# Long Range Passive RFID-Tag for Sensor Networks

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***Abstract*—A novel passive RFID tag for a long reading range composed of a divided microstrip antenna and a rectifying circuit boosting the DC voltage is proposed. Experimental study of fabricated passive tag using varactor diodes, in which 30 m range response can be achieved at 860-950 MHz band, is described. Passive tags for temperature-monitoring system at 2.45 GHz band is also fabricated to demonstrate validity of proposed tags for a range longer than 9 m. The tags have sizes of 90×60×4 mm and 60×25×4 mm for 900 MHz and 2.45 GHz bands, respectively.**

***Keywords-passive RFID; sensor networks; long range transponder; microstrip antenna; multiplying rectifier***

## I. 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 battery used at 2.45 GHz ISM band is most suitable. However, the distance between the reader and the tag is limited because the field strength of the responding signal from the tag is proportional to the inverse of the square of the distance and becomes weak as the distance increases. The longest ranges of RFID tags using conventional dipole antenna have been 3.3 m at 2.45 GHz [1] and 9.25 m at 915 MHz [2]. Therefore, it is strongly desired to develop an RFID tag applicable to a long reading range to realize novel communication network systems.

Recently, a passive RFID tag with a range of 10 m composed of a divided microstrip antenna and a passive voltage multiplying circuit has been proposed by the present authors for the Japanese RFID equipment specification at 2.45 GHz ISM band [3]. In this paper, passive RFID tags for a range longer than 10 m are proposed for 4 W EIRP systems at 2.45 GHz and 915 MHz ISM bands. The proposed tag is composed of a divided microstrip antenna and a passive voltage multiplying circuit, and the size is about $0.6\lambda \times 0.2\lambda \times 0.03\lambda$ where $\lambda$ is the wavelength. The received level at the reader for the case of the proposed tag is about 10 dB greater than that for the case of the dipole antenna of the conventional tag [4]. Since antenna is a microstrip type antenna having a ground plane, it can be used in the vicinity of a metal structure. The proposed rectifying circuit is composed of a tank circuit of a $\lambda/4$ short stub and modified 3-stage Cockcroft-Walton [5] circuit, and can convert from -10 dBm ($Z_O$=50 Ω) RF input of 2.45 GHz CW to more than 1 V DC voltage at $R_L$=33 kΩ which corresponds to the RF/DC power conversion efficiency of about 40%.

## II. GEOMETRY OF TAG ANTENNA

Fig.1 shows the structure of the conventional passive RFID tag [4]. Variable impedance $Z_v$ for the modulation of the transponding signal is connected to the feeding terminals A and B of the tag antenna. A rectifying circuit for receiving the power is also connected in parallel to the terminals A and B. Fig. 2 shows the structure of the proposed passive RFID tag. The tag antenna is a divided microstrip antenna. Two diodes are connected to the terminals A and B as the variable impedance element for the modulation and a rectifying circuit is connected to B and C. Since the microstrip type antenna having a ground plane is employed, the tag can be used in the vicinity of a metal structure.

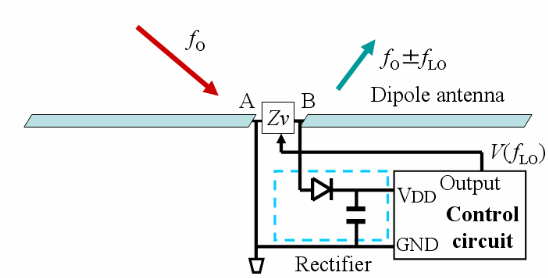



Fig. 1 Structure of conventional passive RFID tag.

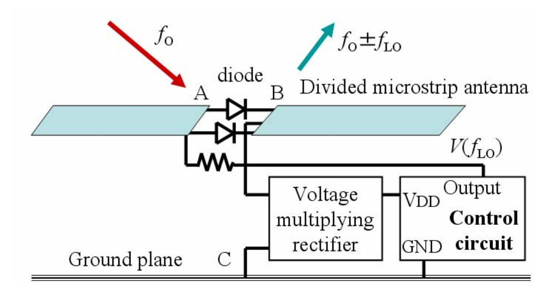



Fig. 2 Structure of proposed passive RFID tag.

