1. Introduction

When metal wires are located around the propagation path, radio waves are diffracted. As a result, some parts of the waves are radiated in undesired directions and the transmission quality deteriorates. The diffraction characteristics of a metal cylinder have been well studied and analyzed such as in [1] and [2]; however, there has been little consideration given to the deterioration in the transmission quality. In the previous studies, a straight metal cylinder has been treated, however, a tightened wire is curved due to the weight of itself. Therefore, we must consider deflection of the wire to analyze the diffraction problem of tightened wire [3].

This paper describes the effects of the curve in the metal wire on the diffraction characteristics. In particular, it is shown that the curve of the wire disperses the direction of diffraction and the energy of the diffracted wave.

2. Effects of Wire Deflection on Diffraction Characteristics

2.1 Analysis Model for Wire Deflection

Figure 1 shows the analysis model used in this study. A wire is deflected in the x-z plane. It is supposed that both ends of the wire are fixed at the same height and the curve is modeled by a catenary curve. A catenary curve can be expressed as

\[ z = a \cosh\left(\frac{x}{a}\right) = a \left( \frac{e^{x/a} + e^{-x/a}}{2} \right) \] (1)

where \( a \) is \( \frac{T}{w} \) (\( w \) [kg/m] is the wire weight and \( T \) [kgf] is the horizontal tension). As shown in Fig. 1, \( d_H \) is the horizontal length and \( d_V \) is the length of the vertical deflection when a wire is tightened. Here, the degree of deflection is defined as \( \frac{d_V}{d_H} \). If \( \frac{d_V}{d_H} = 0 \), it means that a wire is straight. In this paper, the degree of deflection is adjusted by changing the vertical length, \( d_V \). In the following analysis, the horizontal length, \( d_H \), is set to \( 93\lambda \), the wire radius, \( r \), is set to \( 0.23\lambda \) and the wire is consisted PEC (Perfect Electric Conductor).

It is assumed that a plane wave arrives from angle (\( \theta \), \( \phi \)) in the analysis model. Here, the incident plane wave is set to vertical polarization (only \( E_\theta \) component) or horizontal polarization (only \( E_\phi \) component). The method of moment is used for the analysis.
2.2 Diffraction Characteristics by Deflected Wire Located in Incident Plane

The effects of wire deflection on the diffraction characteristics are analyzed when the incident wave is in the \(x-z\) plane. Here, the plane wave is assumed to be vertically polarized. Figure 2 shows the scattering cross section in case of incident angle \((\theta, \phi) = (30^\circ, 0^\circ)\). In Fig. 2, the azimuth angle, \(\phi\), is represented on the horizontal axis and the elevation angle, \(\theta\), is represented on the vertical axis. Figure 2 shows that the direction of diffraction is dispersed as the degree of deflection increases. In contrast, we find that the diffracted wave in the transmission direction \((\theta, \phi) = (150^\circ, 180^\circ)\) is not dispersed, and there is no decrease in the scattering cross section.

Figure 3 shows the relationship between the degree of deflection and Scattering Cross Section in transmission direction and reflection direction by solid line. In Fig. 3, the results when the angle of incidence is assumed the directions of \(0^\circ, 0^\circ\) or \(60^\circ, 0^\circ\) are additionally shown as broken and dotted lines, respectively. As shown in Fig. 3, the variation in the scattering cross section in the transmission direction is very small. In contrast, there is a decrease in the scattering cross section in the reflection direction \((\theta, \phi) = (30^\circ, 180^\circ)\) as the degree of deflection increases. In particular, the scattering cross section changes considerably when degree of deflection \(d_V/d_H\) is less than 0.025.

