**PMC Characteristics of Frequency Selective Reflector with Metal Plate and Its Application to Thin and Metal Attachable RFID Tag**

# Yoshiki Seki¹, Shigeru Makino¹, Shin-ichi Betsudan¹, Tetsuo Hirota¹, Keisuke Noguchi¹, Motoo Mizusawa¹, Tamotsu Nishino²

¹ Kanazawa Institute of Technology
² Mitsubishi Electric Corporation

7-1 Ohgigaoka Nonoichi-town Ishikawa-County Ishikawa Pref. JAPAN
5-1-1 Ofuna Kamakura-city Kanagawa Pref. JAPAN

#jp2nsy@venus.kanazawa-it.ac.jp

### 1. Introduction

Recently several types of thin antennas applicable to metal attachable RFID tags are studied [1]. A method to reduce the thickness of the tag including the antenna is to apply the metamaterials with PMC (Perfect Magnetic Conductor) characteristics [2] to the base plate of the tag [3].

In this paper, reflection phase characteristics of FSR (Frequency Selective Reflector) [4] with a metal plate will be discussed and a simple equation which represents the PMC condition will be introduced. Further it will be applied to the design of the base plate of the tag with PMC characteristics.

### 2. Reflection Phase Characteristics of FSR with Metal Plate

Fig. 1 shows the model of FSR with a metal plate and Fig. 2 shows its equivalent circuit. The FSR is expressed as a normalized susceptance $B$ considering no loss, and the dielectric slab between the FSR and the metal plate is expressed as a transmission line with a propagation constant $\beta$ and a thickness $\ell$.

By using the equivalent circuit of the FSR, the transmission coefficient $T_{FSR}$ and the reflection coefficient $R_{FSR}$ of the FSR are expressed as follows.

$$T_{FSR} = \frac{2}{2 + jB} = \cos\theta_t e^{-j\theta_r}$$  \hspace{1cm} (1) \hspace{1cm} $$R_{FSR} = \frac{-jB}{2 + jB} = -\cos\theta_t e^{j\theta_r}$$  \hspace{1cm} (2)

where $\theta_t$ and $\theta_r$ are the phase of the transmission and the reflection coefficients, respectively. On the other hand, when $\theta_t$ or $\theta_r$ is known, the normalized susceptance $B$ will be known using the following equations.

$$B = -2\tan\theta_t$$  \hspace{1cm} (3) \hspace{1cm} $$B = \frac{2}{\tan\theta_r}$$  \hspace{1cm} (4)

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**Fig.1 FSR with a metal plate.**

**Fig.2 Equivalent circuit of FSR with a metal plate.**
The F matrix considering the FSR and the dielectric slab is expressed as follows.

\[
F = \begin{bmatrix}
1 & 0
\end{bmatrix}
\begin{bmatrix}
\cos \beta \ell & jZ_0 \sin \beta \ell \\
-\frac{j B}{Z_0} \sin \beta \ell & 1
\end{bmatrix}
\]

\[
= \begin{bmatrix}
\cos \beta \ell & jZ_0 \sin \beta \ell \\
-\frac{j B}{Z_0} \cos \beta \ell + j \frac{\sin \beta \ell}{Z_0} & -B \sin \beta \ell + \cos \beta \ell
\end{bmatrix}
\]

\[
= \begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
\]

The voltage \( V_2 \) of the port 2 is zero because the port is short-circuited by the metal plate, so the input impedance \( Z_{in} \) is as follows.

\[
Z_{in} = \frac{V_1}{I_1} = B = \frac{jZ_0 \sin \beta \ell}{-B \sin \beta \ell + \cos \beta \ell}
\]

(6)

As a result, the reflection coefficient \( \Gamma \) is as follows.

\[
\Gamma = -\frac{B \sin \beta \ell - \cos \beta \ell + j \frac{\sin \beta \ell}{Z_0}}{B \sin \beta \ell - \cos \beta \ell - j \frac{\sin \beta \ell}{Z_0}} = -e^{2j\phi}
\]

(7)

where

\[
\phi = \tan^{-1}\frac{\sin \beta \ell}{B \sin \beta \ell - \cos \beta \ell}
\]

(8)

PMC characteristics will appear when \( \phi \) in equation (7) becomes \( \pi/2 \). The condition is shown as follows using equation (8).

\[
B = \cot \beta \ell
\]

(9)

3. Experimental Results

Fig. 3 shows a dual ring type FSR under test. The measured transmission amplitude and phase are shown in Fig. 4. In the figure, the calculated results using FEM (Ansoft HFSS Ver.11) are also shown. Fig. 5 shows the estimated susceptance \( B \) of the FSR using the measured transmission phase \( \theta \) shown in Fig. 4(b) and equation (3). Fig.6 shows the measured reflection phase of the FSR with a metal plate and a dielectric slab \( (\varepsilon_r = 1.2, l = 4.5mm) \). In the figure, the estimated results using equations (7) and (8) are also shown. As shown in the figures, a PMC characteristic is appeared at around 9.5 GHz and the measured and the estimated results coincide very well. So, the validity of the equations are shown.
4. Application to the base plate of the metal attachable RFID tag

To demonstrate the effectiveness of the derived equation (9), a design example of the base plate with PMC characteristics applicable to the metal attachable RFID tag will be shown. To make the dielectric slab between the FSR and the metal plate thinner, the FSR should have a larger normalized susceptance $B$ to be found from equation (9). A candidate of the FSR with a large normalized susceptance is a capacitance grid[5]. Fig. 7 shows the capacitance grid with a metal plate. Fig. 8 shows an example of the calculated normalized susceptance $B$ with the design parameter of a period $t=11$ mm and a width $w=10.9$ mm of the capacitance grid and a thin ceramic slab ($\varepsilon_r = 21, l = 1.0$mm). A thickness of additional ceramic slab to realize PMC characteristic at 850 MHz will be 0.682 mm by using equation (9). So the total thickness of the ceramic slab between the capacitance grid and the metal plate is 1.682 mm and is very thin. The reflection phase calculated by FEM is shown in Fig. 9. As shown in the figure, a PMC characteristic is appeared at around 839 MHz and is different from the result of equation (9) a little. And it will be seen that the band width with PMC characteristic is very narrow.
5. Conclusion
The reflection phase characteristics of FSR with metal plate were discussed and a simple equation which represents the PMC condition was introduced. The validity of the equation was verified by measurements. Further it was applied to the design of the base plate of the tag with PMC characteristics and showed the possibility of the thin and metal Attachable RFID tag. We would like to study more to realize PMC characteristics with wider band width.

References