Fig. 3 shows the schematic diagram for evaluating the received signal level from the tag at the reader. The received signal level at the frequency of $f_0+f_{LO}$ are calculated by using the method of moments (MoM), where $f_0$ is the RF frequency and $f_{LO}$ is the local frequency of the modulation of the RFID tag. The modulation is performed by the PIN diode in the tag. Fig. 4

shows the received signal power normalized by the transmitted power of the reader antenna as a function of the length of the tag antenna $L$ for the cases of the conventional RFID tag having planer dipole antenna without ground plane and the proposed tag with divided microstrip antenna. The actual gain of the reader antenna is assumed to be 6 dBi according to the ISO/IEC 18000-4 specification. The series resistance and the junction capacitance of the PIN diodes are supposed to be $R_s$=1 Ω and $C_0$=2 pF, respectively and the distance between the tag and the reader antennas is $z$=83 $\lambda_0$ (10.16 m). It is noted that the received power level of the proposed tag is about 10 dB higher than that of the conventional tag by selecting an appropriate antenna length $L$.

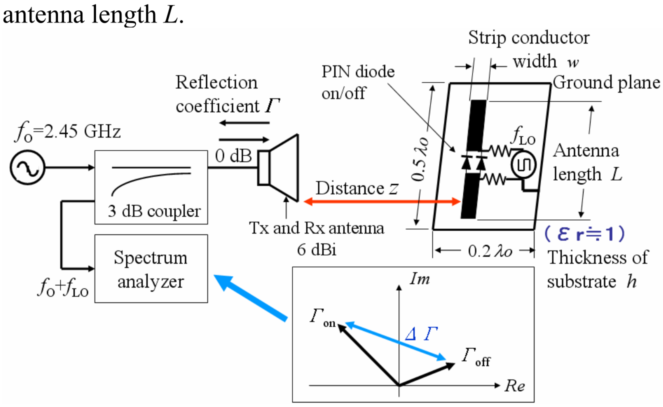



Fig. 3 Schematic diagram for evaluating received signal level at reader.

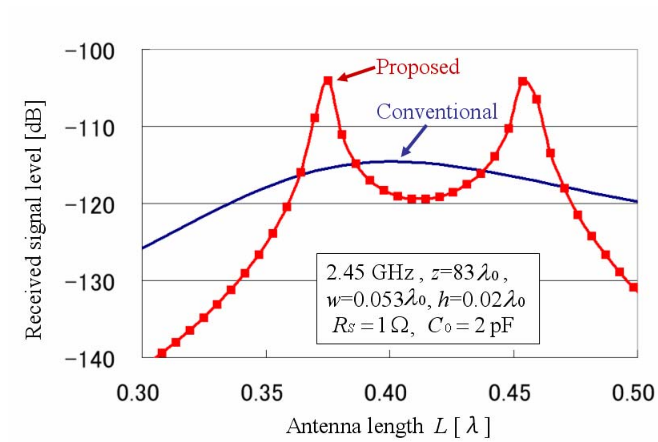



Fig. 4 Received signal level of reader antenna as a function of length of the tag antenna $L$.

## III. Performance Requirement of Variable Impedance Element

In this chapter, the requirement of the characteristics of the variable impedance element for obtaining a strong response signal from the RFID tag antenna is discussed. The level of the response signal received by the reader antenna is numerically analyzed by MoM. Fig. 5 shows the received signal level as a function of frequency with varying the values of series resistance of the diodes $R_s$ attached to the proposed divided microstrip RFID tag antenna, where the junction capacitance of the diode is $C_0$=1 pF. The total length of the antenna is $L$=0.364 $\lambda_0$ and the distance between the reader and tag is 83 $\lambda_0$ (10.16 m). It can be seen that the smaller series resistance is desired to obtain a strong response signal level.

