Characteristics of Electromagnetic Security Tag System

Bulletin of University of Osaka Prefecture
Vol. 44, No. 1, 1995, pp. 13-17

Characteristics of Electromagnetic Security Tag System

Kiyoshi INUI*,**, Yuichiro KATSU**, Masanobu KOMINAMI*** and Hiroji KUSAKA***

(Received June 30, 1995)

The electromagnetic security systems have been proposed for detecting the unauthorized removal of articles from area under the protection. Such systems have been developed fór use in libraries and retail stores. These systems generally include an electromagnetic field provided in controlled area through which articles must pass in leaving stores. The security tag which consists of a resonant circuit is attached to article and the tag's presence in the controlled area is sensed by the security tag system to denote the unauthorized removal of an article. In order to design a security system, it is important to predict the electromagnetic field scattered by the tag accurately. In this paper, a moment method solution is presented for problems of coupling between two antennas and a small tag. Transfer functions are calculated and effects of inductance loading on the received signal are considered. Results are also given for characteristics of the system with 2-element Yagi-type antenna and of a multi-resonant security tag.

1. Introduction

As automatic identification technique, there are (1) bar-code, (2) magnetic stripe, (3) data-carrier, (4) optical character recognition, (5) machine vision, (6) voice data entry and so on[1]. In these, (1), (2) and (3) are indirect identification which reads the codes attached to objects, and (4), (5) and (6) are direct identification using sensors and computer soft-ware in a sense. At present,the indirect recognition can be constructed with simple equipment and is superior to another in the cost performance generally. Since, the data-carrier which uses the penetrative electromagnetic waves as media for information transmission has high environmental properties and the information can be read when it only passes through the detective area of antennas, it is intensively studied recently. In particular, the passive data-carrier which deals with one-bit information of the detection of presence is called the security tag and is broadly used to prevent the unauthorized removal in stores.

The technique of the data-carrier involving the security tag is developed on the basis of the technology, of the wireless, the sensor, the card, the printing, and of the information processing. In order to construct the application of the tag for various use, it is important to predict the electromagnetic characteristics of coupling between the transmitting and receiving antennas and the tag accurately. Previously, we have performed an analysis of the characteristics and the design method of the tag itself[2]. But, it seems that the electromagnetic characteristics of the tag system including the transmitting and receiving antennas has not been considered precisely.

In this paper, for the purpose on revealing the characteristics of the detection of the security system, we investigate the electromagnetic field scattered by the tag being expressed as conductive segments with inductance and being placed between the antennas. Transfer functions representing the coupling between the antennas including the tag of segments are numerically calculated by solving Pocklington's integral equation of the conductors with a moment method. Results are also given for characteristics of the system with 2-element Yagi-type antenna and of a multi-resonant security tag.

2. Analytical Theory

A schematic diagram of a security tag system is shown in Fig. 1. The security system consists of a transmitting antenna, a receiving antenna, a controller and an alarm. The tag consists of the LC resonant circuit. The received signal changes when the tag attached to an article passes between the two antennas

* Research and Development Laboratory, Toyo Aluminium K. K.
** Graduate Students, Department of Electrical and Electronic Systems, College of Engineering.
*** Department of Electrical and Electronic Systems, College of Engineering

