Dual Frequency Band Operations of Composite Right/Left Handed Transmission Line and Inverted-F Antenna

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1. Introduction

Recently, mobile devices are reduced in size and have many functions. Small antennas for different systems are installed in the limited space. Especially in the terrestrial digital broadcasting application, small and broadband antenna is required. As a candidate of compact broadband antenna, a leaky wave antenna (LWA) using a composite right/left handed transmission line (CRLH-TL) composed of a ladder network has been investigated [1],[2]. It was cleared that the operating bandwidth and the attenuation constant depend on the antenna height. In addition, flat gain characteristic was confirmed when number of cells is large. However, the CRLH-TL has the slow wave region at higher band than the fast wave region for using as the LWA. Therefore, this guide band can be used for exciting other antenna for the different system.

This paper presents the simulation results of the LWA terminated with an inverted-F antenna. The leaky wave region of the CRLH-TL composed of the ladder network is designed from 400 MHz to 800 MHz. The inverted-F antenna is designed at 2 GHz. The S_{11} and the radiation characteristics of the LWA terminated with the inverted-F antenna are investigated. And the size effect of finite ground plane to the radiation characteristics is clarified.

2. Configuration of Leaky Wave Antenna

Fig. 1 shows the LWA terminated with the inverted-F antenna. In this figure, the LWA is composed of the ladder network. Shunt L_L and series C_L are left-handed parameters. The unit cell length p = 20 mm, the wire radius R = 0.3 mm, and the height of the main line from the ground plane H = 40 mm. A vertical wire is located under the center of two C_Ls in a unit cell. L_L is inserted in the center of a vertical wire. C_L is inserted in the each center of right/left side of horizontal wire of a unit cell. Right-handed parameters, series L_R and shunt C_R are calculated by Eq. (1) and (2) [3],

$$L_R = \frac{\mu_0 p}{\pi} \ln(H / R), \tag{1}$$

$$C_R = \pi \varepsilon_0 p / \ln(H / R). \tag{2}$$

In this simulation, C_L = 10.5 pF, L_L = 230 nH are used. Dispersion diagram of 1 cell is shown in Fig. 2. Leaky frequency (fast wave region) of the LWA is from 377 MHz to 954 MHz. In addition, the bloch impedance Z_B is about 250 Ω at the fast wave region as shown in Fig. 3. As the LWA terminated with Z_B, 10 cells are arranged on the straight line. The length of CRLH-TL is 200 mm. Fig. 4 shows The S_{11} and the S_{21} characteristic of the LWA. From this, not only low band but also higher band signals are leaked from the LWA. Fig. 5 shows the radiation characteristics of E_θ component in zx plane at the range 400 MHz to 800 MHz. As frequency increases, the beam directions turn upward. In Fig. 5, the effect of the reflected wave is small due to Z_B terminal.

3. Terminal Antenna for Leaky Wave Antenna

A terminal antenna has to be located the same height as the LWA. In this simulation, as shown in the left side of Fig. 1, an inverted-F antenna on a floating ground plane is used. This inverted-F antenna is designed on the bloch impedance of the unit cell of the CRLH-TL. The floating ground plane size α = 75 mm, the antenna wire length l = 38.5 mm, the distance between the antenna wire and the floating ground plane h_s = 4 mm, the distance between a short-circuit wire and a feeding point ls = 4.7 mm. The floating ground plane does not contact with the ground plane, on which the LWA is located. The inverted-F antenna and the floating ground plane are in the free space. The impedance of this antenna is about the range from j15 to j30 Ω at the fast wave region, (55.1 - j7.5) Ω at 2 GHz.

4. Leaky Wave Antenna terminated Inverted-F Antenna

The structure of the proposal antenna is shown in Fig. 1. Fig. 6(a) shows the S_{11} characteristic of the proposal antenna. At leaky band frequencies, S_{11} is about the range from -1 dB to -3 dB. Fig. 6(b) shows the radiation characteristics of E_θ component in zx plane at the range from 400 to 800 MHz. Compared with Fig. 5, each maximum gain increases and the beam directions are upward. Fig. 7 shows the radiation characteristics of E_θ component in zx plane at 2 GHz of the LWA, the inverted-F antenna, and the LWA terminated with the inverted-F antenna. Fig. 8 shows the electric field of the LWA terminated with the inverted-F antenna at 2 GHz. As shown in Fig. 8, the radiation at 2 GHz is mainly generated from the inverted-F antenna. In the simulated system, there is a mismatch between two antennas. That is, the bloch impedance of CRLH-TL is about 250 Ω. In addition, the impedance of the inverted-F antenna is from j15 to j30 Ω at the fast wave region. For this reason, the characteristics in Fig. 6(b) are left-right symmetry due to the effect of the travelling wave and the reflected wave that occurs in the connection point of two antennas.

