18PB-024

Propagation Characteristics of Cylindrical Surface Waves on Periodically Corrugated Metal

周期的コルゲートによる円柱表面波の伝搬特性

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We numerically and experimentally study the characteristics of cylindrical surface wave (CSW) on metallic cylinders with rectangular corrugation. Cavity resonant method using a vector network analyzer is applied to examine dispersion characteristics of CSW. CSWs are classified into bounded surface-wave (BSW) and hybrid surface-wave (HSW). BSW is formed near the upper cut-off frequency and is well confined to the corrugation surface. HSW is formed away from the upper cut-off frequency and has similar dispersion characteristics to Sommerfeld wave. HSW propagates along the surface of metallic cylinder with a broad spread around the cylindrical surface.

1. Introduction

Recently, expectations for various applications of high-frequency electromagnetic waves from millimeter to submillimeter waves are increasing. For propagations of these electromagnetic waves, surface waves on the metal cylinder with periodic structures may be used. Bloch waves are formed by the periodic structure. And Sommerfeld wave by plasma of metal surface also exists. They are mixed in the cylindrical surface wave (CSW) [1], [2]. In actual devices, reflections at both ends of the metallic cylinder quantize the electromagnetic modes into resonant axial modes. These resonant modes are determined by measurements of S-parameters using a vector network analyzer (VNA).

In this study, a cavity resonant method using VNA is applied to examine dispersion characteristics of CSW. And we numerically and experimentally analyze the CSWs on metal cylinders with rectangular corrugations.

2. Experimental Setup

Figure 1 shows schematic diagrams of the measuring system using VNA. Copper disk

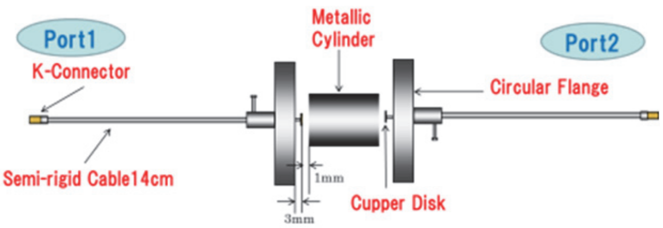

Fig.1. Schematic of metallic cylinders measurement systems

attached to the core of the semi-rigid cable excites the axial mode. Disk diameter is Φ10mm. Circular metal flange has 75 mm diameter made of aluminum and supports the excitation. We use two metallic cylinders. The parameters are an average corrugation radius of 13 mm, a corrugation amplitude of 1.02 mm, a corrugation width of 1.53 mm, and a periodic corrugation length of 2.98 mm. Straight cylinder has a radius of 14 mm. There is a gap of 1 mm between the metallic cylinder and the disk, which have the same central axis as the metal cylinder. VNA is used to measure the scattering (S) parameters: the microwave reflection from the structure and the transmission through the structure. In this system, CSWs form the standing wave along the axial direction by reflections. A mathematical formulation for a rectangular corrugation is presented in Ref. [3].

3. Experimental Results

Figure 2 (a) shows the experimentally measured transmission and reflection of the CSW on the corrugated cylinder. The resonances appear as spikes where reflection decreases while transmission increases. Figure 2 (b) shows the dispersion diagram of axial mode obtained from Fig. 2(a). Spikes in transmission and reflection correspond to axial modes with $k_z = \pi N/L$, where N is a natural number from N = 0 to 10 and L = 10. The axial mode at the π point (N = 10) can be identified from the transmission only (Fig.2). In addition, some peaks are not identified as axial modes of the CSW. This may be due to a poor coupling of the disk to the CSW and additional

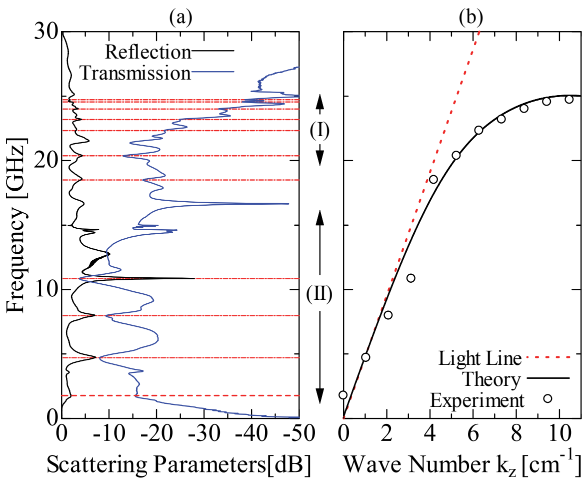

Fig.2. (a) Reflection and transmission profiles of corrugated cylinder. (b) frequency versus wave number for CSW.

