Study on Primary Radiator using Leaky Wave Antenna with Left Handed Waveguides

Shigeyuki Nishimura, Hiroyuki Deguchi, Mikio Tsuji
Department of Electronics, Doshisha University, Kyoto, 610-0394, Japan
eup1304@mail4.doshisha.ac.jp

Abstract – **This paper proposes a primary radiator using leaky-wave antenna with left-handed cylindrical waveguide. Negative permeability is realized by the cutoff TM$_{01}$ mode in a hollow waveguide and also negative permittivity is realized by the cutoff dominant TE mode in a sector waveguide with a ridge. Then the left-handed leaky-wave antenna with slits opened is applied to a primary radiator without sub-reflecting mirror by radiating backward, and can be used a reflector antenna loaded its primary radiator. Its effectiveness is verified numerically from the radiation characteristics.**

Index Terms — **Leaky-wave antennas, Primary radiator, Reflector antenna, Metamaterial, CRLH transmission line.**

1. Introduction

Metamaterial which is an artificial medium having simultaneously equivalent negative permittivity and negative permeability has recently received a lot of attention [1], [2]. Composite right/left-handed transmission lines (CRLH-TLs) consisting of various shapes have been reported [3]. In a cylindrical waveguide, the method constructing CRLH waveguide constructed by combining the section with negative permeability based on the cutoff TM$_{01}$ mode and the section with negative permittivity based on the cutoff dominant TE mode in a sector waveguide has been reported. To achieve the balanced condition without bandgap, a square conductor ridge is introduced in the center of the sector waveguide, thereby adjusting the cutoff frequency of the dominant TE mode. Then, the CRLH waveguide can be successfully applied to a leaky-wave antenna by setting slits on the outer conductor walls radiating from backward to forward. So, the proposed primary radiator using its leak-wave antenna can be used reflector antenna, when is operates for left-handed passband region. The effectiveness is verified from the calculated transmission characteristics, and the radiation characteristics.

2. Structure of CRLH-TL

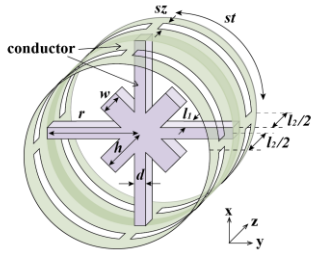


Fig. 1. Structure of the proposed CRLH cylindrical waveguide with slits opened unit-cell.

If the TM mode is below cutoff, the waveguide has equivalently negative permeability medium which can be expressed as a series capacitor, and also if the TE mode is below cutoff, the waveguide has equivalently negative permittivity medium which can be expressed as a shunt inductor. The left-handed medium is realized below cutoff in both modes simultaneously. In a hollow cylindrical waveguide, when a coaxial line is used as input/output waveguides, the field distribution of its dominant TEM mode is very similar to that of the TM$_{01}$ mode. As a result, the TM$_{01}$ mode can be mainly excited by the coaxial line, while excitation of the lowest-order TE$_{11}$ mode is limited. As for the cutoff TE mode, we propose to introduce the dominant TE mode in a sector cylindrical waveguide which is divided into four parts by thin conductor walls. The field distribution of this mode is almost similar to that of the TM$_{01}$ mode, so that it is expected that both modes may be transformed to each other with less mismatching on the connection plane between the TM and TE waveguides. However, the cutoff frequency of the dominant TE mode in the 4-divied sector waveguide is higher than that of the TM$_{01}$ mode. So we introduce a ridge in the center of the sector guide. The cutoff frequency of the dominant TE mode can be made lower.

The unit-cell of the proposed CRLH cylindrical waveguide is shown in Fig. 1. The lengths of the TE mode and the TM mode sections are l_1=1.0[mm], and l_2=10.0[mm], respectively. The radius r=10.12[mm] of the cylindrical waveguide in both sections is equal to each other. The thickness of the conductor wall and the width of the ridge are d=2.0[mm] and w=3.0[mm], respectively. A hollow coaxial line which has the same outer radius and the characteristic impedance 50Ω is used as input and output waveguides.

To use the leaky-wave antenna, slits are opened on the outer conductor walls of the TM waveguide section with the thickness t=1.0[mm]. The slits length is sz=1.0[mm] in the z direction and its width in the θ direction is st=14.13[mm]. Eight slits are opened by each unit-cell, suppressing the grating lobes at lower left-handed frequency. In opposite side of input, end of the waveguide sets to be covered a conductor wall, not relation another any radiation except to leaky-wave radiation from slits.

3. Analytical results

(1) Transmission Characteristics

In this section, dispersion diagram is derived from the Bloch-Floquet theorem and also transmission characteristic is calculated for the guide with the finite 12 unit cells. Here calculations are performed by HFSS (Ansys Inc.). Fig. 2(a) shows the dispersion diagram for various heights of the ridge *h*. It is found from this figure that the left-handed passband region is formed in the lower frequency side, while the right-handed pass region is formed in the higher frequency side, and the bandgap lies between both passband regions. In the case of *h*=4.5mm, the balanced condition in which the bandgap disappears is realized. Fig. 2(b) shows the transmission characteristic for 12 unit cells of the structure fulfilling the balanced condition. The passband starts from 8.82GHz in the left-handed region and smoothly continue to the right-handed region, keeping low insertion loss.

