Long Range Passive RFID-Tag System for Hyperbolic Localization

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Abstract

A novel long range passive RFID-tag system with 30 m reading distance under Japanese standard at 2.45 GHz band is proposed. A reader, which can estimate the location of the tag, is also developed. The accuracy of the localization when three transmitting antennas and four receiving antennas are used for the reader is about 0.5 m in a floor of 20x20 m.

1. Introduction

Recently, RFID system has become popular and has been growing rapidly as identification and tracking technology. The RFID system is composed of the base station (reader) and the transponder (tag). Since the RFID tag is required to be compact, low price and long life without any maintenance, passive RFID tag without using battery at 2.45 GHz ISM band is most suitable. Positioning of human location is also important to realize advanced ubiquitous networks. The conventional positioning system of human location uses active RFID tag because it can bring a long range. However, the time interval of the positioning is limited to be long to save the consumption of the battery in the case of the active RFID tag.

Recently, we proposed a passive RFID tag with reading range longer than 20 m [1] under the Japanese specification of 2.45 GHz band [2]. In this paper, passive RFID tag and reader system for hyperbolic localization in a floor size of 20x20 m is proposed for the RCR STD-1 specification at 2.45 GHz ISM band [2]. Fabricated tag reader has 3 transmitting antennas and 4 receiving antennas to realize the estimation of arbitrary direction of the RFID tag.

2. Tag and reader

Figs. 1 and 2 show the block diagram and photograph of the fabricated passive RFID tag, respectively. The tag is embedded with an 8 bit CMOS microcontroller, which can be used for the various application including functions of EEPROM and ADC [3]. The passive RFID tag proposed by the present authors for Japanese RFID equipment specification at 2.45 GHz band [1] is composed of a divided microstrip antenna and a passive voltage multiplying rectifying circuit. It has been pointed out that the series resistance of diodes used for the transponding modulation is important to increase the level of response signal and varactor diodes are used as the variable impedance elements. The proposed rectifying circuit is composed of a tank circuit of a $\lambda/4$ short stub and modified 3-stage Cockcroft-Walton circuit, and can convert from 0.07 Vrms RF voltages of 2.45 GHz to DC voltages higher than 1 V which corresponds to the conversion efficiency of about 40%.

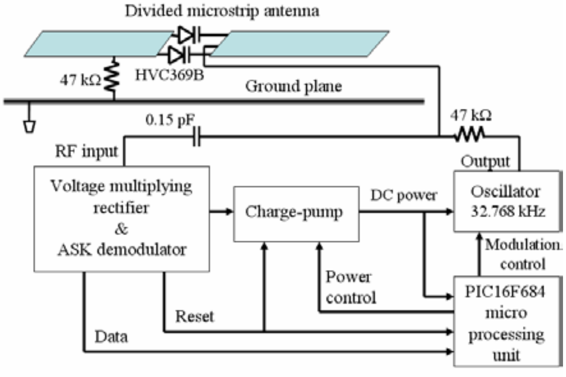

Fig. 1 Block diagram of proposed passive RFID tag.

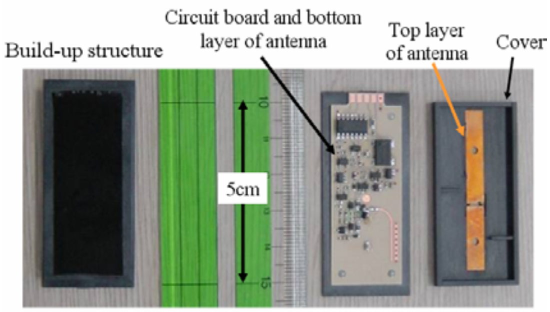

Fig. 2 Photograph of proposed passive RFID tag.

Fig. 3 shows the block diagram of the proposed RFID tag reader. This tag reader was designed to estimate the position of every RFID tag having each ID number. The transmitted carrier of the reader is frequency-hopped within a frequency band of 40 MHz under the RCR STD-1 specification at 2.45 GHz band and the signal having a comb spectrum of 3 MHz width is used. The reason for using comb spectrum as the request carrier to the tag is the Doppler compensation of transponding signal from the tag attached to a moving person. The reader has three channel I/Q demodulators to receive three different frequencies of transponding spectrum from the tag.

The signal transmitted by three fan-beam antennas of the reader is time–shared. The transmitting antennas are arranged to surround positioning area of tag in order to avoid the shielding by the person. The reader has also four receiving antennas to find the distance between each antenna and the tag by using the frequency responses of the received signals. In order to avoid the measurement error caused by the offset error of the transponding phase characteristics of the tag, difference between the distance measured by each antenna and that by one reference antenna is used and the position of tag is estimated by using hyperbolic localization method similar to the global positioning system (GPS).

