Leaky Wave Antenna Using Composite Right/Left-Handed Transmission Line with Rectangular Feeding Structure

#Hirohisa Kitahara, Naobumi Michishita, and Yoshihide Yamada
Department of Electrical and Electronic Engineering , National Defense Academy
1-10-20 Hashirimizu, Yokosuka, Kanagawa, 239-8686
E-mail: naobumi@nda.ac.jp

Abstract

Small leaky wave antennas using composite right/left-handed transmission line have been investigated to achieve broadband operation. To improve the gain, this paper proposes rectangular feeding structure. The bandwidth of 51% and the minimum gain of 0.3 dBi are achieved in the case of two cells (0.27λ).

Keywords : Leaky wave antenna Metamaterial Broadband antenna

1. Introduction

A leaky wave antenna (LWA) using composite right/left-handed (CRLH) transmission line (TL) composed of ladder network has been investigated [1]. The effect of transmission line length and height on the gain and bandwidth is clarified in [1]. In order to increase the gain of the LWA, mushroom-shaped unit cell has been investigated in [2]. Chip capacitance is used for series capacitance. The bandwidth of 113% and the maximum gain of 1 dBi at 1.6 GHz are achieved experimentally in the case of three cells (0.32λ) in [2]. In order to reduce the size of LWA for the application of cellular phones or mobile devices, this paper proposes the mushroom-shaped unit cell with parallel plate capacitance and rectangular feeding structure in the case of two cells. Moreover, the simulation results are verified by using the measured transmission characteristics and radiation characteristics.

2. Composite Right/Left-Handed Transmission Line with Parallel Plate Capacitance

Fig. 1 shows the configuration of the unit cell using mushroom structure with parallel plate capacitance for series capacitance (C_L). The unit cell exists on the finite ground plane. For shunt inductance (L_L), self-inductance of vertical via is used. Structural parameters are p = 20 mm, LW = 20 mm, h = 10 mm, g = 1.3 mm, h_c = 9 mm, r = 2 mm. Fig. 2 shows the dispersion characteristics of unit cell when the width of finite ground plane is from 30 mm to 40 mm. Small band gap exists at around 2.35 GHz. Fast wave region is from 1.86 GHz to 3.62 GHz in the case of GW = 30 mm. Fig. 3 shows the Bloch impedance (Z_B) characteristics. The peak at 2.35 GHz is affected by band gap. The Z_B characteristics are flat at 50 Ω. Therefore, these unit cells provide broadband operation. Fig. 4 shows S_{11} characteristics of the CRLH-TLs using two cells without the effects of feeding structure in the case of GW = 30 mm, 40 mm, and 50 mm. Their bandwidths are 75%, 73%, and 76%, respectively.

3. Effect of Feeding Structure

The CRLH-TL with feeding structure consists of periodically aligned unit cells as shown in Fig. 5. The parallel plates to ground plane compose the main line of CRLH-TL. Three types of the feeding structures are compared to achieve broadband impedance matching. Fig. 6 shows S_{11} characteristics of three types of the feeding structures. The rectangular and trapezoidal feeding structures can achieve broadband impedance matching. However, the triangular feeding structure has dual band characteristics. Fig. 7(a) shows maximum gain of E_θ component at 3 GHz in *zx* plane and the bandwidths for variable *GL* in the case of the 2 cells with *GW* = 30 mm. The upper base of triangular and trapezoidal structure which is connected with main line is 20 mm. The lower base of trapezoidal structure is 10 mm. Feed port is excited as 50 Ω and termination port is terminated in 50 Ω. As *GL* increases, the maximum gain of each structure increases. Under each condition of *GL*, the gain of rectangular feeding structure is higher than that of other feeding structures. In addition, the bandwidths also increase as *GL* increases. The bandwidths of the CRLH-TL with rectangular feeding structure are 41%, 51% and 67% at *GL* = 50 mm, 60 mm, and 80 mm. Fig. 7(b) shows the maximum gain of E_θ component at 3 GHz in *zx* plane and the bandwidths for variable *GW* in the case of two cells with *GL* = 60 mm. As *GW* increases, the bandwidths gradually increase. The bandwidths of rectangular feeding structure are 51%, 58%, and 63% at *GW* = 30 mm, 40 mm, and 50 mm. The effects for the maximum gains of *GW* are little. However, under each condition of *GW*, the gain of rectangular feeding structure is higher than that of other structures. Fig.8 shows the electric field distributions at the center between feed and first parallel plates. The electric field distributions of the waveguide feed and that of the rectangular feeding structure are vertically distributed. On the other hand, the electric field distribution of the triangular structure is affected by its configuration. Therefore, the rectangular feeding structure is suitable for exciting the CRLH-TL with two cells of mushroom structures with parallel plate capacitances.

