Dispersion Engineered Right/Left-Handed Transmission Lines Enabling Near-Octave Bandwidths for Wideband CP Patch Arrays

Joshua M. Kovitz and Yahya Rahmat-Samii
Electrical Engineering Department
University of California Los Angeles
Los Angeles, CA, USA
jmkovitz@ucla.edu, rahmat@ee.ucla.edu

Jun Choi
Electrical Engineering and Computer Science Department
Syracuse University
Syracuse, NY 13244, USA
jhcho100@syr.edu

***Abstract*—Composite right/left-handed (CRLH) transmission lines have recently attracted a significant interest due to their abilities to generate phase characteristics which go beyond the typical right-handed lines. In this work, we demonstrate their use in generating a wideband quadrature phase excitation for creating circular polarization (CP) with antenna systems capable of generating two orthogonal polarizations. In particular, we investigate their application towards a patch antenna array of sequentially rotated elements. By engineering the dispersion of the CRLH lines, we have been able to measure roughly 60% AR-S_{11} bandwidth with a prototyped 2×2 array of sequentially rotated wideband, single layer patch antennas.**

I. Introduction

Achieving wide bandwidth remains a prevalent challenge in the context of circularly polarized patch antennas and arrays. A given design must satisfy the requirements of $|S_{11}| \leq -10$ dB and AR $\leq$ 3 dB simultaneously over the desired frequency band. Multi-polarized patch antenna systems such as dual-polarized patches and sequentially rotated arrays offer a direct control mechanism of each polarization where each input to the antenna system directly excites a certain polarization. Thus, one can create circularly polarized patch antennas by applying an equal magnitude, quadrature phase excitation on the two ports. However, the development of a microwave network creating this excitation over a wide bandwidth must also be incorporated into the design. Developing a compact, integrated feed network alongside the patch array presents an interesting challenge to engineers, and the current state-of-the-art has much room for improvement.

The quarter wavelength transmission line often is the first choice for microwave engineers due to the inherent simplicity. However, phase error quickly becomes an issue for frequencies other than the center, limiting the bandwidth capabilities of such a design. Antenna designs employing this technique are often limited to an AR-S_{11} bandwidth under 25% [1]. Other designs have made use of wideband phase shifter networks to achieve wide AR-S_{11} bandwidths [2], however the size of the feed network may not be amenable for arrays and other size-constrained applications. Others also have utilized 3 dB hybrids to generate equal magnitude, quadrature phase excitations, but the bandwidth remained on a similar order to the quarter wavelength transformer.

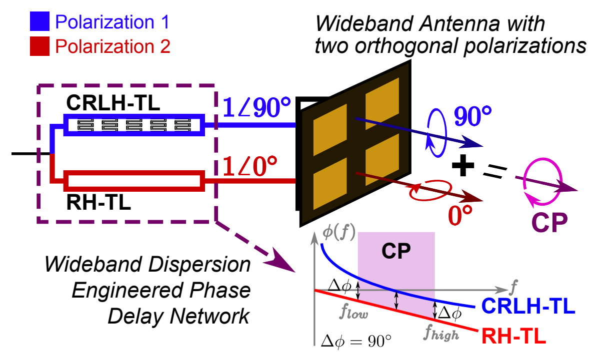

Fig. 1. A general wideband CP antenna system using a CRLH transmission line to provide $\Delta\phi = 90°$ with respect to a right-handed transmission line (RH-TL). This wideband phase delay network enables CP by feeding a multi-polarized antenna with the proper phase and magnitude.

In this paper, we propose the novel use of composite right/left-handed transmission lines (CRLH-TL) to generate circular polarization from a 2×2 patch array over a wide bandwidth. When connected to an antenna capable of generating two orthogonal polarizations over a wide bandwidth ($|S_{11}| \leq -10$ dB and reasonable isolation), a properly designed CRLH-TL network enables wideband CP generation as depicted in Fig. 1. The additional degrees of freedom provided by the left-handed portion of the lines enables such a network whose dispersion can be engineered to provide an approximately constant phase difference over a certain bandwidth [3]. We apply the CRLH lines to a rotated array of single-layer, single feed patch antennas with a wide S_{11} bandwidth. Our resulting 2×2 array design was able to achieve nearly 60% AR-S_{11} bandwidth with a thickness of roughly $\lambda_0/10$. To our best knowledge, this is the first time that CRLH concepts are being applied to arrays to achieve wideband CP characteristics.