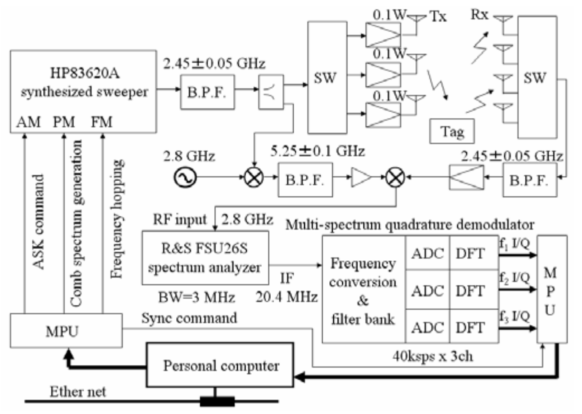

Fig. 3 Block diagram of proposed tag reader.

3. Simulation of hyperbolic localization

Fig. 4 shows the simulation model of RFID tag localization which includes the effect of multipath propagation. The floor size is 6 m x 6 m and the height is 3 m. The RFID tag is located randomly and the hyperbolic localization of the tag is used by signals emitted by the tag and received by 4 antennas in the room. Transponding signal from the tag is reflected by scatterers in the room such as the floor and the walls and received by four antennas of the reader in the multipath environment.

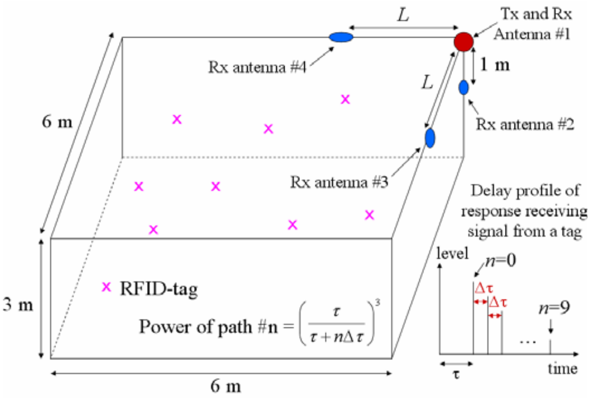

Fig. 4 Model for localization of RFID tag.

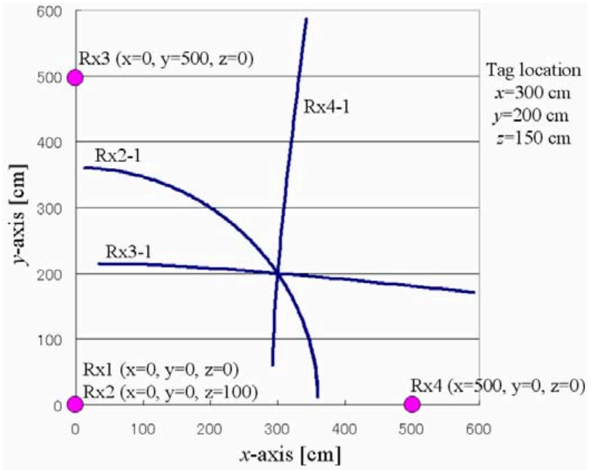

Fig. 5 Hyperbolic curves when height of estimation plane coincides with height of tag (z=150 cm).

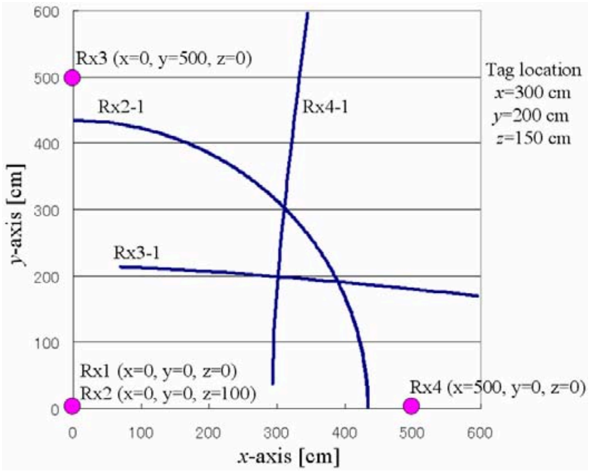

Fig. 6 Hyperbolic curves when height of estimation plane is z=170 cm.

