CRLH Leaky-Wave Antenna using Transmission Line Resonators

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***Abstract*---In this paper, a composite right/left-handed leaky-wave antenna using transmission line resonators is presented. The leaky-wave antenna is designed as a bandpass filter and has non-uniform element values at the first and last few cells which is regarded as a matching section. A filter consisted of K-inverters, J-inverters, and transmission line resonators is translated into a microstrip line structure. A 24th-order example is designed and tested with a numerical simulator.**

***Index Terms*---CRLH TL, Leaky-wave Antenna, Chebyshev filter.**

1. Introduction

Composite right/left-handed (CRLH) transmission lines (TLs) have been a subject of extensive studies. One of the unique properties of CRLH TLs is a capability of supporting backward waves. By introducing the CRLH TLs into the design of leaky wave antennas, beam scanning over backward to forward direction has been achieved [1]. In antenna applications, low input return loss is required. This property can be achieved by making the characteristic impedance of a CRLH TL constant. However, this requirement is difficult to satisfy if electrical lengths of components in a CRLH unit cell cannot be ignored. The electrical lengths are modeled as right-handed TLs and cause a drastic change in the characteristic impedance with frequency. Another approach to obtain low return loss is adding a matching section. In [2], the design procedure of a matching section for CRLH TLs consisted of lumped elements utilizing a filter design is presented.

In this work, the design procedure of a matching section for CRLH TLs consisted of lumped elements and right-handed TLs is presented. The CRLH TL is treated as a Chebyshev bandpass filter made of K inverter, J inverter, and $\lambda/4$ transmission line resonator. The K and J inverters are translated into shunt inductances and series capacitances. The shunt inductances and series capacitances are implemented as microstrip stubs with grounded vias and gaps, respectively. The result of the microstrip implementation and a circuit model show a good agreement. The radiation patterns show that frequency scanning from $-60°$ to $60°$ is achieved.

2. Theory

The top layer structure of the leaky-wave antenna is shown in fig. 1. The stubs are connected to the ground plane with vias. The same topology is used in a filter design [3]. The filter is a microstrip implementation of a circuit shown in fig. 2(a) with K-inverter (b) and J-inverter (c). Chebyshev filter coefficients for a given ripple level and filter order determine the values of K and J inverters. The following relations associate the values of K and J inverter to X and B.

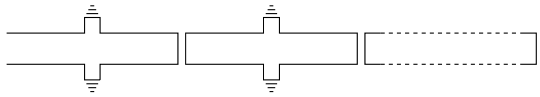

Fig. 1. Top layer pattern of the leaky-wave antenna.

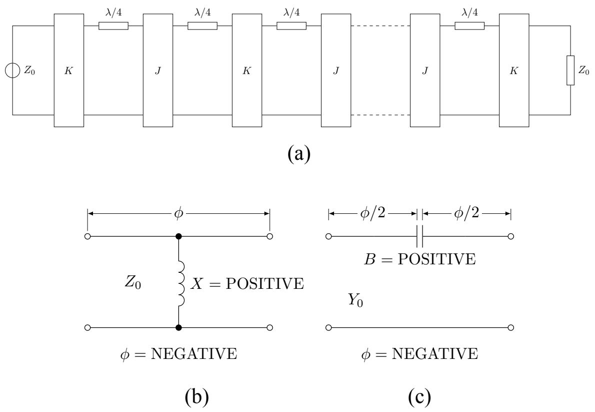

Fig. 2. (a) Band-pass filter with $\lambda/4$ resonators and (b) K-inverter (c) J-inverter.

$$\left|\frac{X}{Z_0}\right| = \frac{K/Z_0}{1-(K/Z_0)^2}, \quad \phi = -\tan^{-1}\frac{2X}{Z_0} \tag{1}$$

$$\left|\frac{B}{Y_0}\right| = \frac{J/Y_0}{1-(J/Y_0)^2}, \quad \phi = -\tan^{-1}\frac{2B}{Y_0}, \tag{2}$$

Fig. 3 shows the coefficients of a 24th-order Chebyshev filter with ripple of 0.1. As can be seen, $K/Z_0 \approx J/Y_0$ is satisfied except the first and last few elements. By substituting $K/Z_0 = J/Y_0$ into eq. (1) and (2),

$$Z_0 = \sqrt{\frac{L}{C}} \tag{3}$$

is obtained. This is known as a balance condition for closing the gap between the left-handed frequency range and the right-handed frequency range [4]. Therefore, the filter can be considered as a balanced CRLH TL with matching