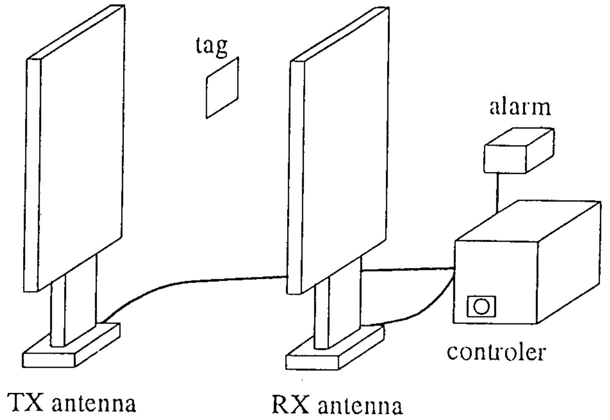

Fig. 1 Schematic diagram of a security tag system

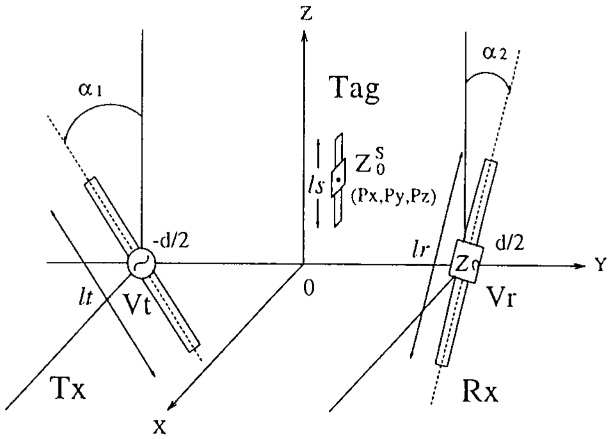

Fig. 2 Electromagnetic model of a system

arranged at the both sides of entrances of the stores. Thus, the system recognizes the unauthorized removal of the article and denotes this removal by alarm activation. Fig. 2 shows an electromagnetic model of this system. A short dipole representing the tag is placed between the two antennas of dipoles of $1/2\lambda_0$ length, where λ_0 is wave length of the center frequency f_0. It is also possible to express the system as an array of square loops,but it is complicated to calculate their coupling and inaccurate in results[3]. Hereby, we use the array of dipoles for considering the electromagnetic coupling between the tag and the system fundamentally. The antennas, both of T_X and R_X, are parallel to the X-Z plane, centering on the Y axis with angle α_1 and α_2 versus vertical, and distance between them, d, is λ_0. The short dipole is fixed vertically, centering on the X-Y plane.

With a piecewise-sinusoidal expansion mode $\boldsymbol{J}_n(\boldsymbol{r})$, a current distribution $\boldsymbol{J}(\boldsymbol{r})$ on each of dipoles is expressed as

$$\boldsymbol{J}(\boldsymbol{r})=\sum_{n=1}^{N} I_n \boldsymbol{J}_n(\boldsymbol{r}) \tag{1}$$

where $\boldsymbol{r}$ is a vector representing points of current, I_n and N are unknown coefficients and a total number of the expansion mode. By the moment method, I_n is given by solving the following equations[4]:

$$\sum_{n=1}^{N} Z_{mn} I_n \quad (m=1, 2, 3,\cdots\cdots, N) \tag{2}$$

Each of the terms in the above equations is described as

$$V_m=\begin{cases} V_t\text{(at the fed point of } T_X) \\ 0 \text{ (at except the above point),} \end{cases} \tag{3}$$

$$Z_{mn}=\iint_s \iint_{s'} \boldsymbol{J}_m(\boldsymbol{r})\cdot \overline{\boldsymbol{K}}(\boldsymbol{r},\boldsymbol{r}')\cdot \boldsymbol{J}_n(\boldsymbol{r})\, ds ds' + L_{mn}, \tag{4}$$

where $\overline{\boldsymbol{K}}(\boldsymbol{r},\boldsymbol{r}')$ is the dyadic Green's function of free space. L_{mn} is described with the loaded impedance Z_r of the receiving antenna R_X and the loaded impedance Z_t of the tag. That is

$$L_{mn}=\begin{cases} Z_r \text{ (at the terminal of } R_X) \\ Z_t \text{ (at the loaded point of the tag)} \\ 0 \text{ (at except the above points).} \end{cases} \tag{5}$$

