A Dual-Band Leaky-Wave Antenna Based on Generalized Negative-Refractive-Index Transmission-Lines

Colan G. M. Ryan* and George V. Eleftheriades
Edward S. Rogers, Sr. Department of Electrical and Computer Engineering, University of Toronto, Canada
E-mail: colan.ryan@utoronto.ca

Introduction

A composite right/left-hand microstrip leaky-wave antenna exhibits beam scanning from backward to forward end-fire directions and even through broadside as the frequency is swept over the left- and right- handed passbands. In this paper, we propose a novel leaky-wave antenna that possesses a pair of left/right-hand passbands and consequently has two frequencies where broadside radiation can be achieved. A generalized negative-refractive-index transmission-line (NRI-TL) unit cell suitable for this purpose was proposed in [1]. This design featured two left-handed bands and two right-handed bands; the conditions necessary for closing each of the two stopbands was also derived. The unit cell has been physically realized for a dual-band filter application using lumped elements [2], while a fully-printed unit cell has been reported in [3]; this latter work, however, did not achieve closure of either stopband and is thus unsuitable for the present dual-band leaky-wave application. To minimize both the cost and complexity of fabrication, fully-printed implementations are desirable. This paper therefore presents a fully-printed leaky-wave antenna based on the generalized NRI-TL which is capable of scanning from a backward to a forward direction and through broadside over two frequency bands.

Unit Cell Design

A. Circuit Design

The schematic of the unit cell is shown in Fig. 1. As derived in [1] and [3], the conditions that yield closed stopbands is $L_{HS}C_{HP}=L_{VS}C_{VP}$. In addition, each L-C resonator resonates at the same frequency, $\omega_{res,}$ (although this condition could be relaxed in order to arbitrarily select the two passbands). The values of the circuit components are chosen as L_{VS}=2.46 nH, C_{VS}=1.31 pF, L_{VP}=5.7 nH, C_{VP}=0.57 pF, L_{HP}=3.1 nH, C_{HP}=1.04 pF, C_{HS}=2.39 pF, and L_{HS}=1.35 nH. The right-handed transmission line equivalent circuit components (C_{VP} and L_{HS}) are represented by a transmission line section of length 6 mm and width 5 mm. The circuit is simulated in Agilent Design System (ADS) using the selected lumped elements values; a Rogers 5880 substrate of relative permittivity ε_r=2.2 and loss tangent of 0.009 is used.

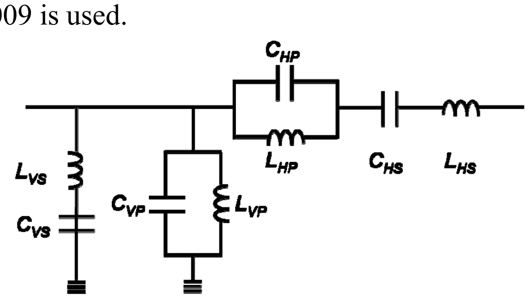

Fig. 1. Circuit schematic of the NRI-TL unit cell.

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B. Full-wave Simulations

Ansoft's High-Frequency Structure Simulator (HFSS) was used to design the fully-printed unit cell; the layout is that proposed in [3], in which L_{VS} and C_{VS} are realized from the meander-line and patch, C_{HS} from the interdigitated capacitor, L_{VP} from the shunt stub, and L_{HP} and C_{HP} from the defected ground plane. Simulating each of the components in turn in conjunction with applying the desired lumped-element boundary conditions in HFSS allowed the physical dimensions for each of the elements to be determined. A final optimization was then performed to compensate for any coupling effects between the elements that were not accounted for in the circuit diagram. In particular, the large cut-out forming the defected ground plane alters the behaviour of its surrounding components, and for this reason, the stub and meander line-patch combination were both offset from the cut-out to mitigate its effect. The final unit cell is shown in Fig. 2 while Table I lists its dimensions.

