Achievement of Inverse Frequency-Dependent Phase Shift by Using Composite Right/Left-Handed Phase Shifter

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1. Introduction

In the conventional base station antenna, a linear array antenna is used. For suppressing the interference between neighbouring cells, the main beam is down-tilted to the cell edges of own radio zones [1]. Recently, the multi-frequency base station antenna is used due to a limited space in the base station [2]. The beam tilt angle is usually designed by conventional phase shifters. For example, in the dual-frequency (1.5 GHz and 2 GHz) base station antenna, the beam tilt angle becomes frequency-independent. However, the half-power beamwidth at 1.5 GHz is broader than that at 2 GHz. Therefore, the interference to the neighbouring cell becomes large at 1.5 GHz. To suppress the interference at 1.5 GHz, the composite right/left-handed (CRLH) phase shifter has been proposed for achieving inverse phase shift at each frequency by using the dispersion relation of the CRLH transmission line [3]. The variation of the dispersion curve can be obtained by mechanically-shifting the patch for series capacitance. This paper presents the dispersion design of the unit cell and the experimental verification of the inverse phase shift at each frequency.

2. Requirement of Phase Shift in Base Station Antenna

Figure 1 shows the configuration of the base station antenna. The conventional base station antenna consists of the sub-arrays with antenna elements, the variable phase shifter, and feed lines. The dispersive transmission lines are not included in the present base station configuration. In order to achieve beam tilt angle \(\theta_T\), the microstrip feed network is used in each sub-array. Feed lines as shown in Fig. 1 are set to have the same lengths. Moreover, additional phase advances at higher-installed sub-arrays are given by variable phase shifters. In order to reduce the horizontal directivity for suppressing the interference to the neighbouring cell, the deep tilt angle is required at 1.5 GHz.

In the proposed configuration, the dispersive transmission lines are inserted between the conventional phase shifter and each antenna element. A CRLH transmission line is adopted as the dispersive transmission line. The tilt angle \(\theta_t\) is the sum of the tilt angle \(\theta_g\) obtained by the conventional phase shifter and the tilt angle \(\theta_{TL}\) obtained by the dispersive transmission line. Since the tilt angle \(\theta_g\) is identical at each frequency, the different tilt angle \(\theta_{TL}\) is required at each frequency. In the situation of the dual-frequency base station antenna, it is required that the phase shift at 1.5 GHz is larger than that at 2 GHz.

3. Dispersion Design for Achieving Inverse Phase Shift

Figure 2 shows the configuration of the proposed CRLH transmission line with five unit-cells. Series capacitance is realized by the parallel plate capacitor. The MIM capacitors are added by arranging the additional patches above the parallel plate capacitors. The dispersion characteristics are varied by sliding the patch mechanically in \(x\) direction. The crossover between the additional patch and the main patch is 10% as shown in Fig. 2. The crossover of 100% corresponds to the...
additional patch is located directly above the main patch. The variable range of the proposed phase shifter is defined as the range from crossover of 10% to 100%.

Figure 3 shows the dispersion diagram of the unit cell. The finite element method is used for the electromagnetic simulation. The phase constants at the target frequencies of 1.5 GHz and 2 GHz are designed in the slow wave region for guided wave propagation. To achieve the deep tilt angle at 1.5 GHz, the phase difference between crossover of 10% and 100% at 1.5 GHz needs to be larger than that at 2 GHz. When $h$ decreases as shown in Fig. 3(a), the large phase shift can be achieved by varying the slope of the dispersion curve. When $d$ decreases as shown in Fig. 3(b), the phase shift increases by frequency-shifting of the dispersion curve in the crossover of 100%. Figure 4 shows the phase shift characteristics of the 5-cell CRLH transmission line when the crossover of the additional patch is varied. The phase shifts at 1.5 GHz and 2 GHz are 145 deg. and 36.7 deg., respectively.

4. Experiment of 5-cell CRLH Phase Shifter

Figure 5 shows the photograph of the fabricated phase shifter composed of the 5-cell CRLH transmission line with input and output circuits. The length of the parallel plate capacitors for the input and output matching are 5 mm. The connection parts between 50Ω microstrip line on the dielectric substrate with 0.8 mm thickness and the main line are the taper structures. The phase shifter is packaged by the perfect electric conductor box. The inner conductors of the coaxial cables are connected with the input and output microstrip lines. Figure 6(a) shows the magnitude of simulated S-parameter characteristics of the phase shifter. $|S_{11}|$ are less than −10 dB at 1.5 GHz and 2 GHz. $|S_{21}|$ are −0.69 dB and −0.56 dB at 1.5 GHz and 2 GHz, respectively. Figure 6(b) shows the phase of $S_{21}$ characteristics of the phase shifter. The phase shifts at 1.5 GHz and 2 GHz are 136.4 deg. and 41.8 deg., respectively. Figure 7 shows the measured S-parameter characteristics of the fabricated phase shifter. $|S_{11}|$ and $|S_{21}|$ become −6.7 dB and −2 dB at 1.5 GHz in the crossover of 100%. The phase shifts at 1.5 GHz and 2 GHz are 124.2 deg. and 51.2 deg., respectively. The large phase shift at lower frequency is verified through experiment.

5. Conclusion

This paper presents the experimental verification of inverse phase shift at two frequencies by using dispersion relation of CRLH transmission line. Large phase shift at lower frequency provides the reduction of the horizontal directivity in the base station antenna. As a result, the interference to neighbouring cell at lower frequency can be suppressed. The variation of dispersion curve by mechanically sliding of additional patches is verified through simulation and experiment.

References

Figure 1: Configuration of base station antenna

Figure 2: Composite right/left-handed (CRLH) transmission line with MIM capacitors. (a) 5-cell transmission line. (b) Unit cell.

Figure 3: Dispersion diagram of unit cell when crossover of additional patch and (a) $h$ and (b) $d$ are varied.
Figure 4: Phase shift characteristics of 5-cell CRLH transmission line with $l = 8$ mm, $g = 0.5$ mm, $p = 8.5$ mm, $w = 3$ mm, $r = 0.25$ mm, $h = 8$ mm, $l_{pp} = 2.9$ mm, $d = 0.3$ mm when crossover of additional patch is varied.

Figure 5: Photograph of CRLH phase shifter. (a) Top view. (b) Side view.

Figure 6: Simulated S-parameter characteristics of CRLH phase shifter. (a) Magnitude. (b) Phase.

Figure 7: Measured S-parameter characteristics of CRLH phase shifter. (a) Magnitude. (b) Phase.