5. Size effect of finite ground planes

The simulated results are affected by ground plane. When the ground plane width W is varied and the ground plane length L = 500 mm, C_L also changes. For this reason, it is necessary to design the unit cell again. In addition, the inverted-F antenna is also designed again because the design of the inverted-F antenna is based on the bloch impedance of the unit cell. Architectural parameters are as follows. When W = 500 mm, C_L= 11.25 pF, L_L = 212.0 nH, bloch impedance Z_B is about 250 Ω. The design of the inverted-F antenna is the same as the infinite ground plane case. When W = 50 mm, C_L= 10.37 pF, L_L = 218.8 nH, Z_B is about 232 Ω, the inverted-F antenna wire length l = 38.5 mm, the distance between the short-circuit wire and the feeding point l_s = 5 mm, the distance between the short-circuit wire and the feeding point h_s = 4 mm. When $W \approx 0$ mm (wire), C_L= 7.67 pF, L_L = 345.2 nH, Z_B is about 380 Ω, l = 35.4 mm, l_s = 5 mm, h_s = 7 mm. Fig. 9(a) and Fig. 9(b) show the radiation characteristics of E_θ component in zx plane at 600 MHz and 2 GHz of each ground width. At 600 MHz, the symmetry in Fig. 6(b) collapses. That is, the contribution of the reflected wave changes. However, the radiation characteristics at 2 GHz do not change particularly.

6. Conclusions

This paper presents the CRLH-TL terminated with the inverted-F antenna. The radiation characteristics of two different bands are shown. From these results, practical use of the CRLH-TL terminated with other antenna for two bands is clarified. However, the value of the leakage from the LWA is still more low level. In order to achieve high gain of the LWA, it is required to control the attenuation constant of the unit cell.

References

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[2] S. Kamada, N. Michishita, Y. Yamada, “Short-Length Leaky Wave Antenna using Composite Right/Left-Handed Ladder Network for UHF Band,” 2010 IEEE International Workshop on Antennas and Technology, PS2.8, pp.1-4, Lisbon, Portugal, March 2010.
[3] C. Caloz, and T. Itoh, Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications, John Wiley & Sons, Inc., 2006.