The dyadic Green's function $\overline{\boldsymbol{K}}(\boldsymbol{r},\boldsymbol{r}')$ is expressed with the distance $|\boldsymbol{r}-\boldsymbol{r}'|$ between the point $\boldsymbol{r}'$ of the origin and the observation point $\boldsymbol{r}$ as the following equation:

$$\overline{\boldsymbol{K}}(\boldsymbol{r},\boldsymbol{r}')=(k^2\overline{\boldsymbol{I}}-\nabla\nabla')\cdot\frac{1}{j4\pi\omega\varepsilon_0}\cdot\frac{e^{jk|\boldsymbol{r}-\boldsymbol{r}'|}}{|\boldsymbol{r}-\boldsymbol{r}'|}, \tag{6}$$

where k is the phase constant of free space and $\overline{\boldsymbol{I}}$ is the unit dyad. The unknown coefficients of the expansion are derived from Eq. (2). Thus

$$I_n=\sum_{n=1}^{N} Y_{nm} V_m, \tag{7}$$

where Y_{nm} is the elements of an inverse matrix of generalized impedance matrix $[Z_{mn}]$. The terminal voltage V_r of receiving antenna R_X is given by

$$V_r=H(f)\,V_t, \tag{8}$$

where $H(f)$ is the transfer function between the transmitting antenna T_X and the receiving one R_X. $H(f)$ is expressed as

$$H(f)=Z_r Y_{mr,\ mt}. \tag{9}$$

In the above equation, $Y_{mr,\ mt}$ is the mutual admittance between T_X and R_X, where mr and mt are sequence numbers of the terminal of R_X and the fed point of T_X, respectively. Since the short dipole representing the tag cannot resonate at f_0 by itself, we made it to be resonant at f_0 by loading the inductance at the center. Hereby, the short dipole would be regarded as the tag of the LC circuit resonant at f_0.

The loaded impedance Z_t is described as

$$Z_t = j2\pi f_0 L \qquad (10)$$

at f_0, where L is the loaded inductance to resonate the tag dipole i.e., $2\pi f_0 L = |Z_t| = |$ (capacitive) reactance of the tag dipole at $f_0 |$

3. Basic Characteristics of Tag

On the basis of the above theory, basic electromagnetic characteristics of the security tag is discussed with numerical calculation. First, we consider behavior of received signal versus various conditions of the tag when the tag exists between the antennas.

The angle α_1 and α_2 are fixed to be 45° *i.e.*, Tx and Rx antennas are arranged perpendicularly with each other. We assume the tag dipole to be sufficiently short ($0.05\lambda_0$) and to be various length (0.5, 0.4, and $0.2\lambda_0$). L is loaded into the $0.05\lambda_0$ dipole to resonate.

By calculating the transfer function $|H(f)|$, amplitude distribution of received signals at f_0 against the position of the tag is shown in Fig. 3, when the tag moves along X axis. From these results, it is shown that the received signal in general decreases with a decrease in the length of the tag. However, the received signal becomes greater than that with the dipole having ten times length ($0.5\lambda_0$), when the tag (dipole) is resonated by loading the inductance at the center. Thereby, it is understood that the electromagnetic scattering cross section of the resonant tag becomes to be larger than that of the dipole having as long as ten times length.

Next, we analyze frequency domain behavior of received signals with the tag versus the plane of polarization of Tx and Rx antennas. Fig. 4 (a) and (b) show the received signals with the antennas, parallel and perpendicular with each other,respectively. In the latter, the antennas are not electromagnetically coupled with each other directly. The tag is the dipole of $0.05\ \lambda_0$ length loaded the inductance $L = 0.132\ \mu$H ($f_0 = 300$ MHz) at the center. In Fig. 4 (a), the characteristics of coupling between the antennas and the characteristics of scattering of the tag overlap each other. In Fig. 4 (b), the characteristics of scattering of the tag appears by itself. Each of the change of received signals on presence of the tag has approximately the same range. Thereby, it can be thought that the system with the antennas arranged perpendicularly with each other is preferred for detecting the presence of the tag.