(2) Radiation Characteristics

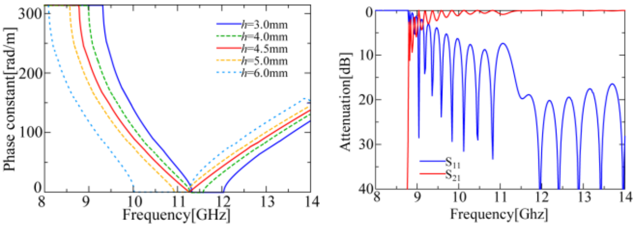
CRLH leaky-wave antenna is designed as shown in Fig. 1 with slits opened. To determine to operate frequency as leaky-wave antenna, Fig. 3(a) shows VSWR each frequency. For 10.5GHz, the lowest number is 1.14 in the left-handed passband region. And Fig. 3(b) shows the calculated radiation patterns on the plane of from φ=0°, 45°, 90°, 135° and 180° at 10.5GHz. The highest gain 6.8dB is obtained in the direction of θ=±140°. Note that main and cross polarized radiation levels are almost similar. It is verified that the leaky-wave antenna can radiate to backward in the inverse z direction.

(3) Primary Radiator

Reflector antenna with the proposed leaky-wave antenna as a primary radiator is designed. First, for design the reflector, the phase center distance is *k*=50[mm] from the reflector to a plane at the between input exciter and leaky-wave antenna unit-cell, and then a curved surface of the reflector is calculated. To set the reflector antenna, It becomes integrated the leaky-wave antenna and the calculated reflector as shown in Fig. 4(a). Fig. 4(b) shows the calculated radiation patterns. The highest gain 16.6dB is obtained in the direction of θ=±8°, and side-lobe level is 3.7dB in the direction of θ=±36°.However, this beam shapes are torus, because the primary radiator radiating concentrically is unable to radiate for θ=0°.

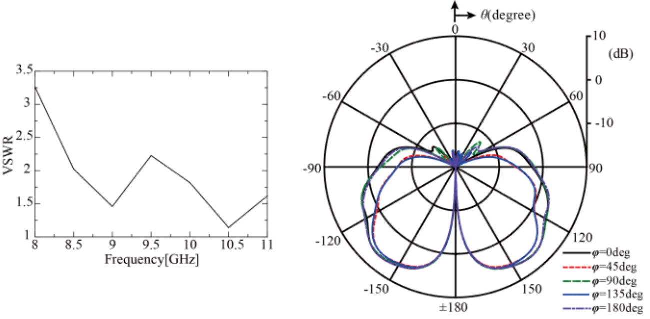
4. Conclusion

We have proposed the primary radiator using leaky-wave antenna with left-handed waveguides. Usefulness of the proposed primary radiator has been verified from radiation characteristics for the finite-number of the unit cells.



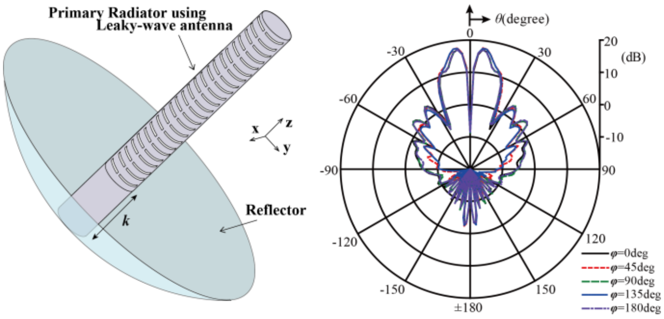
(a) (b)

Fig. 2. (a) Dispersion diagram for various heights of the ridge *h*, and (b) transmission characteristics for 12 unit cells for *h*=4.5[mm].



(a) (b)

Fig. 3. Leaky-wave antenna. (a) VSWR, and (b) radiation characteristics at 10.5GHz.



(a) (b)

Fig. 4. Reflector antenna. (a) Structure of reflector antenna, and (b) radiation characteristics with reflector at 10.5GHz

Acknowledgment

This work was supported in part by a Grant-in-Aid for Scientific Research (c) (24560428) from Japan Society for the Promotion of Science.

References

[1] V. Veselago, "The electrodynamics of substrates with simultaneously negative values of ε and μ," Soviet Physics Uspekhil, vol. 10, no.4, pp.509-514, 1968.

[2] R. A. Shelby, D. R. Smith, and S. Schultz, "Experimental verification of a negative index of refraction," Science, vol.292, no.5514, pp.77-79, 2001.

[3] M. Yuki, M. Kishihara, I. Ohta, "Constitution of left-handed waveguide based on cutoff TE- and TM-mode," IEICE Technical Report, MW2013-65, pp.43-47, May 2014.