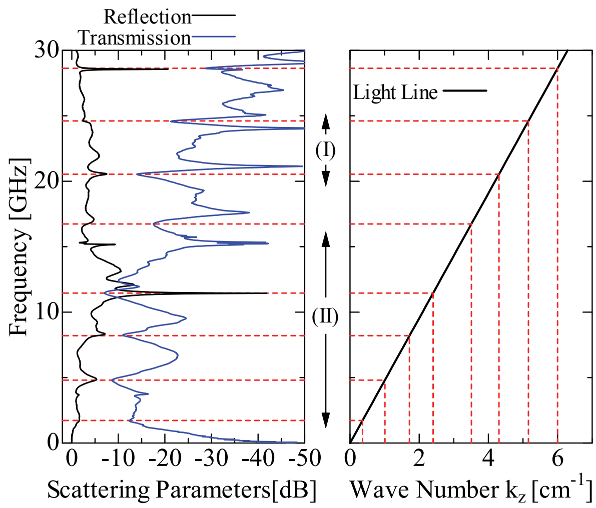

Fig.3 Reflection and transmission profiles of Straight cylinder.

resonant modes caused by the excitation section composed of the cupper disk and cable.

Figure 3 shows the axial mode measured for a straight cylinder. In the region (II), clear difference is not observed between Figs. 2 and 3. But significant difference can be observed in the region (I).

CSW of the corrugated cylinder may greatly depend on periodic structure and Bloch wave is dominant in the region (I). In the region (II), CSW has the dispersion characteristics close to the light line and Sommerfeld wave is dominant. CSWs on the corrugated cylinder are named bounded surface-wave (BSW) in the region (I) and hybrid surface-wave (HSW) in the region (II). Since the Sommerfeld wave has almost the same dispersion as the light line, the axial mode frequencies are plotted on the light line as shown in the right frame of Fig. 3. Structure length L = 39.2 mm is obtained from the $L = \pi / \Delta k$, which does not match the length

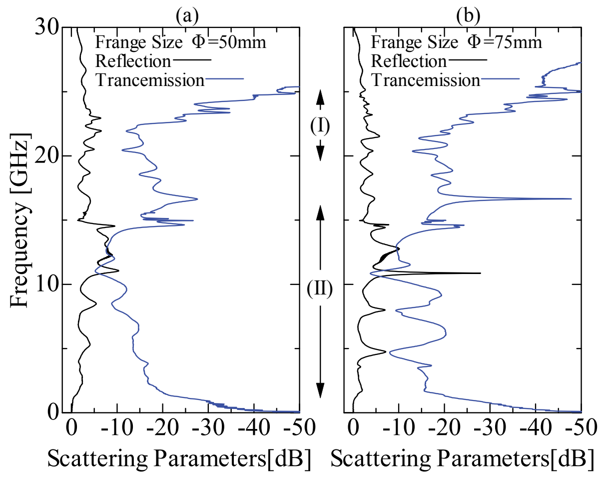

Fig. 4. Reflection and transmission profiles of corrugated cylinder by Using flange (a) Φ = 50 mm and (b) Φ = 75 mm.

of the straight cylinder and agrees with the distance between the circular flanges. Thus, Sommerfeld wave may be reflected by the flanges, not by the corrugation ends.

We examine the characteristic of CWSs on corrugated cylinder by changing radius of the circular flange from 50 mm to 75 mm (Fig.4). Spikes become sharper by increasing the radius of the flange in region (II). Therefore, it is presumed that HSW propagates with a about 75mm-spread around the cylindrical surface.

4. Summary

CSW of the corrugated cylinder is classified into BSW region (I) and HSW in region (II). Frequency region of each CSW is identified by comparing axial mode of Fig. 2 and Fig.3. BSW is well confined to the surface corrugation, and axial modes are determined by the corrugation parameters including the total length. HSW has an axial mode similar to the CWS of the straight cylinder, which shows the dispersion characteristics close to the light line. In addition, HSW has the propagating property with a broad spread around the cylindrical surface. This propagation property resembles Sommerfeld wave and correspond to the hybrid surface plasmon of Ref. [4].

References

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