Figs. 6 and 7 show the peak value of the received signal level as functions of the series resistance $R_s$ and the junction capacitance of the diode $C_0$ for the cases of the conventional RFID tag using dipole type antenna and the proposed RFID tag, respectively. Since the frequency of the peak of the response level varies as the values of the series resistance $R_s$ and the junction capacitance $C_0$ change, peak value of the received signal level was numerically sought with changing frequency and is plotted in these figures. In the conventional RFID tag, the junction capacitance $C_0$ strongly affects the received signal level, while the series resistance $R_s$ does not. On the other hand, $R_s$ strongly affects the received signal level, while the $C_0$ does not in the case of the proposed antenna as can be seen in Fig. 7.

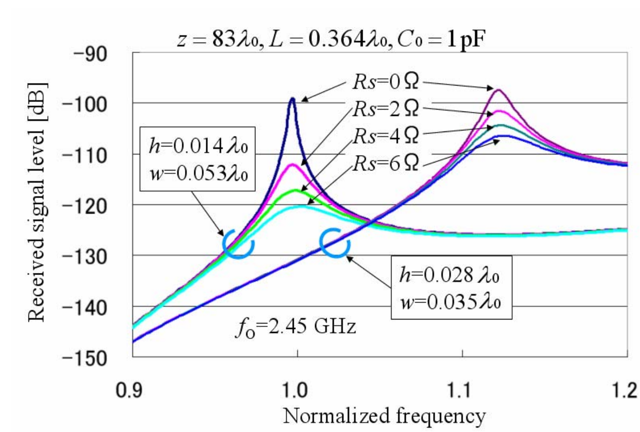



Fig. 5 Received signal level of reader antenna versus thickness $h$ and strip width $w$ in case of proposed RFID tag.

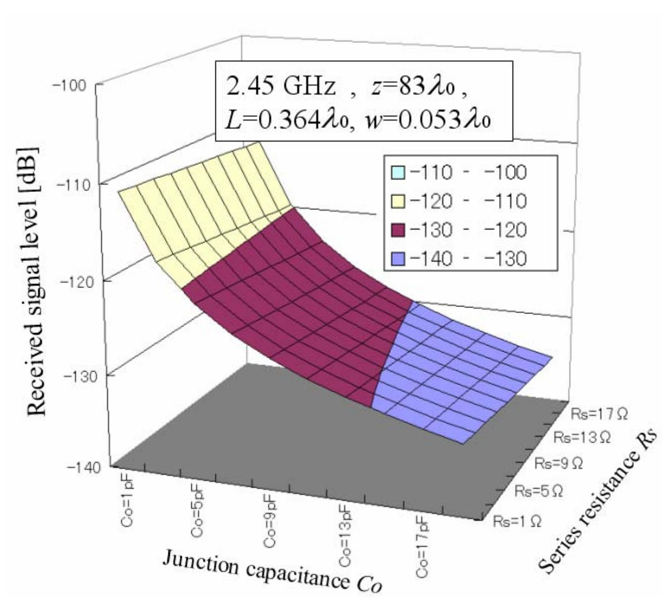



Fig. 6 Received signal level of reader antenna versus $C_0$ and $R_s$ of PIN diode in case of conventional RFID tag.