TABLE I DIMENSIONS OF PRINTED UNIT CELL

Parameter	Value (mm)	Parameter	Value (mm)
L_{Cell}	11.2	L_{Finger}	5.8
W_{TL}	5	W_{Finger}	0.3
L_S	8.75	S_{Finger}	0.2
W_S	1	L_{Cutout}	16.8
$W_{Meander}$	0.2	W_{Cutout}	6.5
$S_{Meander}$	0.2	L_{Tee}	4.75
W_{Patch}	3.6	S_{Tee}	0.2
L_{Patch}	4.8	W_{Tee}	0.3
V_{Diam}	0.2		

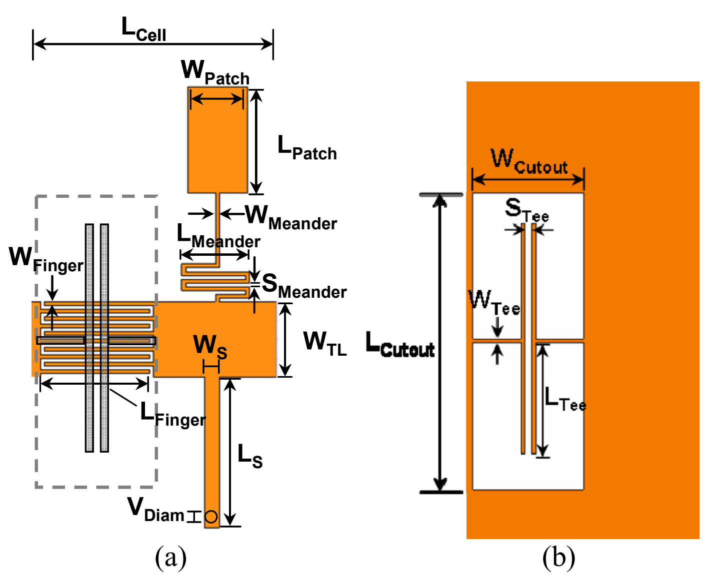

Fig. 2. Layout of printed NRI-TL unit cell (a) Top view (b) Bottom view. Drawings are not to scale.

Fig. 3 presents a comparison between the dispersion diagrams obtained from ADS circuit simulation and from HFSS full-wave analysis. Reasonably good agreement between the two sets of data is obtained for the lower passband; discrepancies arise at higher frequencies since equivalent circuit parameters for the printed structures were obtained closer to the lower band where the response was relatively constant. Nevertheless, the results show that the fully-printed unit cell possesses a pair of right-handed/left-handed transmission bands and that both stopbands are closed.

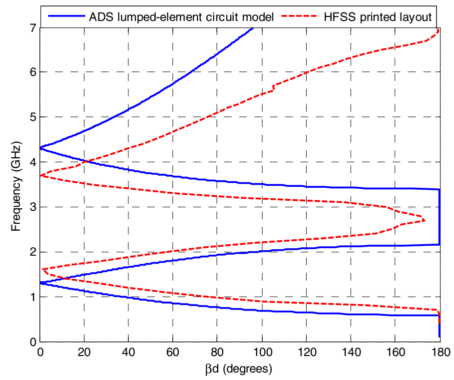

Fig. 3. Comparison of dispersion diagrams from lumped element circuit simulation and from printed full-wave analysis.

Leaky-Wave Antenna Simulated Results

A leaky wave antenna comprising 10 unit cells was simulated in HFSS. The transmission and reflection magnitudes versus frequency are shown in Fig. 4; the layout of the antenna is depicted in Fig. 5a while Fig. 5b and Fig. 5c present the simulated gain versus elevation angle in a cut along the length of the antenna at both the lower-band and upper-band frequencies. At the lower band, the reflection magnitude is usually below –10 dB from 1.3-1.9 GHz, while a narrow stopband is observed in the upper frequency range at 3.7 GHz, thus indicating that further optimization is necessary in this frequency range. However, it is also observed that the antenna does indeed scan through broadside over both bands with a total angular range of ±30º from 1.5-1.9 GHz and of –40º to +15º over a frequency range of 3.4-3.9 GHz. Moreover, the gain is relatively constant over each of the frequency ranges. One drawback is that significant radiation occurs in the bottom half of the plane in the upper frequency band. This radiation, likely due to the large cut-outs in the ground plane, represents wasted power and could create interference with other components in the system. Consequently, a method of eliminating this radiation must still be found. One possibility may be to include a second ground plane connected through vias to the defected ground plane.

