# Circuit Parameters Maximizing Phase Dispersion of Frequency Dispersive Phase Shifter for Multi-Band Base Station Antenna

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***Abstract* - Frequency dispersive phase shifter for a multi-band base station antenna, which is capable of increasing the communication capacity by deep tilt angle in the lower frequency bands, has been proposed. In this paper, in order to enlarge the amount of phase shift of the frequency dispersive phase shifter, we first derive the equivalent circuit of the unit cell of the phase shifter. A lossless symmetrical T equivalent circuit is used as the equivalent circuit. Then, the results designing the left-handed components of the equivalent circuit that can enlarge the amount of phase shift of the phase shifter while maintaining Bloch impedance around 50Ω are described.**

***Index Terms* — Phase Shifter, CRLH-TL, Equivalent Circuit Analysis**

## 1. Introduction

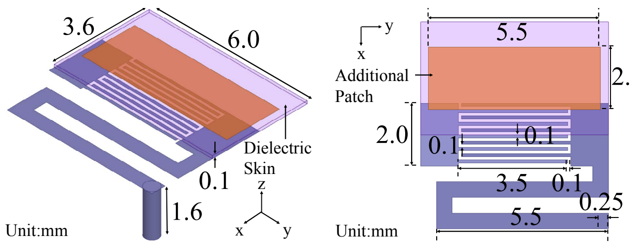
A frequency dispersible phase shifter has been proposed. This can improve the communication capacity by tilting the beam in the low-frequency band deeply in multi-band base station antennas operating in the 1.5GHz band and the 2.0GHz band [1]. The phase shifter is composed of composite right/left-handed transmission line (CRLH-TL) configured on a dielectric substrate. This phase shifter has achieved larger phase shift in 1.5 GHz band than that in 2GHz band. Thus the tilt angle of the base station antenna in 1.5GHz band can be increased than that in 2GHz band. Increasing the variable range of the phase difference between the two frequency bands expands the range of the adjustable tilt angle difference between the two frequency bands.

This paper investigates the optimum design parameters that can enlarge the variable range of the phase difference in the two frequency bands by the T-type equivalent circuit analysis.

## 2. Configuration of unit cell and equivalent circuit

Fig. 1 shows the unit cell structure of the considering phase shifter [1]. Series capacitor is configured by both inter-digital capacitor and an additional patch located on the dielectric substrate which is placed on the inter-digital capacitor. The phase of the phase shifter can be adjusted by moving the substrate having the additional patch in the x direction. The ratio of the area on the inter-digital capacitor overlapped by the additional patch is called crossover in this paper.

Fig. 2 shows the T-type equivalent circuit used to derive the design parameters. To derive the parameters of the equivalent circuit, we first calculate the circuit parameters of asymmetry T-type equivalent circuit including loss components. The parameters are calculated from the Z matrix of the unit cell obtained by the finite element method (FEM) analysis [2]. Ansys HFSS is used for the FEM analysis [3]. Then the loss components are omitted and series synthetic inductance $L_{se}$ and capacitance $C_{se}$ are calculated. Finally these inductance $L_{se}$ and capacitances $C_{se}$ are divided as shown in Fig. 2 to obtain the symmetric T equivalent circuit. By using the lossless T-type equivalent circuit, it is possible to reduce the circuit design parameter to four. Note that we have confirmed that there is no significant effect on circuit performance even when ignoring loss component. The average values from 1.5GHz to 2GHz are used as the inductance and capacitance.



(a) (b)

Fig. 1. Configuration of unit cell. (a)Downward view of Crossover50% (Crossover is Percentage of additional patch covers the microstrip line). (b)Top view of Crossover10%.

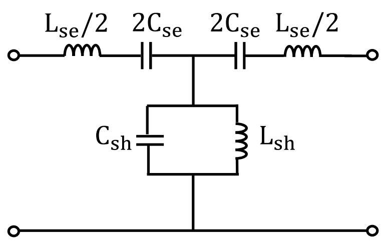



Fig. 2. Equivalent circuit

## 3. Design of Left-handed components

In our preliminary study, we found that the right handed components $L_{se}$ and $C_{sh}$ do not significantly contribute to increase the phase difference. Thus, we focus on the design of left handed components $C_{se}$ and $L_{sh}$.

