180° Analogue S-Band Phase Shifter Based on Composite Right/Left-Handed Transmission Lines

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Abstract

A tuneable composite right/left handed transmission line with a controllable dispersion relation accompanied by a change of the phase constant from negative to positive values is used for a control of the phase increment along the line section. An analogue phase shifter based on such a line and controlled by varactor diodes is presented. The device is implemented as a printed circuit board with surface-mounted components and demonstrates a flat phase shift across a fractional bandwidth of 25% at 2.7 GHz.

1. Introduction

Miniature microwave phase shifters are widely used, e.g., in phased antenna arrays. The use of metamaterials approach for the design and implementation of a phase shifter makes it possible to design miniature devices with low insertion loss and wide impedance-matched tuning range.

A unit cell of a composite right/left-handed transmission line (CRHL TL) was described in detail in [1]. The design of a phase shifter based on such a line controlled by ferroelectric varactors was treated in [2]. This paper presents a novel analogous 0°-180° composite line-based phase shifter laid out as a printed circuit board (PCB) with surface mount components. The tuning is implemented by commercial semiconductor varactor diodes.

2. Design Considerations

The equivalent T-shaped unit cell of a tuneable CRHL TL is presented in Fig.1. Changes of the values of tuneable capacitors lead to variations of the electrical length of the cell and, hence, changes of the phase increment along the artificial transmission line section.

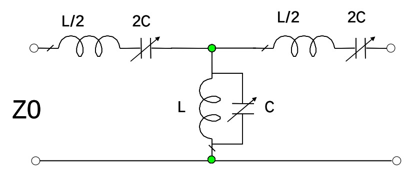

Fig.1: Equivalent diagram of a symmetric unit cell of composite right/left handed transmission line.

The single cell of a CRHL TL section is described by the ABCD-matrix [1]:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1+ZY & 2Z\left(1+\frac{ZY}{2}\right) \\ Y & 1+ZY \end{bmatrix}, \tag{1}$$

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where the series impedance Z and shunt admittance Y are given by:

$$Z = j\omega \frac{L}{2} + \frac{1}{j\omega \cdot 2C}, \tag{2}$$

$$Y = \frac{1}{j\omega L} + j\omega C \,. \tag{3}$$

The transmission coefficient S_{21} can be found from a well-known transformation of (1).

To provide matching, the characteristic impedance Z_c [1] of the CRHL TL should be equal to the input impedance Z_0: $Z_c = Z_0 = 50$ Ohm at the central frequency f_0 of the operational frequency band. In our case, the matching condition leads to

$$L = \frac{Z_c}{2\pi f_0} \tag{4}$$

The tunability $n = C(V1)/C(V2)$ is defined as the ratio of the two capacitance values C(V1) and C(V2) of the tunable capacitor corresponding to the different values of the applied voltage. The dependence of the phase shift on the tunability of a single cell of the CRHL TL, for the balanced case [1], is described by:

$$\Delta\varphi(n) = \Delta\varphi_{RH} + \Delta\varphi_{LH} = 2\pi f \sqrt{LC}(1-\sqrt{n}) + \frac{1}{2\pi f \sqrt{LC}} \frac{1-\sqrt{n}}{\sqrt{n}}, \tag{5}$$

The dependence of the transmission coefficient and phase shift on tunability *n* for a single cell of the CRHL TL is shown in Fig.2.

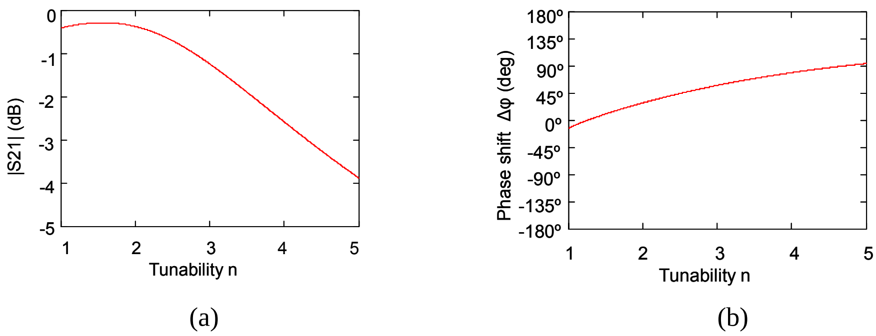


Fig. 2: Transmission coefficient (a) and phase shift (b) versus tunability *n* for a single cell of a CRHL TL.