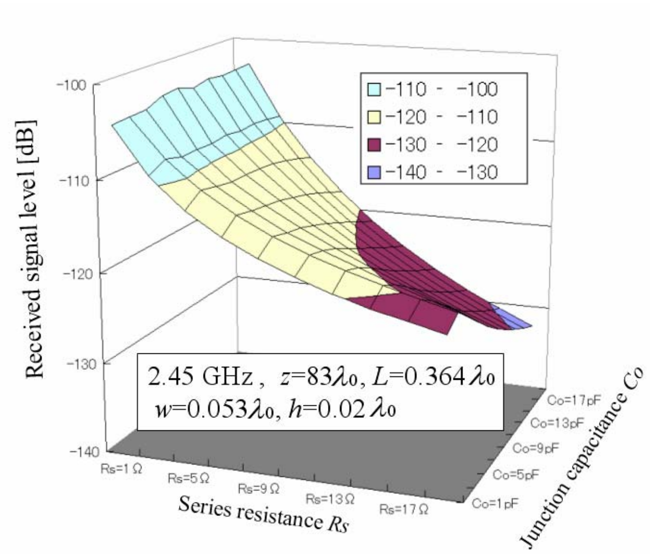



Fig. 7 Received signal level of reader antenna versus $R_s$ and $C_0$ of PIN diode in case of proposed RFID tag.

## IV. RECTIFYING CIRCUIT

For the case of the rectifying circuit of the conventional tag shown in Fig. 1, a high impedance of the tag antenna is desirable to obtain the high DC voltage. However, required power to generate 1 V for the control circuit is higher than 0 dBm even when a high impedance antenna such as the folded dipole antenna is used, because a simple diode rectifying circuit is used.

The received power of the microstrip antenna of the proposed tag is estimated to be about -10 dBm at the distance of $z$=3.5 m assuming that the transmitted power is 1 W and the gain of the reader antenna is 6 dBi. This power is enough to operate the control circuit of the RFID tag. However, the estimated value of the received DC voltage is as low as 0.1 V assuming 50 Ω load, which is too small to operate the control circuit. Therefore, a rectifying circuit boosting DC voltage more than 10 times and working at 2.45 GHz band is required to obtain the DC voltage higher than 1 V with 30 µW power consumption.

Fig. 8 shows the proposed rectifying circuit composed of a tank circuit of a 3λ/4 short stub and modified 3-stage Cockcroft-Walton circuit. The first diode of the original Cockcroft-Walton circuit [5] is removed. The uniform values of the capacities in the original Cockcroft-Walton circuit are also changed as lower capacitance of the input side capacities. The rectifying diode used in this study is HSMS-286 ($C_0$=0.25 pF). DC output of the proposed rectifying circuit is numerically analyzed by using the SPICE transient simulator. Fig. 9 shows the frequency response of the proposed rectifying circuit when the input RF power is -10 dBm and load resistance is $R_L$=33 kΩ. DC voltage of about 1.15 V is obtained which is considered to be enough to operate the control circuit. The conversion efficiency of the proposed rectifying circuit is about 40%, which is much greater than the conventional Cockcroft-Walton circuit. The most efficient rectifying circuit for the used conventional Cockcroft-Walton structure is 5 % at 2.45 GHz, -10 dBm input [2].

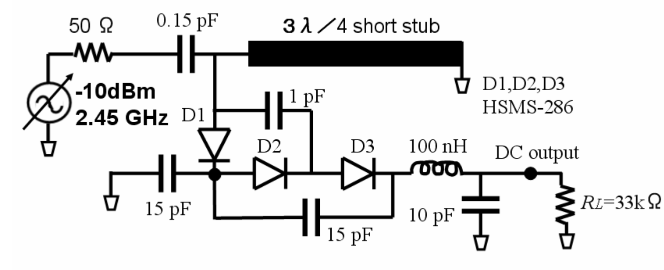



Fig. 8 Proposed rectifying circuit.

