-point window, the frequency resolution is not good enough to detect the resonances. For 64 and 128-point windows, the frequency resolution are good enough to detect the time and frequency of the resonances. Between these two, the 128-point window performs better having good separation between adjacent resonances. For 256-point window, the time resolution is poor and resonances can be identified but not the time of resonances. Fig. 5 shows the results for different window lengths for 2048-point FFT. The result of the time-frequency analysis is shown in the following table.

Table 1: Result of the Time-Frequency Analysis

FFT size	**Window size**	**Tag 1 resonance**		**Tag 2 resonance**	
		Time	***Frequency***	***Time***	***Frequency***
1024	32	Poor frequency resolution			
1024	64	1.4	8.5	2.6	9.8
		1.6	7.5	2.6	8.7
		1.9	7.7	2.8	7.6
				3.0	7.5
1024	128	1.4	8.6	2.72	8.6
		1.5	7.0	2.73	9.7
		1.53	7.7	2.86	7.0
				2.86	7.7
1024	256	Poor time resolution			
2048	32	Poor frequency resolution			
2048	64	1.4	8.6	2.6	9.9
		1.6	7.5	2.6	8.7
		1.9	7.7	2.76	7.7
				3.0	7.6
2048	128	1.4	8.5	2.7	9.6
		1.5	7.0	2.7	8.5
		1.53	7.7	2.8	7.7
				2.9	7
2048	256	Poor time resolution			

Fig. 6 shows the time-frequency plot of collided signal of two tags. Tag 1 has no resonances where as tag 2 have four resonances. The envelope of the backscattered signal is also shown in left of each time-frequency plot to relate it with the time-frequency result. Each tag response regions have been marked with black dotted rectangular box. It is easily visible that tag 1 is having no resonances and tag 2 is having four resonances. This simulation result again proves the significance and reliability of the method.

From Table 1, we can see that there is an average of 500 MHz frequency shift in the resultant resonance frequencies. This is because of the optimization between time and frequency scale for time-frequency analysis. However, in our future work this will be investigated in details to have more accurate result with less frequency shift.

VI. CONCLUSION

This paper proposes a novel technique for collision detection in chipless RFID tags using time-frequency analysis via STFT. The backscattered collided signal is analysed in time-frequency domain and the tag IDs are decoded successfully by this method. It works with UWB pulse signal and hence provides a faster reading than the FMCW technique. Moreover, it does not require any hardware modification for the reader rather than adding a post-processing unit. Therefore this method can be a potential option for collision detection in chipless RFID systems.

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