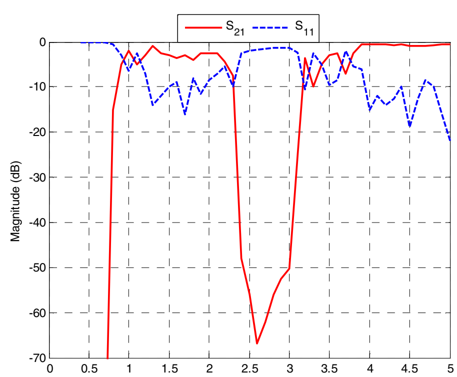

Fig.4 Reflection and transmission magnitude versus frequency

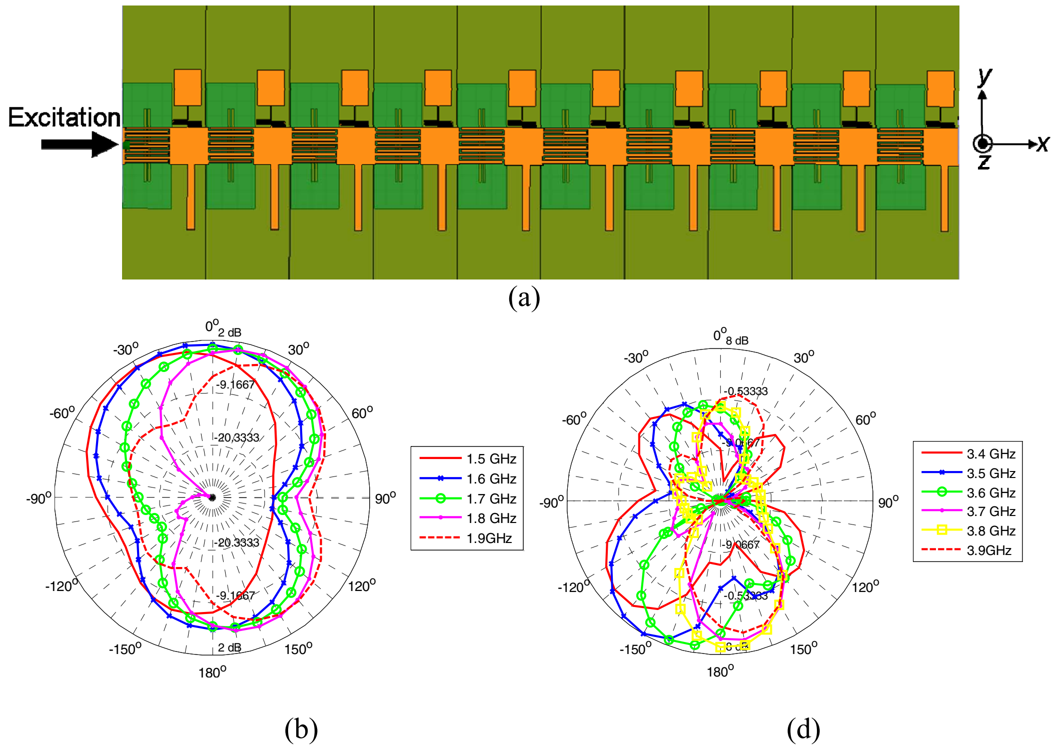

Fig. 5 (a) Schematic of leaky-wave antenna and antenna gain in elevation plane for (b) 1.5-1.9 GHz and (c) 3.4-3.9 GHz

Conclusion

A novel leaky wave antenna based on the generalized NRI-TL has been proposed. The design process has been demonstrated and good agreement between circuit and full-wave simulations has been obtained. The antenna has been shown to scan from a backward to forward direction over two frequency bands that were selected by proper choice of the equivalent circuit components. The antenna will next be fabricated and measured results are expected to be presented during the symposium.

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