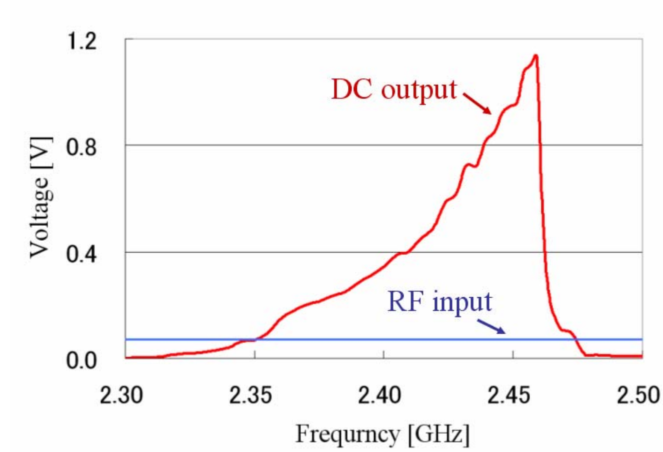



Fig. 9 Frequency response of proposed rectifying circuit.

## V. SYSTEM AND EXPERIMENTAL RESULTS

The ranges of passive RFID systems at 2.45 GHz and 900 MHz band have been less than 4 m and 10 m, respectively. For example, the range of tag of SAW temperature sensor operating at 2.45 GHz has been 3.3 m [1], and that of ID transponding tag at 915 MHz has been 9.25 m, where a conventional Cockcroft-Walton circuit was used [2]. In this section, experimental results of wireless temperature monitoring systems using long range passive RFID tag operating under ISO/IEC 18000 specification are presented.

The circuit diagram of a fabricated temperature sensing passive RFID tag for the multipoint temperature-monitoring system is shown in Fig. 10. In this circuit, varactor diodes are used as the variable impedance $Z_v$ elements instead of the PIN diodes described in Sec. III, since varactor diode has a small series resistance and its consumption power and operating voltage are less than those of the PIN diode. The varactor diode has a large junction capacitance, but it does not affect the responding signal level significantly in the case of proposed tag as can be seen in Fig. 7. The RFID tag also has a X'tal oscillating circuit used for sensing the temperature and modulating the received signal which is controlled by an advanced CMOS gate IC operating with ultra low voltage. The length of the short stub in the rectifying circuit is $\lambda_0$/4. The DC

output voltage and current of the rectifying circuit are 0.6 V and 2μA, respectively, for the input power of -20 dBm.

Figs. 11 and 12 show the fabricated passive RFID tags having temperature sensors for 2.45 GHz band and 860-950 MHz band, respectively. The actual gains of antennas used in these tags are about 5 dBi. The received powers by the readers 10 m and 30 m away form the tags at 2.45 GHz and at 860-950 MHz band are both -20 dBm under the operations of ISO/IEC 18000 specifications part 4 and 6, respectively.

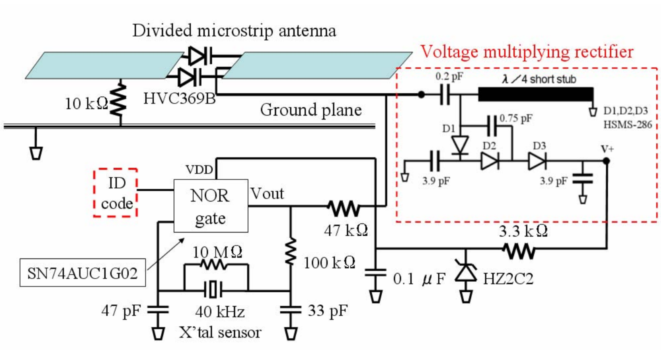
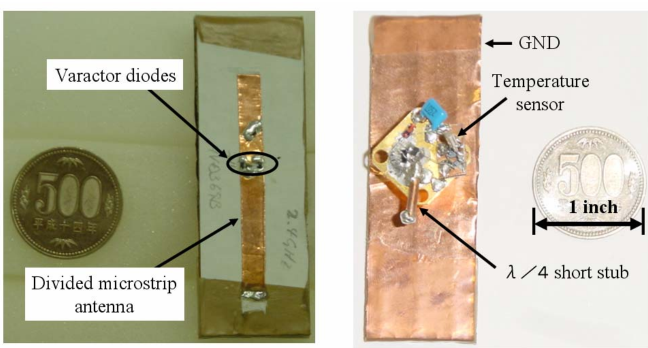



Fig. 10 Circuit diagram of temperature sensing passive RFID tag.




