Detection of paper sheets based on variation of antenna resonance characteristics

Kenjiro KUBO1, Kazuki SHINTANI1, Hisato IWAII, Shinsuke IBI1, Takuya KURIHARA2, Satoru SHIMIZU1,2, and Yoshinori SUZUKI2

1 Graduate School of Science and Engineering, Doshisha University, Japan
2-3, Miyakodani, Tatara, Kyotanabe, Kyoto 610-0394, Japan
2 Advanced Telecommunications Research Institute International, Japan
2-2-2, Hikaridai, Seika-cho, Souraku-gun, Kyoto 619-0288, Japan

a) ctwd0329@mail4.doshisha.ac.jp

Abstract: This paper discusses the detection of the presence of paper inserted between the metal and the antenna. In order to clarify the feasibility of the sensing technique, we analyzed change of frequency characteristics of return loss in the presence or absence of paper near the antenna. Numerical analysis using the FDTD method was performed and experiments were carried out to compare the calculated and measured results. By the results, we confirmed detectable amount of change can be observed.

Keywords: Proximity sensor, Antenna, Paper detection, Return loss.

Classification: Sensing

References

[1] K. Yoshimura, T. Tsujimoto, S. Ogata, Y. Higashi, M. Kamiya, A. Kimata, H. Takasu, S. Asaoka, A. Yamamura, M. Ooki, T. Yuasa, “Development of intelligent media sensor,” KONICA MINOLTA Technology Report, Vol. 17, pp.34-40, 2020. (in Japanese)
[2] S. Shimizu, T. Kurihara, Y. Suzuki, K. Kubo, H. Iwai, ”A study on proximity sensing technology using antenna characteristics,” 2020 IEEJ National Convention, 3-151, March 2020. (in Japanese)
[3] K. Kubo, H. Iwai, S. Shimizu, T. Kurihara, Y. Suzuki, “Analysis of frequency resonance of a patch antenna neighboring a human body by FDTD method,” 2020 IEEJ National Convention, 3-152, March 2020. (in Japanese).
[4] K. Kubo, H. Iwai, T. Kurihara, S. Shimizu, Y. Suzuki, “Analysis of characteristics of an antenna for detection of human body and paper,” Proc. ISAP2020, 4G3, Jan. 2021.
[5] T. Kitaura, “Electrical resistivity control of plastic composites,” Journal of the Imaging Society of Japan, Vol.39, No.1, pp.18-24, 2000. (in Japanese)
[6] M. Takahashi, “Antenna design for RFID tags,” CORONA Publishing Co., Ltd., 2012. (in Japanese)
1 Introduction

In this paper, we discuss proximity sensors for the purpose of detecting paper. The principle of the detection is based on changes of the frequency characteristics of antenna reflection loss.

Currently, sensors aimed at detecting paper are used in equipment such as paper manufacturing lines, printers, ATMs, and so on. In the equipment, light transmission sensors and ultrasonic sensors are mainly used for the paper detection [1]. The light transmission sensor has a problem, when the paper type is different, the transmission characteristics changes due to the difference of ingredients to match the color of the paper and hence the detection performance deteriorates [1]. In the case of the ultrasonic sensors, it is common to make the transmitting and receiving sensor arrangement diagonal to the paper surface in order to avoid the effects of the reflections from the sensor units and the paper surface. This increases structural constraints of the detection system. On the other hand, the method discussed in this paper utilizing the changes of antenna characteristics is not affected by the color and ingredients of the paper. Moreover, it is not necessary to install it diagonally.

In this paper, we discuss a sensor method that detects paper near the antenna. The sensing principle of the method is based on the change of the frequency characteristics of the antenna reflection loss [2-4].

Assuming paper detection in a printer, conductor materials are generally used for the transporting surface of paper [5]. This is because it is necessary to use conducting materials as the transport surface and ground it in order to prevent the paper jam due to static electricity generated by the friction of the papers. Generally, the impedance of antennas decreases in the environment close to conductors [6], and matching with the feeding line becomes a problem. On the other hand, by using a folded dipole antenna that has high impedance in the free space, good matching can be achieved even in the proximity to the metal surface [6], and as a result, a clear difference of the reflection loss depending on the presence or absence of paper can be obtained.