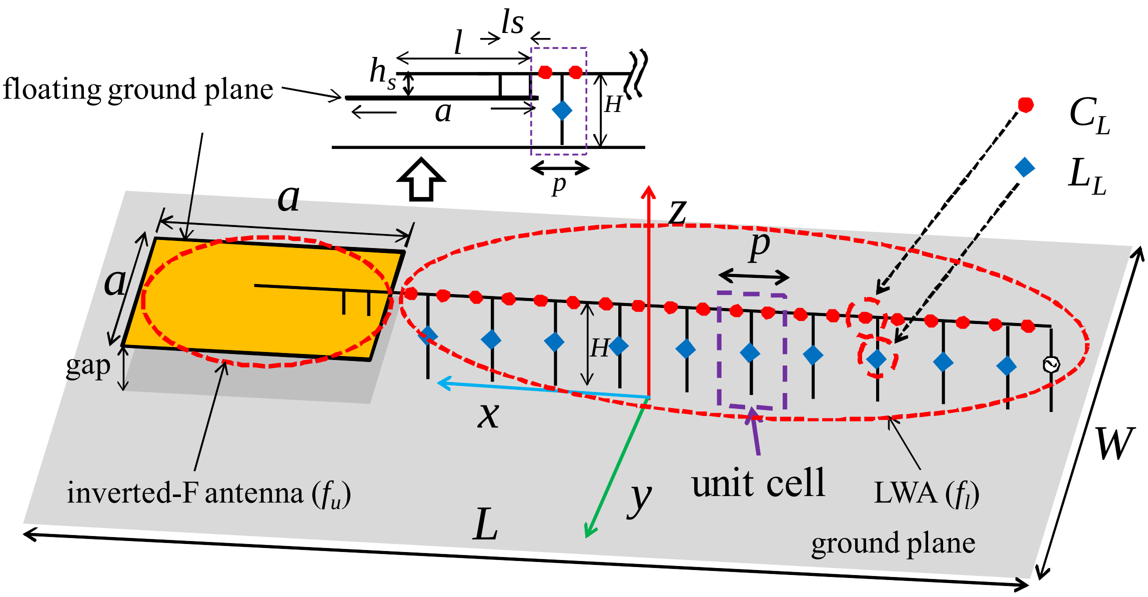


Fig. 1 Leaky wave antenna terminated with inverted-F antenna

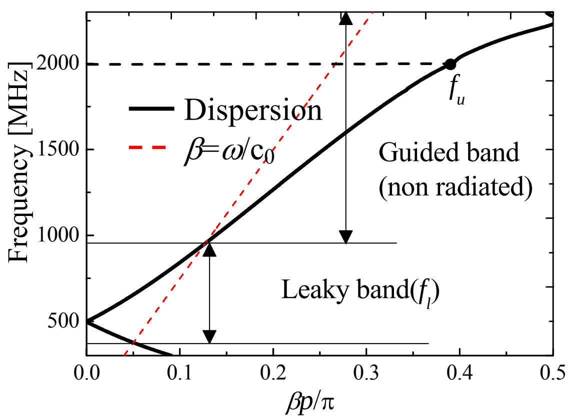


Fig. 2 Dispersion diagram

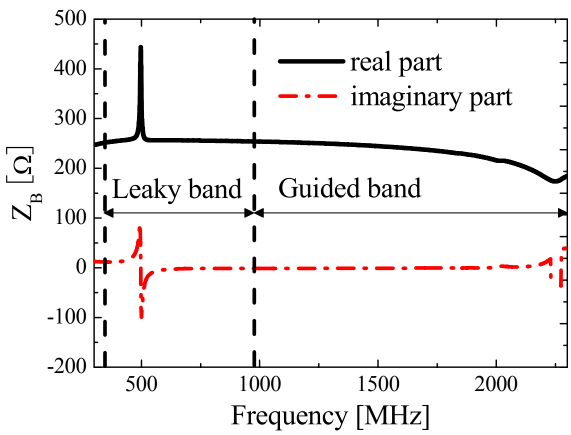


Fig. 3 Bloch impedance

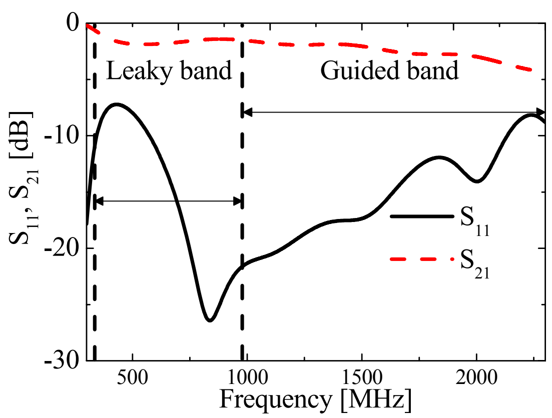


Fig. 4 S_{11}, S_{21} characteristics of CRLH-TL

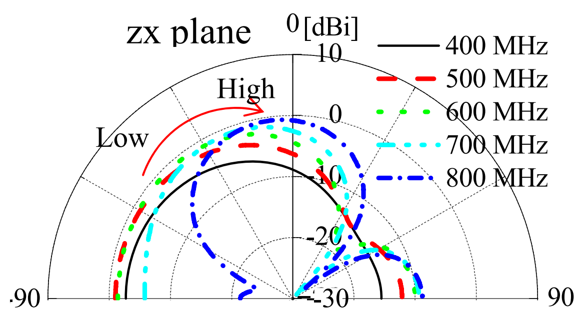
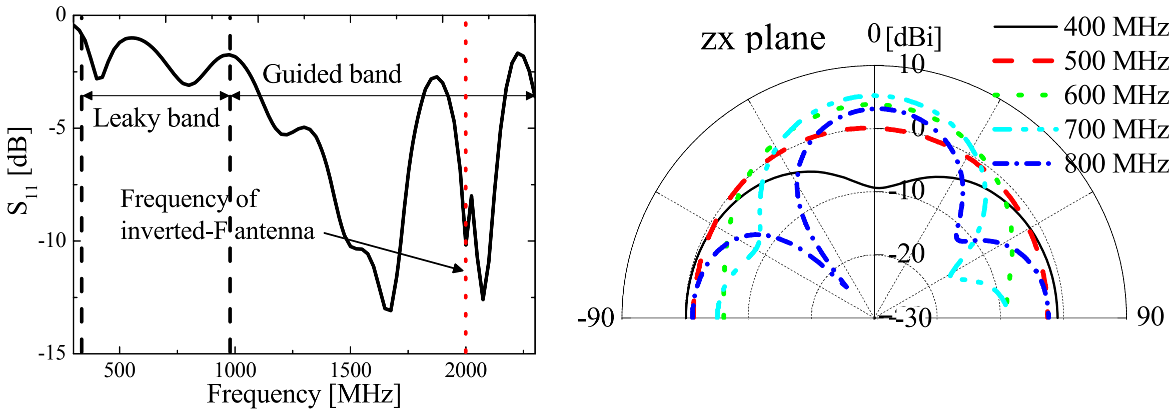