Front view

Rear view

Fig. 11 Photograph of 2.45 GHz band passive RFID tag.

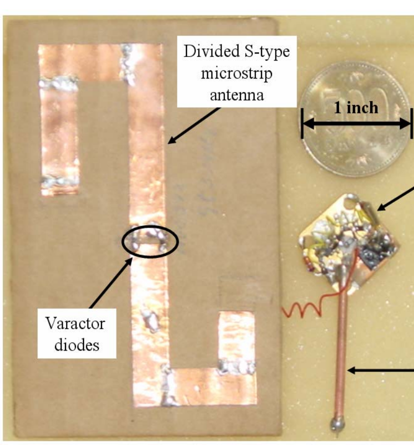



Fig. 12 Photograph of 860-950 MHz band passive RFID tag.

Fig. 13 shows the measured DC voltage of the fabricated tag for 860-950 MHz band as a function of the career frequency, where transmitted power of the reader is 0.25 W EIRP and the distance between the reader and tag is $z$=3 m. Although the divided microstrip antenna and the quarter-wavelength short stub have narrow band characteristics, the overall rectifying characteristics have a broad bandwidth greater than 10 % and the proposed RFID tag can be used for both Japanese system at 950 MHz and European system at 860 MHz.

Indoor experiment of the temperature-monitoring system using two passive tags for 2.45 GHz band was performed. Figs. 14 and 15 show the experimental setup. The transmitting and receiving antennas of reader are both double-ridged guided horn antennas. The response signal received by the reader antenna is delivered to a spectrum analyzer. The transmitted power of the reader is 0.1 W and the value of the EIRP is 0.56 W which is only 14 % of the ISO/IEC 18000-4 specification. Since the space for the experiment is limited, the distances between the tags and the reader are 3 m and 3.5 m for tags #1 and #2, respectively. These ranges are corresponding to 8 m and 9.35 m under the ISO/IEC 18000-4 operation, respectively. Each tag converts the received career frequency into an individual sub-career frequency depending on the temperature and transmits it to the reader.

Fig. 16 shows the frequency deviation of the response signals received by the reader antenna. The combinations of the temperature of tags #1 and #2 were (27°C, 27°C), (44°C, 27°C) and (44°C, 53°C). It can be seen that the temperature can be monitored with a frequency deviation of approximately 1 Hz/°C confirming the validity of the passive RFID tags. In this system, temperature of -40°C to 85°C can be measured with an accuracy of 0.3°C.

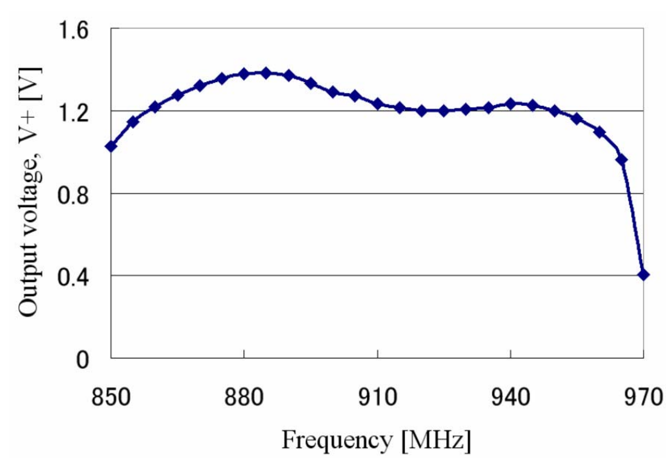



Fig. 13 DC power voltage of 860-950 MHz band passive RFID tag as a function of the career frequency.