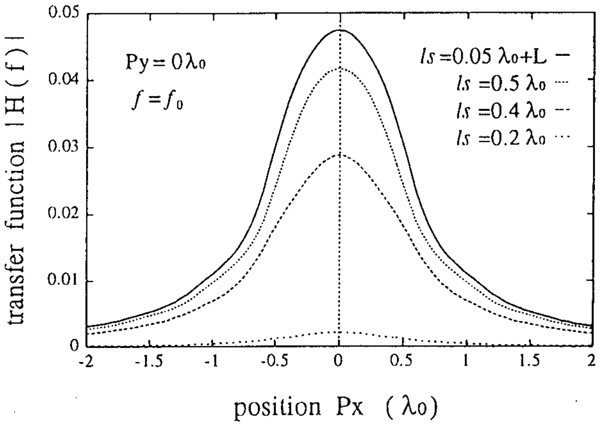

Fig. 3 Amplitude distribution of received signal along X axis

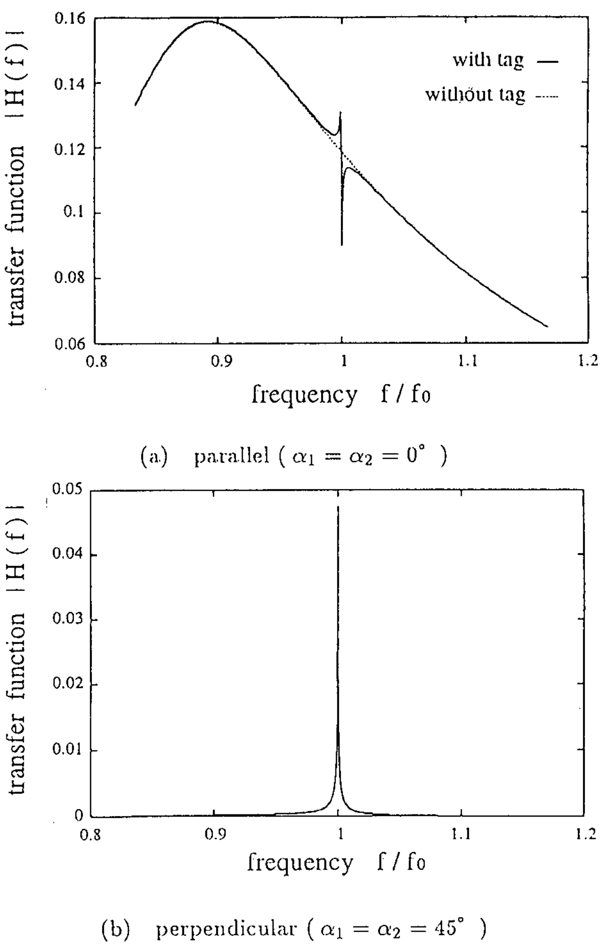

Fig. 4 Frequency domain behavior of received signal
(a) With parallel antennas
(b) With perpendicular antennas

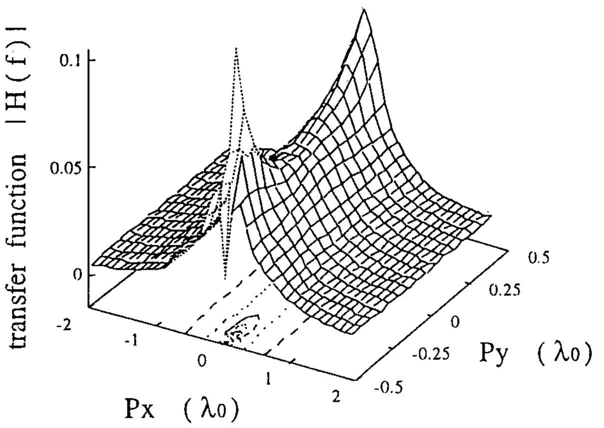

Fig. 5 Three-dimensional representation of received signal

Fig. 5 shows the change of the received signal versus the position (P_x, P_y) of the tag when the tag moves on the X-Y plane ($P_z=0$). From this result, it is shown that the amplitude of the received signal varies slowly between the antennas as the shape of the saddle. Since the change of the sensitivity of the detection is small between the antennas, it can be resulted that no area where the tag cannot be detected exists.