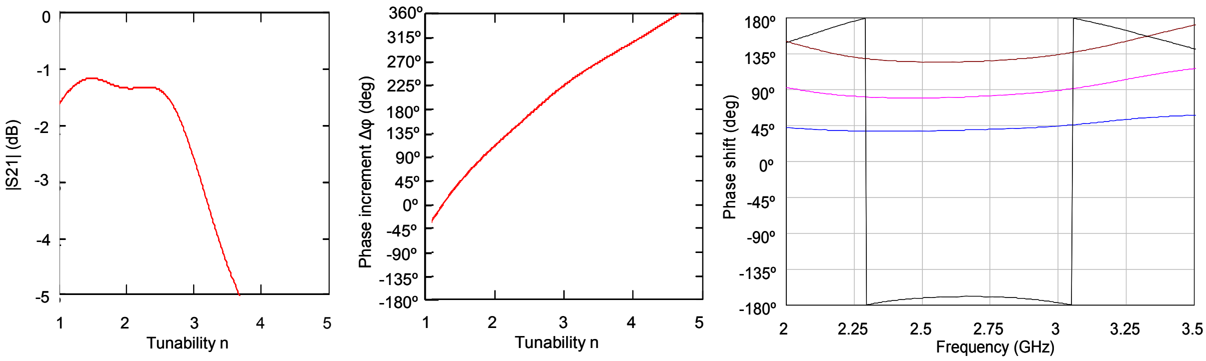
Taking into consideration the above mentioned key points of the design, the number of unit cells should be chosen such as to achieve a phase shift of up to 180°. The analysis and schematic simulations of the phase shifter for the frequency range of interest showed that four cells are minimum. Such a device would provide an insertion loss of 2.5 dB and a return loss of 15 dB. The use of five cells would improve the matching bandwidth though at the expense of higher insertion loss. As a compromise, four unit cells of the CRHL TL were used to design an analogue 0°-180° phase shifter operating at S-band frequencies.

3. Topology and Measurements

The layout of the designed four-cell 0°-180° CRLH TL phase shifter implemented on a 1.27 mm thick printed circuit board from Rogers RO3010 with surface-mount device components is depicted in Fig. 3. Fig. 4 (a) and (b) show the results of circuit simulations of the insertion loss and phase increment of the device depending on the tunability of the varactor diodes. Fig. 4 (c) displays the phase response obtained from electromagnetic simulations.

Fig. 3: Layout of the four-cell 0°-180° CRLH TL phase shifter.

Miniature flip-chip varactor diodes from Microsemi and high-Q 0402 chip inductors from Murata were used to design the device. All varactors are tuned jointly by applying voltages in the range from 1 to 3 V, corresponding to a tunability n = 2.2. The area of the phase shifter measures 17 mm × 8.4 mm. At a centre frequency of 2.7 GHz over a fractional bandwidth of 25%, the EM simulation revealed a flat phase shift with an error less than ±10° for the 180° phase shift (Fig. 4c), an insertion loss less than 4 dB and a return loss better than 15 dB.



(a) (b) (c)

Fig. 4: Insertion loss (a) and phase increment (b) versus tunability; panel (c) displays the frequency dependence of 180°, 135°, 90°, and 45° phase shifts of the 4-cell CRLH TL phase shifter.

4. Conclusions

An S-band analogue phase shifter operating over 25% fractional bandwidth is presented. The device was designed as cascaded four cells of tuneable CRHL transmission line sections controlled jointly by varactor diodes on a small voltage level. The phase shifter exhibits a small phase shift error. The cheap and high reproducible technology employing printed circuit boards with surface-mount device components was used. The implementation and experimental characterisation of the miniature device are in progress.

References

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