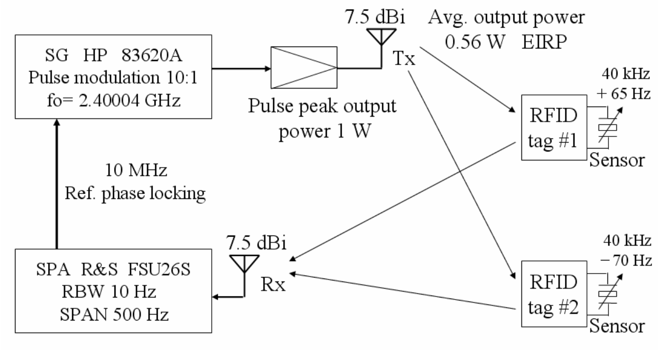



Fig. 14 Block diagram of experimental setup.

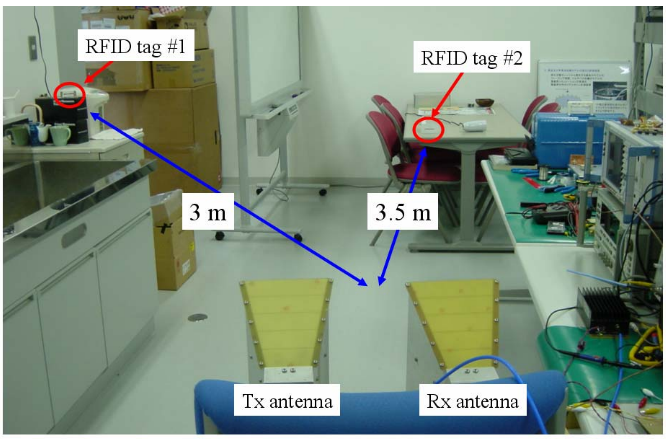



Fig. 15 Photograph of experimental setup.

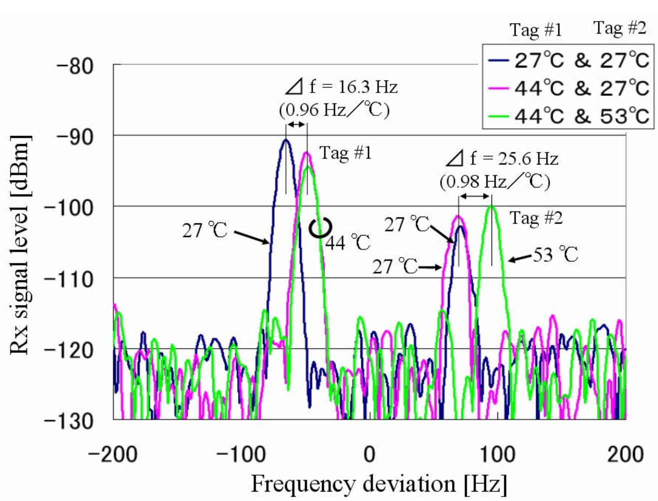



Fig. 16 Frequency spectrum of received signal from RFID tags at reader.

## VI. CONCLUSION

A novel passive RFID tag for a long reading range composed of a divided microstrip antenna and a rectifying circuit boosting the DC voltage has been proposed. It has been shown that the received level at the reader for the case of the proposed tag is about 10 dB greater than that for the case of the dipole antenna of the conventional tag. Since antenna is a microstrip type antenna having a ground plane, it can be used in the vicinity of a metal structure. 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 efficiency of about 40%.

Passive temperature sensor tags for 10 or 30 m reading distances have been proposed for 4W EIRP systems at 2.45 GHz band or 915 MHz band. It has been pointed out that the series resistance of diodes used for the modulation is important to increase the level of response signal. Experimental study of fabricated passive tag using varactor diodes shows that 30 m range response can be achieved at 860-950 MHz band. Passive tags for temperature-monitoring system at 2.45 GHz band have been also fabricated to demonstrate validity of proposed tags for a range longer than 9 m. The tags have sizes of 90×60×4 mm and 60×25×4 mm for 900 MHz and 2.45 GHz bands, respectively.

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