Fig. 5 Radiation characteristics (E_θ) (termination = Z_B)



(a) S_{11} characteristics (b) Radiation characteristics (E_θ)

Fig. 6 S_{11} and radiation characteristics of LWA with inverted-F antenna

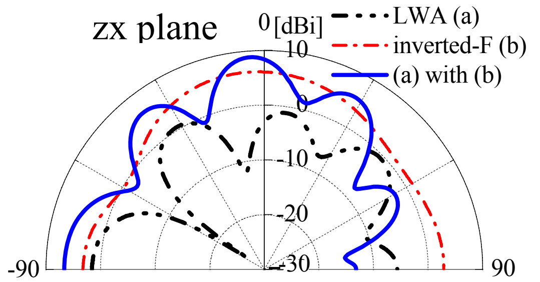


Fig. 7 Radiation characteristics (E_θ) at 2 GHz

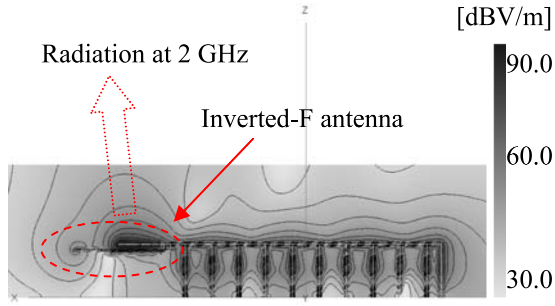
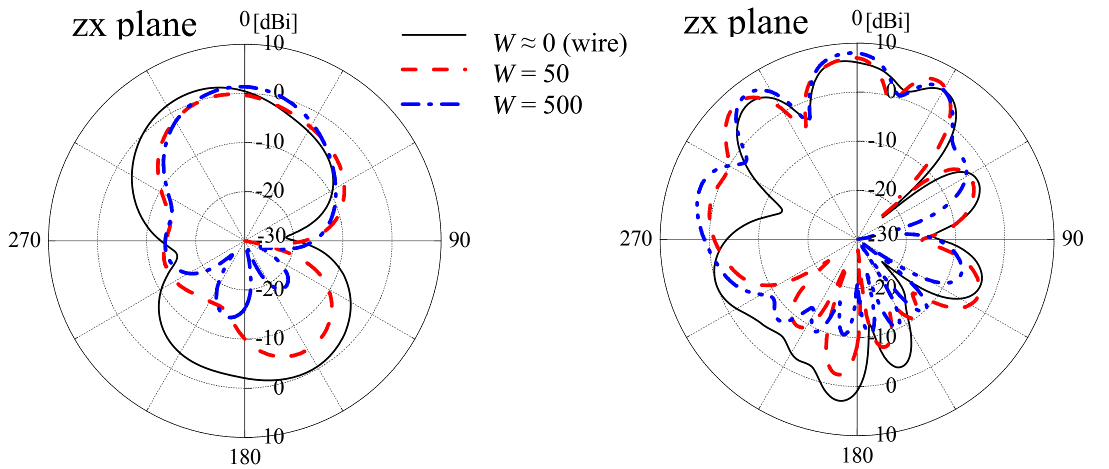


Fig.8 Electric field at 2 GHz



(a) Radiation characteristics of at 600 MHz (b) Radiation characteristics at 2 GHz

Fig. 9 Radiation characteristics (E_θ) for variable GND widths