Fig. 3 shows the phase difference φ between 1.5 GHz and 2 GHz of the phase shifter when changing the series capacitance $C_{se}$ and shunt inductance $L_{sh}$. The right-handed components $L_{se}$ and $C_{sh}$ are set to 1.80 nH, and 0.35 pF in this calculation. The contour lines are plotted every 20 degrees. The white area in the figure represents a cut-off region of the phase shifter. From Fig. 3, the phase difference φ increases as the phase characteristics approach to the cut-off region.

Changing the circuit components also affects the Bloch impedance characteristics as well as the phase characteristic. Fig. 4(a) and (b) show the real part of the Bloch impedance at 1.5GHz and 2GHz, respectively when changing the series capacitance $C_{se}$ and shunt inductance $L_{sh}$. The area inside the closed dotted line represents that the Bloch impedance satisfies between 45 and 55 Ω in the range between 1.5 GHz to 2 GHz. This is obtained by overlapping Fig. 4 (a) and (b). $C_{se}$ and $L_{sh}$ corresponding to this area should be suitable for the phase shifter.

The minimum and maximum phase difference φ in the closed dotted line are given at P1 and P2 in Fig. 3, respectively. By changing $C_{se}$ and $L_{sh}$ from P1 to P2 within the closed dotted line, the phase characteristics between 1.5 GHz and 2GHz can be varied while maintaining impedance matching to 50Ω.

## 4. Right-handed component adjustment

Since the right-handed components also somewhat effect on the circuit characteristics, we optimize the right-handed components to maximize the variable range of the phase difference θ while satisfying the real part of the Bloch impedance from 45 to 55 Ω. As the results of parameter studies that draw Fig.3 and Fig.4 by changing the right-handed components, we found that the right handed components $L_{se}$ and $C_{se}$ that give the maximum variable range θ are 1.80 nH and 0.35 pF, respectively. The left handed components $C_{se}$ and $L_{sh}$ corresponding to P1 and P2 in Fig.3 are 2.68 pF and 10.1 nH, 1.10 pF and 4.17 nH, respectively. The maximum variable range θ of 20.26 degrees is obtained. This value is almost the twice of that obtained by the phase shifter proposed in [1].

## 5. Summary

This paper investigated the circuit parameters of frequency dispersive phase shifter proposed in [1] that maximize the variable range of the phase difference between 1.5 GHz and 2 GHz. As the results of equivalent circuit analysis, we clarified the circuit parameters that the variable range can be double of that obtained by the phase shifter proposed in [1] with maintaining good impedance matching. The clarification of the actual structure realizing the circuit parameters is future study.

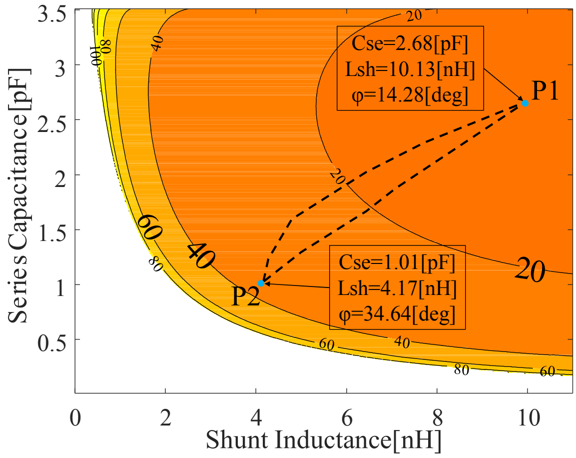



Fig. 3. Phase variation characteristic by varying left-hand components.

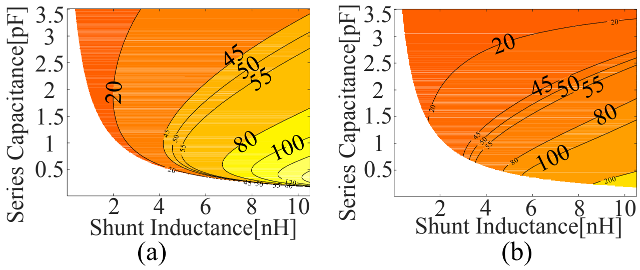



Fig. 4. Bloch impedance real part by varying left-hand components. (a)1.5 GHz. (b)2.0 GHz.

## References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