4. Proposition for High Function

It has been intensely desired that the system has higher sensitivity or higher function for expanding the application fields of the securitysystem. It has been revealed from a practical consideration of the tag using Al foil that the sensitivity of the system is proportional to the product of Q and the area S of the tag, $Q \cdot S$[2]. Since the size of the tag is limited, They are difficult to increase Q or S by modifying the tag itself and to enhance the sensitivity of the system by increase of Q or S themselves. Therefore, we propose that the transmitting and receiving antennas are each arrayed to enhance the sensitivity of the system for the signal receiving. The parasitic elements of length of 0.55 λ_0 are each added outside Tx and Rx antennas of dipoles of Fig. 2, and the antennas become a 2-element Yagi-Uda antennas as shown in Fig. 6.

The characteristics of the signal receiving is analyzed. Fig. 7 (a) shows a comparison of the radiation pattern of the said dipoles of $1/2\lambda_0$ with that of the 2-element Yagi-Uda antennas used here. It is seen that the latter has about 2 times gain at the front direction. The comparison of the amplitude of the received signals is shown in Fig. 7 (b). In the system

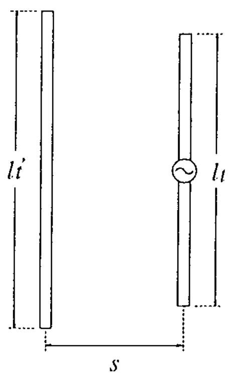

Fig. 6 2-element Yagi-Uda antenna

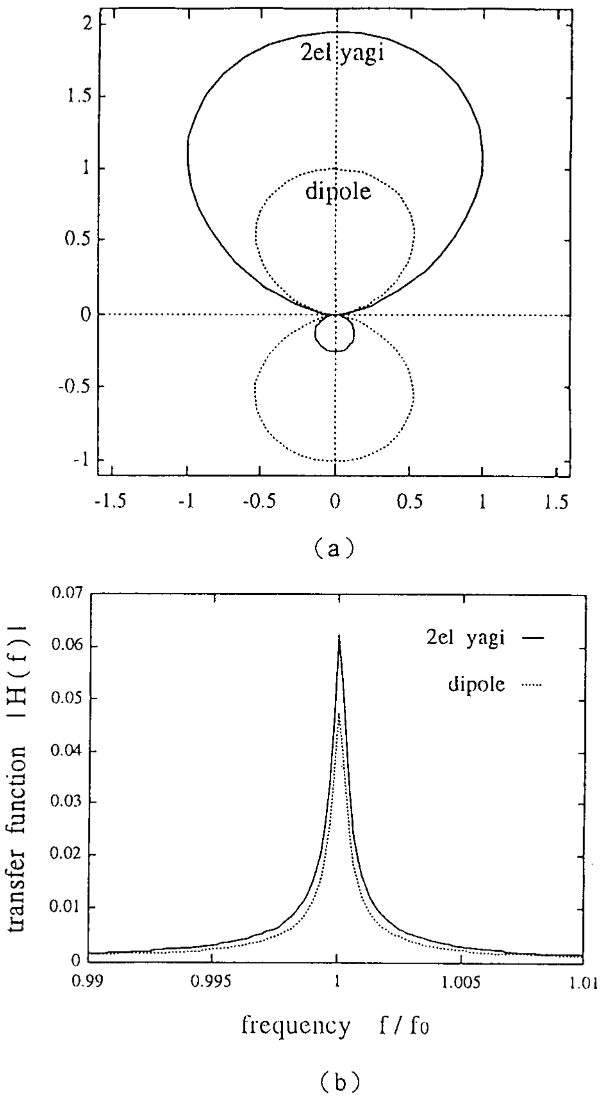

Fig. 7 Characteristics of gain-enhanced system
(a) Radiation pattern of far-field
(b) Amplitude of received signal

with the 2-element antennas, the received signal is enhanced about 1.2 times. It is thought that the disagreement of 2 and 1.2 times is due to the difference between the characteristics of far-field in Fig. 7 (a) and

