# Transmission Characteristic Comparison between Right and Left Handed Leaky Wave Antennas Composed of CRLH Coplanar Strip Line

Akira Sakamoto1, Keizo Cho1, Naobumi Michishita2, Takuya Seki3, Ichiro Oshima3
1Graduate School of Engineering, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino, Chiba, 275-0016 Japan
2National Defense Academy, 1-10-20 Hashirimizu, Yokosuka, Kanagawa, 239-8686 Japan
3Denki Kogyo Co., Ltd., 13-4 Satsuki, Kanuma, 322-0014 Japan

***Abstract* - This paper analyzes the $S_{21}$ characteristics of a leaky wave antenna composed of CRLH coplanar strip line by using 2-port network equivalent circuit. The left and right handed modes are considered and the comparison of the $S_{21}$ characteristics between the two modes is investigated. The results show that the coupling component between the unit cells radiates in the left handed mode, on the other hand, almost no radiation is observed in the right handed mode.**

***Index Terms* — leaky wave antenna, CRLH coplanar strip line, intercell coupling.**

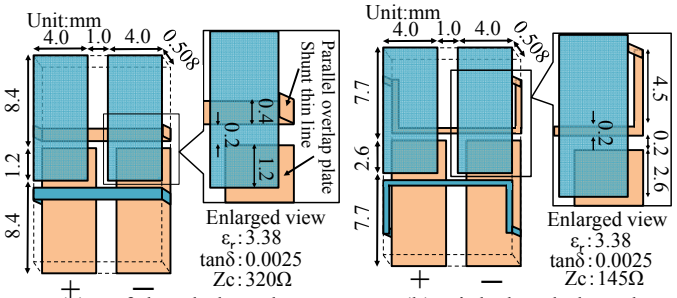
## 1. Introduction

A leaky wave antenna using composite right/left handed (CRLH) coplanar strip line has been proposed as a slender omni-directional base station antenna [1]. The objective of this study is to clarify the operation mechanism of the leaky wave antenna. Some analyses of the leaky wave antenna using the series of 2-port network circuit have been reported [2] [3].

This paper investigates leak characteristics of the leaky wave antenna [1] by using the series of 2-port network circuit analysis. We especially focus on transmission characteristics ($S_{21}$) and compare the $S_{21}$ characteristics between the left handed and right handed leaky wave antenna.

## 2. Antenna structure

Fig. 1 shows the unit cell structures of the leaky wave antenna [1]. CRLH coplanar strip line is configured by placing series capacitors and shunt inductors. The series capacitor is made by overlapping the strip lines and shunt inductor is made by connecting between the coplanar strip lines with a shunt thin line as shown in Fig. 1 (a) and (b). The left handed and right handed modes are designed by changing the length and the width of the overlapped strip lines and the shunt thin lines. The design frequency of the unit cells is 3.5 GHz. 17 unit cells are connected in series to configure the leaky wave antenna. The total length of the antenna is 306 mm. The detail dimensions of the antenna configuration are shown in Fig. 1.




(a) Left handed mode (b) Right handed mode

Fig. 1. Unit cell structures of the leaky wave antenna.

## 3. Equivalent 2-port network circuit

Equivalent 2-port network circuit of the leaky wave antenna is expressed by *ABCD* matrix as shown in Fig. 2. The matrix $F_A$ represents the matrix of the unit cell. Intercell coupling between the unit cells is considered by introducing the intercell coupling $F_C$ [2]. The leaky wave antenna is configured by cascaded connection of 17 $F_A$ and 16 $F_C$. The scattering matrix (*S* matrix) corresponding to the matrix $F_A$ is derived by the full-wave analysis of the unit cell using the moment method [4]. The matrix $F_C$ is derived from the following equation by using the *ABCD* matrix of the whole antenna obtained by full-wave analysis and matrix $F_A$ [2].

$$F_C = F_A^{-1}\left(F_X \cdot F_A^{-1}\right)^{\frac{1}{n-1}} \tag{1}$$

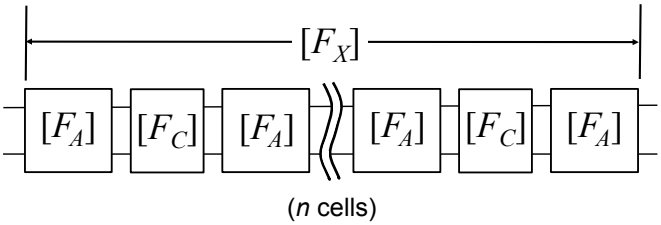
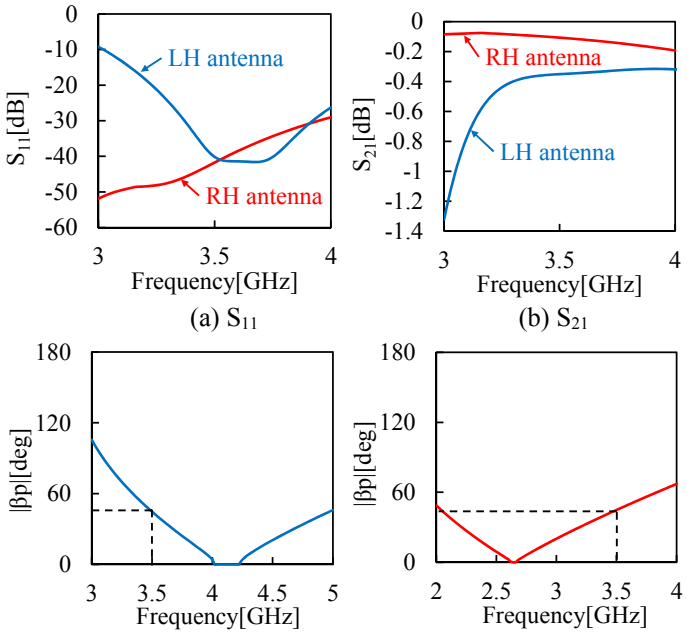



Fig. 2. Equivalent 2-port network circuit of the leaky wave antenna.