4. Experiment

For practical purpose, dielectric substrate is used as main line and parallel plate capacitor of the CRLH-TL as shown in Fig. 9. The thickness of dielectric substrate is 1.6 mm and its relative permittivity is 2.6. Structural parameters of the LWA using two cells are *GW* = 30 mm, *GL* = 60 mm, *LW* = 20 mm, *L* = 40mm, *g* = 1.6 mm, *h* = 8 mm, h_c = 7.5 mm, *r* = 1.5 mm, *a* = 4.2 mm, *b* = 8.4 mm. The fabricated antenna is shown in Fig. 10. Both ends of the CRLH-TL are connected with the SMA connector under ground plane via the rectangular feeding structure respectively. Simulated and measured results of S_{11} and S_{21} characteristics are shown in Fig. 11. The simulated and measured results agree well. However, there is discrepancy of upper limit of operating band due to manufacturing error. The bandwidths of simulated and measured results are 59% and 51%, respectively. S_{21} of measured result is lower than −1.2 dB between operating band. Radiation characteristics are shown in Fig. 12. In simulated results, the maximum gains are 0.6 dBi, 1.3 dBi, and 1.6 dBi at 2 GHz, 2.2 GHz, and 3 GHz. The gains are smaller than the model without dielectric substrate. In measured results, the maximum gains are 0.3 dBi, 1.1 dBi, and 1 dBi at 2 GHz, 2.2 GHz, and 3 GHz. The simulated and measured results agree well.

5. Conclusions

This paper presents the LWA using mushroom-shaped unit cells with parallel plate capacitance and the rectangular feeding structure. The characteristics of the LWA are compared with the trapezoidal feeding structure and the triangular feeding structure. For variable ground plane length and width, the maximum gain of the LWA with rectangular feeding structure is higher than that of other feeding structures. Therefore, in order to obtain impedance matching for this CRLH-TL, the rectangular feeding structure is available. The simulated results are verified experimentally. The bandwidth of 51% and the minimum gain of 0.3 dBi are achieved by fabricated antenna in the case of two cells (0.27λ).

References

[1] S. Kamada, N. Michishita, and Y. Yamada, "Leaky Wave Antenna Using Composite Right/Left-Handed Transmission Line Composed of Ladder Network for UHF Band," *IEICE Trans. Commun.*, vol.E93-B, no.10, pp.2562-2569, Oct. 2010.

[2] H. Kitahara, W. Kim, N. Michishita, and Y. Yamada, “Leaky Wave Antenna Using Broadband Composite Right/Left-Handed Transmission Line,” *IEEE AP-S Int’l Symp.*, Spokane, WA, July 2011, to be presented.

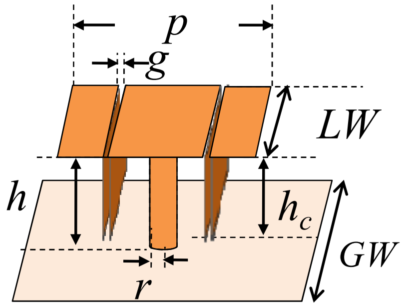


Fig. 1 Configuration of unit cell.

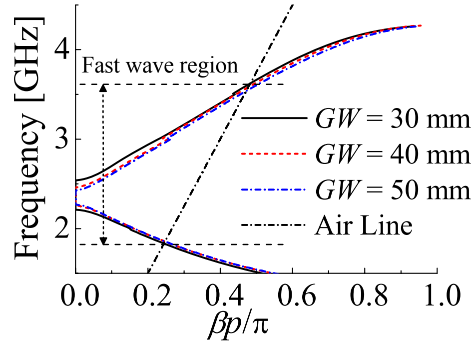


Fig. 2 Dispersion characteristics (Unit cell).

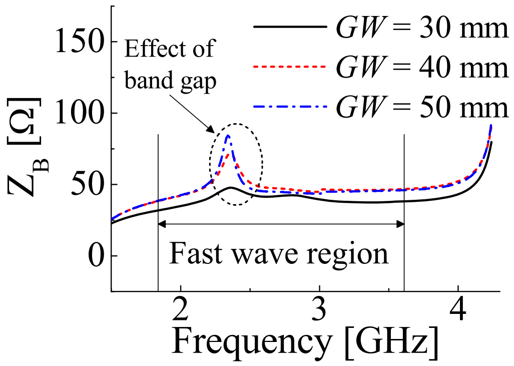


Fig. 3 Bloch impedance (Unit cell).