In Fig. 4, τ is the propagation delay of the direct wave which is determined by the distance between the locations of the tag and the receiving antenna of the reader shown in Fig. 4. Δτ is time interval between the neighboring multipath waves which is assumed to be constant for the numerical simulation. The number of the direct and multipath waves is assumed to be 10. The power and the phase of the reflected wave are assumed to be proportional to the inverse of the cube of the path length and random, respectively.

Figs. 5 and 6 show the hyperbolic curves obtained by the difference of the time delay τ between the direct waves received by antenna #1 and other antennas #2, #3 and #4 when the tag is located at *x*=300 cm, *y*=200 cm, *z*=150 cm and there is not any reflected wave. In Fig. 5, the height of the estimation plane coincides with that of the tag and one cross point is observed, which is the real position of the tag. On the other hand, three cross points are observed and the tag position can not be estimated in the case of Fig. 6, since the height of the estimation plane is different from the tag height. In the actual measurement, unique cross point can not be obtained by the effects of multipath and the noise in addition to the difference of the heights of the estimation plane and that of the tag. Therefore, the actual localization of the RFID tag is performed by minimizing the RMS error.

Fig. 7 shows the simulation results of the RMS error of the 3-dimensional hyperbolic localization of the tag including the effect of multipath propagation shown in the Fig. 4 as a function of the time interval Δτ. Three estimation methods, i.e., group delay averaging (GD avg) method, multiple signal classification (MUSIC) method and inverse fast Fourier transformation (IFFT) method are used as the algorithm to exclude the error caused by multipath and these results are plotted in Fig. 7. The parameter of Fig. 7 is the spacing *L* of the receiving antennas shown Fig. 4. In the numerical simulation, the time delay τ is estimated by the frequency response from the tag when the carrier is scanned in 40 MHz band with 1 MHz step. The RMS error of localization in Fig. 7 is defined by $\sqrt{(x-x')^2+(y-y')^2+(z-z')^2}$, where ($x'$, y', z') is the estimated point and (x, y, z) is the real position of the tag. The simulation is performed for the tags located randomly at 1000 positions, and these results are averaged and shown in Fig. 7.

It is observed that the localization error for the case of *L*=4 m is always less than the case of *L*=2 m when any algorithm is used since the difference of the direction angle to the receiving antennas from the tag is wide when *L* is large. It is also noted that the large Δτ yields higher accuracy of the propagation time of the direct wave and small localization error.

In the present simulation, the localization error of MUSIC is larger than that of other methods. This phenomenon is caused by the fact that MUSIC algorithm can not separate the coherent multipath waves accurately since the values of the phase shift at the reflectors are assumed to be random but are independent of frequency, although the correlation suppression by moving average process is introduced. In the GD avg method and the IFFT method, performance of the separation of the direct path and the reflected path is not enough but they yield better accuracy for estimation of the propagation time τ of the direct path having large response power. These simulation shows that the method of IFFT is the best method to obtain the high accuracy of the localization.

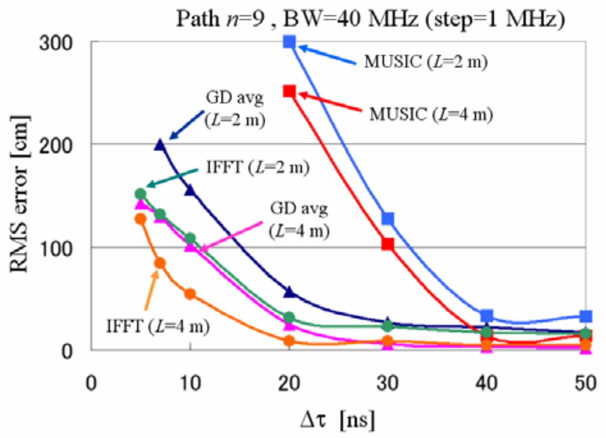

Fig. 7 Simulated results of 3D hyperbolic localization error when effect of multipath propagation is included.

4. Experimental results

Fig. 8 shows the experimental setup for the hyperbolic localization of the proposed passive RFID tag. The experiment was performed in a semi-anechoic chamber with metal floor as the reflector and several metal reflectors are also placed in the chamber. As the transmitting antennas of the reader, three antennas having fan beam with a half power width of 90 degrees in horizontal plane were used and each antenna transmitted 1 W EIRP. As the receiving antennas of the reader, four antennas having circular beam with a half power width of 70 degrees were used. The proposed tag antenna is a microstrip type antenna having a ground plane and can be used in the vicinity of a human body but the tag antenna has directional pattern. For this reason, the tag was rotated in horizontal plane as shown in Fig. 8.