## 4. $S_{21}$ characteristics of the left and right handed leaky wave antenna

Fig. 3 (a) and (b) show the $S_{11}$ and $S_{21}$ characteristics of the left handed and right handed mode unit cells, and Fig. 3 (c) and (d) show $\beta$p characteristics of them, respectively. The left and right handed property of each configuration can be confirmed and $\beta$p are both almost 45 degrees at 3.5 GHz. $S_{11}$ of both configuration are both -10 dB or less at 3.5 GHz. $S_{21}$ at 3.5 GHz are -0.35 dB and -0.11 dB for the left and right handed modes. Fig. 4 shows the $S_{21}$ characteristics derived from intercell coupling matrix $F_C$ is calculated from the 17 cell series configuration.

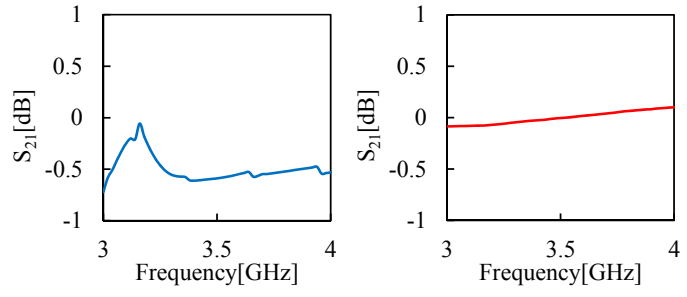
$S_{21}$ of -0.5 dB, which is lager transmission loss than that of the unit cell, is observed in the left handed mode at 3.5 GHz. On the other hand, $S_{21}$ in the right handed mode is close to 0 dB at 3.5 GHz, and it increases as increasing the frequency. We see some return wave of that radiation from the unit cell when observing the electric filed distribution of the right handed mode antenna. We consider that this is the reason of the $S_{21}$ beyond 0 dB.




(a) $S_{11}$ (b) $S_{21}$

(c) $\beta$p (Left handed mode) (d) $\beta$p (Right handed mode)

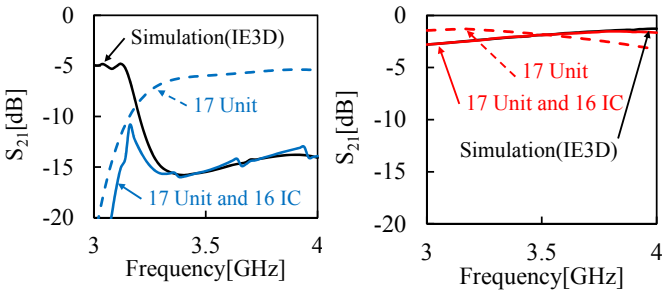
Fig. 3. $S_{11}$, $S_{21}$ and $\beta$p characteristics corresponding to the unit cell matrices of the left and right handed modes.




(a) Left handed mode (b) Right handed mode

Fig. 4. $S_{21}$ characteristics corresponding to the intercell coupling matrices of the left and right handed modes.

Fig. 5 (a) and (b) show $S_{21}$ characteristic comparison between the moment method analysis and 2-port network circuit analysis for the left handed and right handed leaky wave antennas. Two cases with and without considering the intercell coupling matrices are shown for the 2-port network circuit analysis. In the 2-port network analysis, only $S_{21}$ corresponding the matrix $F_A$ and $F_C$ are considered to derive the total transmission loss here. As can be seen in Fig. 5, the total $S_{21}$ characteristics of 2-port network circuit analysis considering intercell coupling fairly agrees with that calculated by the moment method. The $S_{21}$ increase from the cascade of the unit cell $S_{21}$ observed over 3.5 GHz in the right handed antenna can be also explained by considering the intercell coupling. The disagreement in the low frequency region will be the non-consideration of multi-reflection between the unit cells. This will be presented in the conference.




(a) Left handed mode (b) Right handed mode

Fig. 5. $S_{21}$ characteristic comparison of the leaky wave antenna between full-wave analysis and 2-port network circuit analysis.

## 5. Conclusion

This paper investigated $S_{21}$ characteristics of the left and right handed leaky wave antenna composed of the CRLH coplanar strip line by using the series 2-port network circuit analysis. As the result, we found that the leakage is observed between the unit cells in the left handed mode. Moreover, a little power back from the radiated power is observed in the right handed mode.

## References


[1] I.Oshima, et al., "Omnidirectional Composite Right/Left-Handed Leaky-Wave Antenna with Downtilted Beam", in Proc. IEEE Antennas Propag. Soc. Int. Symp. (APSURSI'15), 2015, pp.2439-2440.

[2] A.Sakamoto, et al., "Influence of Inercell Coupling of Left-Handed Leaky Wave Omni-directional Antenna", in Proc. IEEE International Workshop on Electromagnetics. (iWEM2015), Nov.2015.

[3] Y.Mukainoge, H.Deguchi, M.Tsuji, "An Optimized Design Method of Composite Right/Left Handed Transmission Lines Considering Higher-order Mode Interaction by Genetic Algorithm", Proc. IEEE iWEM2014, pp.78-79

[4] http://www.mentor.com/pcb/hyperlynx/3d-em/