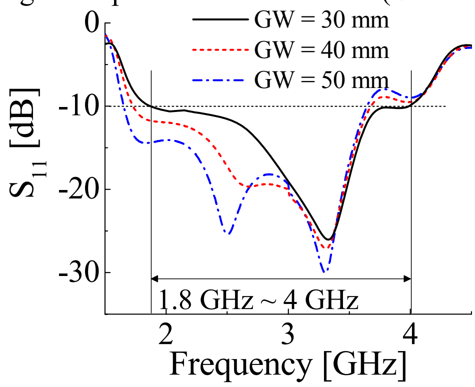


Fig. 4 S_{11} characteristics of two cells.

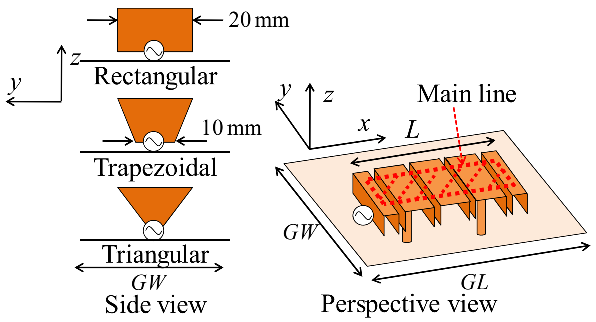


Fig. 5 Configuration of CRLH-TL (2 cells) and three types of feeding structures.

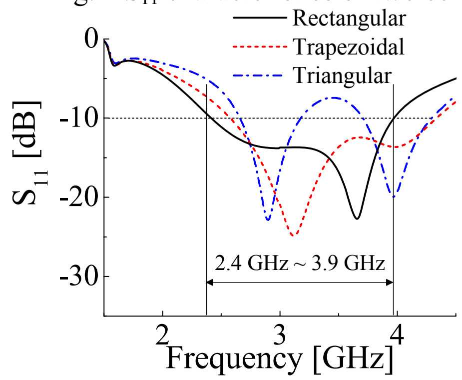
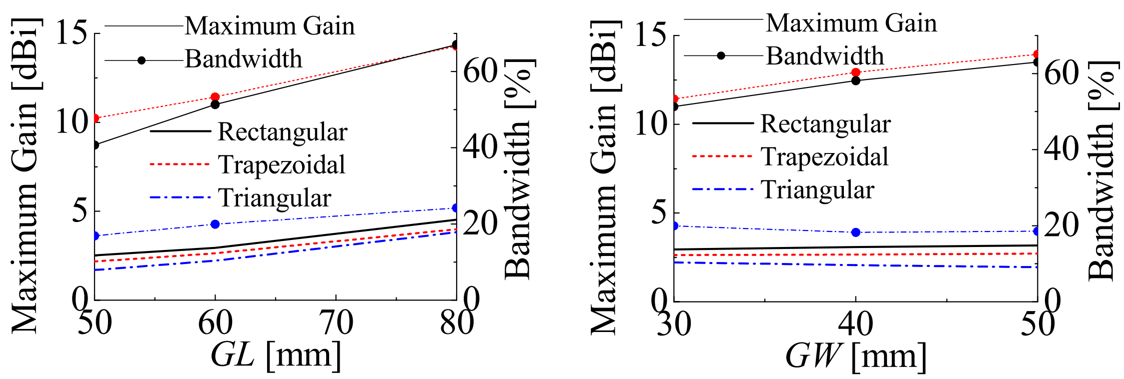


Fig. 6 S_{11} characteristics of three types of feeding structures



(a) For variable GL (GW = 30 mm) (b) For variable GW (GL = 60 mm)

Fig. 7 Maximum gain and bandwidth (2 cells, E_θ component, 3 GHz, *zx* plane).