In order to show such characteristics, we evaluate by the FDTD analysis and experiments the effect of the presence of paper on the antenna return loss assuming an environment where metal exists near the antenna. Although it is considered difficult to detect paper using radio waves since the permittivity of paper is generally very low, we show the feasibility of the paper detection of this method by presenting the effect of paper existing near the antenna.

2 Calculation model and experiment configuration

We evaluate the effect of the presence of paper on the antenna reflection characteristics in an environment where metal is installed near the antenna. The calculation model and measurement specifications are summarized in Fig. 1 and Table 1. We use a folded dipole antenna by which good matching to the feeder line
is expected even in the proximity to the metallic materials. In addition to the folded dipole antenna, a dipole antenna was also evaluated for comparison. The actual dipole and folded dipole antennas used in the experiment are shown in Fig. 1(b). They are printed on a dielectric substrate. The relative permittivity and thickness of the dielectric were 4 and 0.2 mm, respectively. Considering sufficient gap width for paper transporting space to prevent jam in a printer, the distance between the antenna and the metal is set as 4 mm and the distance between the antenna and the paper was the half of the distance, 2 mm. As for the frequency, the size of the antenna was designed with the target of 2.4 GHz in both the FDTD calculation and the experiment. In each situation, the frequency characteristics of the return loss were calculated and measured by changing the presence or absence of paper to be inserted between the antenna and the metal. The impedance of the feeding is 50Ω in the FDTD analysis and measurement. The return loss was measured by using a network analyzer.

![FDTD model](image)

**Fig. 1 FDTD calculation model and experimental setup.**

![Experiment](image)

**Table 1 Specifications of FDTD calculation and measurement.**

| FDTD          | Analysis field                  | 200mm × 200mm × 40mm |
|---------------|--------------------------------|----------------------|
|               | Boundary                       | Perfectly matched layer: 5 layers |
|               | Relative permittivity of paper | 2                    |
|               | Thickness of paper             | 0.1 mm               |
| Measurement   | Thickness of paper             | 0.182 mm             |

**3 Results**

Figure 2 shows the change of the frequency characteristics of the return loss with and without paper. According to the FDTD calculations, the resonance frequency of the dipole antenna changes by 7MHz depending on the presence or absence of...
the paper in the free space without metal, but it cannot be matched to the feeder impedance when the metal is close. On the other hand, the folded dipole antenna is matched in the presence of the metal, and the resonance frequency changes by 10 MHz. It can be confirmed that the same tendency was obtained from the measurement. The resonance frequency of the folded dipole antenna changes by 8 MHz. It is sufficiently detectable difference in actual sensing situation.

|            | Dipole antenna | Folded dipole antenna |
|------------|----------------|-----------------------|
| FDTD       | ![Graph](image1) | ![Graph](image2)      |
| Measured   | ![Graph](image3) | ![Graph](image4)      |

Fig.2. Change of frequency characteristics for presence or absence of paper sheet by FDTD and measurement.

4 Conclusion

In this paper, we investigated a method that utilizes changes of antenna reflection characteristics as a proximity sensor for paper detection. In order to clarify the feasibility of detecting paper existing near the antenna, we performed calculations using FDTD and experiments. Considering the actual implementation, it is necessary to realize paper detection in an environment where metal exists near the antenna. Therefore, we evaluated the effect of paper on the antenna reflection characteristics when metal is present near the antenna. A dipole antenna did not match well when metal was nearby, and a folded dipole antenna showed good matching. Furthermore a clear difference was detected between with and without paper. It is generally considered that the permittivity of paper is very low and it is not easy to detect it using radio waves, but it was shown that it is feasible by both the FDTD analysis and the experiment.

Acknowledgments

This research and development work was supported by the MIC/SCOPE #196000002.