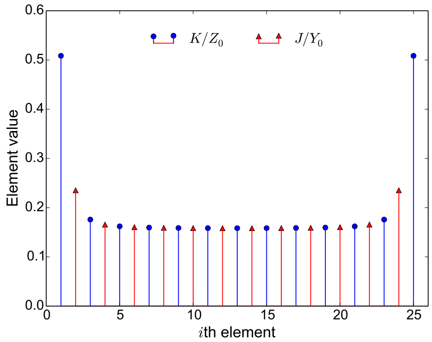

Fig. 3. Element values of a 24th-order Chevyshev prototype.

sections. In the following design, K and J are replaced by the values satisfying eq. (3) except the first and last two Ks and one J.

3. Design

Based on the filter design in the previous section, a CRLH leaky-wave antenna is implemented as a microstrip structure. The shunt inductance and series capacitance are realized by a stub connected to a grounded via and a gap, respectively. However, the stub and gap introduce parasitic inductances and capacitances. The effect of those parasitic elements can be modeled as transmission lines attached to the shunt inductance or series capacitance. The electrical length of the attached transmission lines and the value of the elements have to be estimated. By taking a Taylor expansion and ignoring terms higher than 2nd order, the following combinations of the components of the ABCD matrix are associated with the electrical length θ, Z, or Y.

$$C + (1-A)D/B \approx iY_0\theta, \quad B - CZ_0^2 \approx Z \qquad (4)$$

where Y_0 is the characteristic admittance of the transmission line connected to the gap and $Z = 1/j\omega C + R$. The A, B, C, and D are the components of the ABCD matrix of a series impedance with transmission lines attached to the input and output port. The similar relation can be derived for a stub as follows.

$$B + (1-D)A/C \approx iZ_0\theta, \quad C - B/Z_0^2 \approx Y \qquad (5)$$

where $Y = 1/j\omega L + G$. The electrical length θ in eq. (4) and (5) is removed from the $\lambda/4$ transmission line resonators in fig. 2(a).

The scattering parameters of a leaky-wave antenna is shown in fig. 4. The substrate with $\varepsilon_r = 2.2$ and a thickness of 1.57mm is used. The operating frequency is chosen as 4 to 6 GHz. The required physical dimensions of gaps and stubs are evaluated at the center frequency of 4.8GHz. The scattering parameters of the filter is also shown in fig. 4. The losses found in microstip gaps and stubs are added to the original filter coefficients. The degradation in S11 at 4.8GHz is associated with a discontinuity in the attenuation constant. Fig. 5 shows radiation patterns of the leaky-wave antenna. The antenna beam scans from $-60°$ to $60°$ at 4.2 to 5.8 GHz.

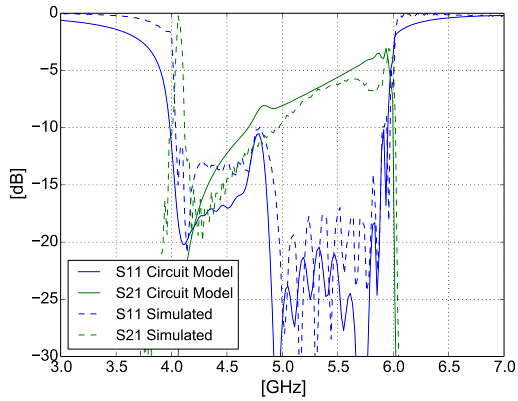

Fig. 4. Scattering parameters of the leaky-wave antenna.

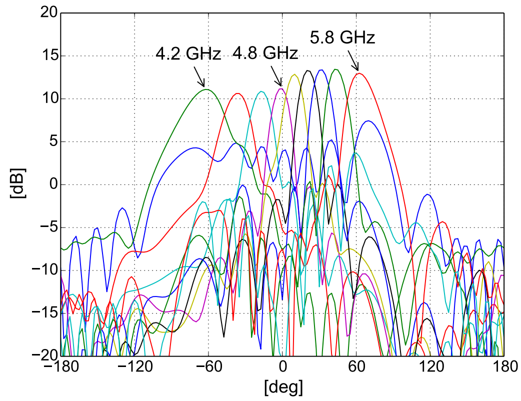

Fig. 5. Radiation patterns of the leaky-wave antenna.

4. Conclusion

A CRLH leaky-wave antenna using transmission line resonators is presented. The antenna is designed as a Chebyshev bandpass filter. The scattering parameters of the designed antenna agree with the result of the filter. Radiation patterns of the antenna confirm beam scanning with a frequency sweep.

References

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