2.3 Diffraction Characteristics by Deflected Wire Located Out of Incident Plane

The effects of wire deflection on the diffraction characteristics are analyzed when the incident wave arrives from a general angle. Here, the plane wave is assumed to be vertically polarized. Figure 4 shows the scattering cross section in case of incident angle \((\theta, \phi) = (60^\circ, 45^\circ)\). As shown in Fig. 4, the diffraction direction is dispersed as the degree of deflection increases, but direction is not dispersed in two specific directions. One is the transmission direction and the other is the direction symmetrical to the transmission direction in the \(x-z\) plane, which is defined as the direction of maximum reflection.

Figure 5 shows the relationship between the degree of deflection and the scattering cross section in four directions: the transmission direction, direction of the maximum reflection, and directions A and B (A and B are shown in Fig. 4(a)). As shown in Fig. 5, the variation in the scattering cross section in the transmission direction and that in the direction of the maximum...
reflection are very small. In contrast, there is a decrease in the scattering cross section in direction A or B as the degree of deflection increases.

These results show that a slight spread in the diffraction direction results in a decrease in the scattering cross section. For example, when the degree of deflection is only 1/20 ($d_V/d_H=0.05$), there is a decrease in the scattering cross section of approximately 10 dB.

3. Effects of Bend in Wire on Diffraction Characteristics

3.1 Analysis Model for Bend in Wire

In Sec.2, it was found that the direction of the maximum reflection does not affect the wire deflection. In order to achieve a decrease in the scattering cross section in the direction of the maximum reflection, a slight bend is generated in the $y$-$z$ plane. Figure 6 shows a model for the bend in the wire. The location of the bend in the wire in the $x$-$y$ plane is expressed as

$$y = d_r \times \sin \left( \frac{2\pi x}{d_H} \right)$$

where $d_r$ is amplitude of the bend in the $y$-axis. The plane wave is assumed to arrive from angle $(\theta, \phi)$.

![Figure 6: Model for Bend in Wire](image)

Figure 4: Dispersion of Diffraction Direction (Case of $(\theta, \phi)=(60^\circ, 45^\circ)$)

![Figure 5: Relation Between Degree of Deflection and Scattering Cross Section (4 Directions)](image)

Figure 5: Relation Between Degree of Deflection and Scattering Cross Section (4 Directions)
3.2 Decrease in Scattering Cross Section in Direction of Maximum Reflection

Figure 7 shows the scattering cross section in the case of incident angle \((\theta, \phi)=(60^\circ, 45^\circ)\). The degree of deflection is set to 0.05. Figure 7 shows that the diffraction wave in the direction of the maximum reflection is dispersed as \(d_p\) increases.

Figure 8 shows the relationship between amplitude \(d_p\) of the wire and the scattering cross section in the direction of the maximum reflection when incident angle \((\theta, \phi)=(60^\circ, 45^\circ)\). Here, the plane wave is assumed to be vertically polarized and the degree of deflection \(d_v/d_H\) is set to 0.025, 0.05, and 0.125. In Fig. 8, \(d_v/d_H\) (\(d_p\) is normalized by \(d_H\)) is represented on the horizontal axis and the scattering cross section in the direction of the maximum reflection is represented on the vertical axis. As shown in Fig. 8, there is a decrease in the scattering cross section in the direction of the maximum reflection \((\theta, \phi)=(120^\circ, 135^\circ)\) as \(d_p/d_H\) is increased. Furthermore, we find that the amplitude of the wire in the \(y-z\) plane does not affect the scattering cross section.

4. Conclusion

We found that the diffraction direction was dispersed by wire deflection, and the scattering cross section was changed. In particular, we found that there was a decrease in the scattering cross section even with a slight deflection in the wire. For example, there was a decrease in the scattering cross section of approximately 10 dB, even if the deflection length compared to the length of the wire was only 1/20. When the deflection was too large, however, the effect on the decrease in the scattering cross section was slight. In contrast, the transmission direction and the direction of the maximum reflection were not influenced by the wire deflection. Furthermore, we found that there was a decrease in the scattering cross section in the direction of the maximum reflection due to the bend in the wire.

References