II. CRLH-TL Network and Antenna Design

CRLH transmission lines make use of both right-handed (RH) and left-handed (LH) transmission lines to enable many interesting characteristics which cannot be realized though right-handed lines alone [3]. A nearly constant phase differ-

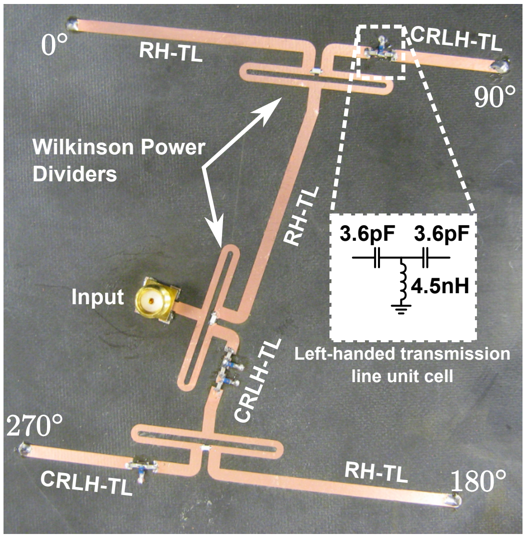

Fig. 2. Prototyped CRLH feed network used to achieve wideband CP radiation. The first power dividing/CRLH stage provides 180° phase delay between the two branches, and each subsequent stage provides 90° phase.

ence can be achieved when pairing CRLH-TL with conventional RH-TL. The design strategy for CRLH-TL in providing the constant shift is similar to that in [4], where one branch after each power divider contains a CRLH-TL while the other branch is merely a right-handed transmission line (RH-TL) as depicted in Fig. 1. We implemented the LH portion of the transmission lines via lumped elements.

For the particular array configuration, we generated relative phase excitations of 0°, 90°, 180°, and 270° using four CRLH unit cells as shown in Fig. 2, where each unit cell in combination with the RH-TLs offer a 90° phase advance with respect to the RH-TL branch. This excitation feeds a sequentially rotated array of patch elements having wideband impedance matching performance [5]. The element design exhibited good $S_{11} \leq -10$ dB performance for 1.9-2.7 GHz and even AR ≤ 3 dB for roughly 2.34–2.46 GHz ($\approx 5\%$).

III. Design Results and Measurement

We designed the CRLH-TL feed network to provide the desired phase shifts along with good S_{11} at 1.8 GHz and 3.0 GHz. Over this bandwidth, the network showed phase errors less than $\pm 6°$, and amplitude imbalances were less than 0.6 dB. We also simulated the feed network with the manufacturer's measured S-parameter data for each of the lumped components, and a maximum of 0.5 dB insertion loss was observed. We simulated the entire array including the feed network within HFSS. We then fabricated this same array as illustrated in Figs 2-3 via chemical etching. The measured S_{11} and broadside AR results are shown in Fig. 4, demonstrating an incredibly wideband performance from 1.7-3.2 GHz which amounts to an AR-S_{11} bandwidth over 60%. The radiation patterns also revealed good characteristics over the entire band, with directivities ranging from 8.5-13.5 dB due to the changes in array electrical size versus frequency. Directivity decreases at the upper frequencies can be attributed to increases in cross-polarization at non-broadside elevation angles.

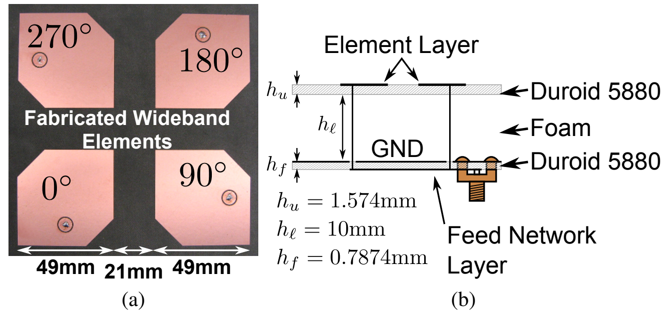

Fig. 3. Sequentially rotated array using a wideband truncated corner patch antenna to achieve wideband circular polarization performance. (a) Top view showing array element configuration. (b) Side view of array.

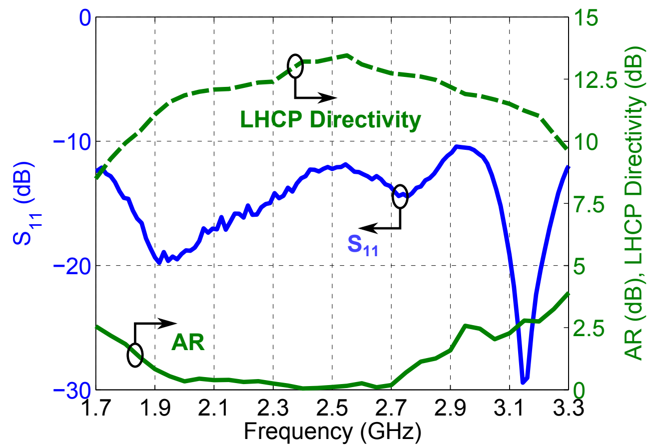

Fig. 4. Measured S_{11}, broadside AR, and broadside LHCP directivity performance for the sequentially rotated array with a CRLH feed network.

IV. Conclusions

This work has described and demonstrated the application of CRLH transmission lines towards the development of wideband CP patch arrays. By tuning the CRLH-TL phase response, we were able to realize a wideband feed network which generates the proper phase and magnitudes for a sequentially rotated array. Previous designs using quarter wavelength lines have only shown a 25% bandwidth capability, and thus CRLH-TL feed networks can provide a significant bandwidth improvement with minimal losses. Overall, the prototyped antenna array was able to achieve good characteristics over the entire 60% bandwidth (nearly an octave); such a feat is not easily replicated with other techniques.

References

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