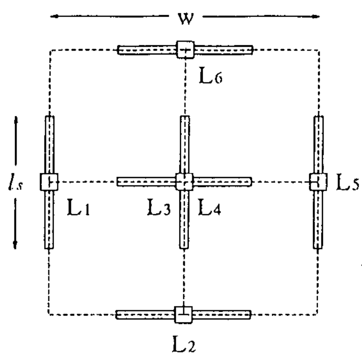

Fig. 8 Geometry for construction of a multi-resonant tag

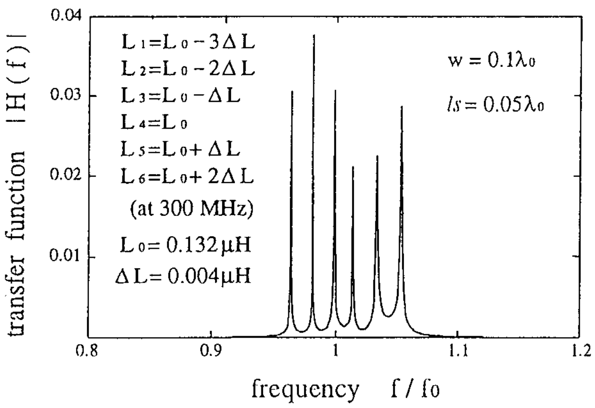

Fig. 9 Frequency response of a 6-resonant tag

characteristics of near-field about 1.0 λ_0 with T_X and R_X antennas arranged perpendicularly in Fig. 7 (b).

Finally, we propose the tag having multi-resonant circuit as one of method to give the multiple bit information to the security tag, while, which can be only detected its presence originally. Fig. 8 shows a geometry of construction of a multi-resonant tag proposed here. It is assumed that the tag has six short dipoles on the both sides of an insulating film. The electromagnetic distance between each elements is as long as possible while the tag's size is restricted, by considering the perpendicularlity of the plane of polarization of the dipoles also.

The frequency response of this 6-resonant tag is shown in Fig. 9. The loaded inductance in dipoles, L_n ($n=1, 2, \cdots, 6$), is fixed to resonate the tag at suitable frequencies as shown in the figure. It is seen that the resonant characteristics has approximately constant interval and the same amplitude. Therefore, it can be thought that a identification equipment like the optical bar-code system can be constructed with the device using the resonant characteristics such as the above tag.

5. Conclusions

The electromagnetic characteristics of the security tag system has been analyzed accurately with the moment method and the various results of the numerical calculation has been shown. From these, we revealed that the perpendicular arrangement of the transmitting and receiving antennas was preferred because of no direct coupling, and that the scattering cross section increased by inductance loading and the sensitivity of the system varied slowly between the antennas. In addition, we proposed the enhancement of the sensitivity with the array of the antennas and the construction of the tag with multi-resonant elements coupling as weakly as possible by considering the perpendicularity of the plane of the polarization of the dipoles for higher functions.

References

1) M. Izumiya, Power Saving and Automatization, Ohm Co., Inc., 11, 65 (1993).
2) K. Inui, H. Tada, M. Kominami and H. Kusaka, Trans. IEICE. E77-A (11), 1951, (1994).
3) Y. Katsu, M. Kominami, H. Kusaka, and K.Inui, Rec. Kansai-Sec. Joint Con. G-248, (1994).
4) R. F. Harrington, "Field Computation by Moment Method", Chap. 6, Macmillan (1968).