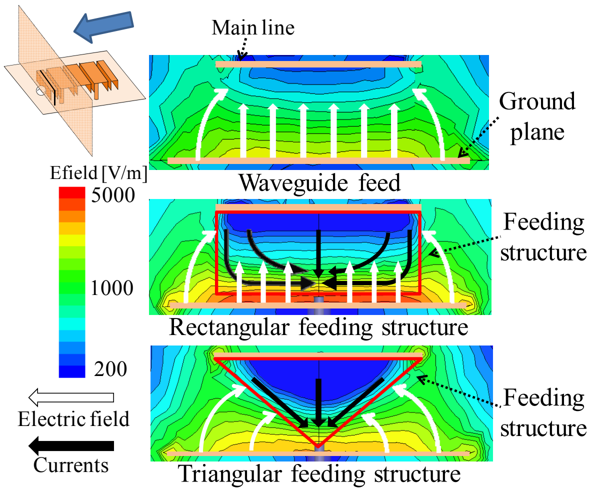


Fig. 8 Electric field distribution near feed portions

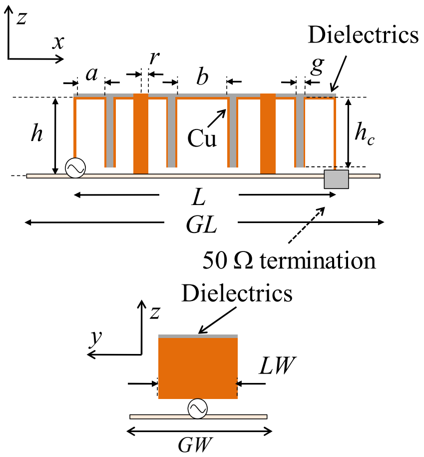


Fig. 9 Actual model using dielectric substrate

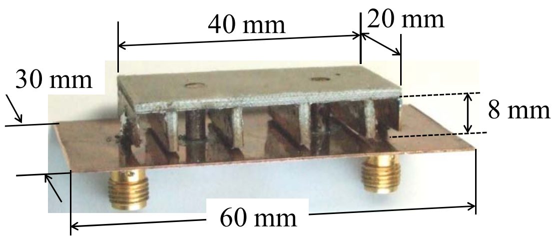


Fig. 10 Photograph of fabricated antenna

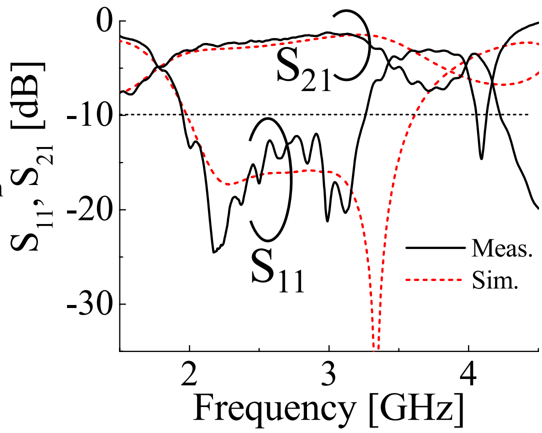
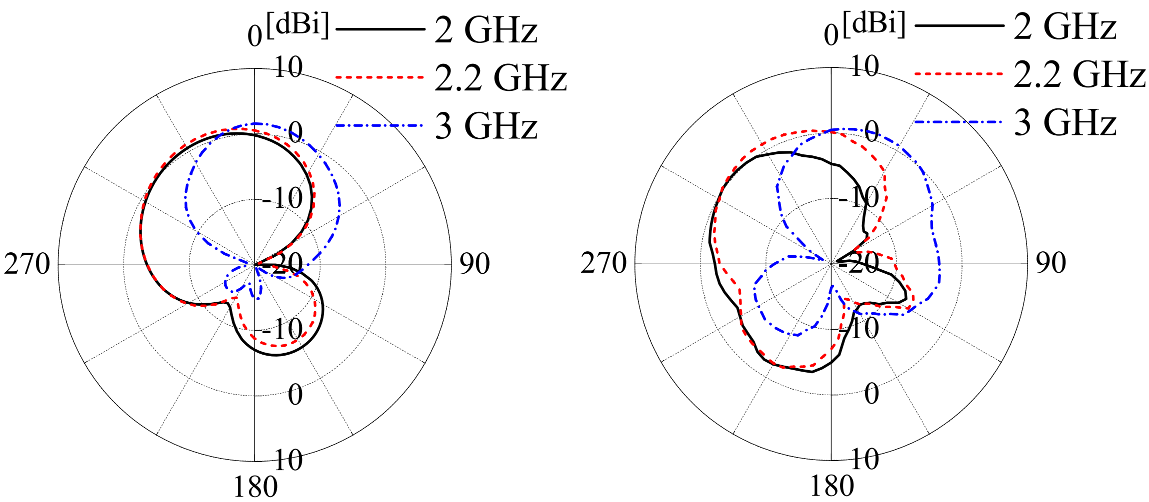


Fig. 11 Simulated and measured S-parameter characteristics



(a) Simulated results

(b) Measured results

Fig. 12 Radiation characteristics (E_θ, *zx* plane)