Fig. 9 shows received signal at the reader when the frequency hopping sequence was not used. Left figure is the detected ID of the tag in time domain and right figure is the frequency spectrum. The carrier of comb spectrum transmitted by the reader and several sub carriers of the signal modulated by the tag are observed in the right figure. The received power ratio of the carrier of the reader and transponding sub carriers of the tag is about 80 dB and it is not easy to separate the carrier and sub carriers by using the frequency spectrum. In order to overcome this difficulty, proposed RFID tag reader introduces filter bank and I/Q demodulation by DFT processing as shown in Fig. 3. Measurement of the transponding signal from the tag is repeated by switching the receiving antennas of the reader with every 5 ms time interval. Each tag responds to command from the reader at a time decided singly for each ID of the tag.

Fig. 10 shows the experimental results of hyperbolic localization by using the proposed passive RFID tag system, where only x coordinate of the real and the estimated position is plotted. There are many influences on the localization error such as the reflection of human body and the direction of the tag, and maximum error of about 1 m as is observed. However, localization error of the proposed system is less than 0.5 m for most cases as can be seen in Fig. 10.

5. Summary

A novel passive multifunctional tag for long reading range composed of a divided microstrip antenna, a rectifying circuit boosting the DC voltage and micro processor PIC16F684 has been proposed. Passive RFID tags for positioning system of human location have been proposed for 2.45 GHz ISM band. The size of tag is 55x25x4 mm and can be used in the vicinity of a human body.

A reader for hyperbolic localization of the tag attached to a human body has been also developed. It has been shown that the localization error is improved when the difference of the direction angle to the receiving antennas from the tag is wide and the IFFT method is suitable to estimate the propagation delay time of direct path. Experimental investigation performed by using three transmitting antennas and four receiving antennas shows that localization error of the proposed system is less than 0.5 m confirming the validity of the proposed passive RFID tag and reader system.

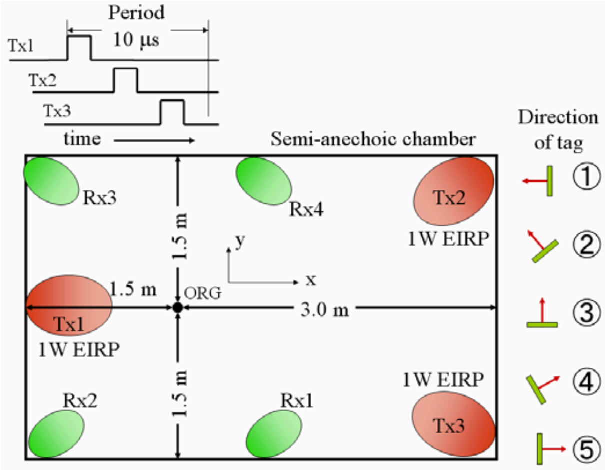

Fig. 8 Experimental setup for positioning of RFID tag location.

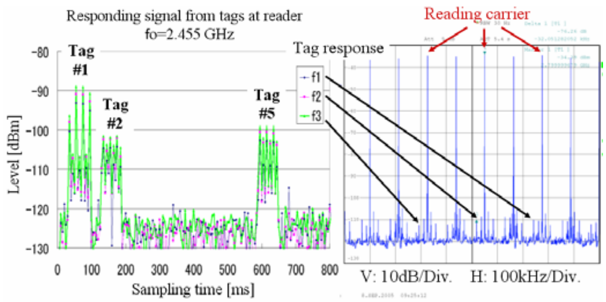

Fig. 9 Received signal at receiving antennas of reader.

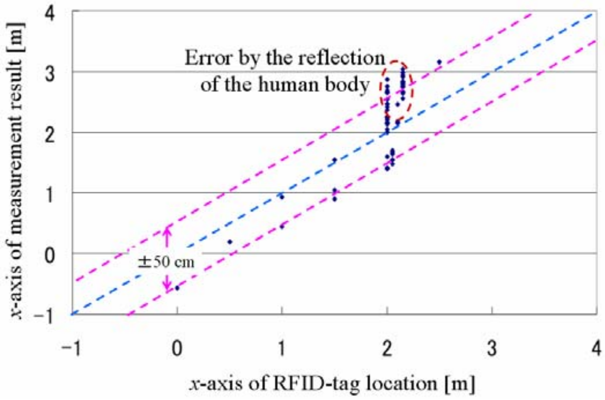

Fig. 10 Experimental results of hyperbolic localization.

References

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