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# Amplifying CRLH Delay Line for Frequency Scanning Reflectarrays

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***Abstract*—An amplifying composite right/left-handed (CRLH) delay line is presented for frequency scanning reflectarrays. Using a reflection-type amplifier, the reflective unit with the CRLH delay line can maintain the original polarization state. Gain enhancement and scanning is demonstrated by incorporating the measured delay line responses into full-wave simulation.**

## I. Introduction

Beam steering is an appealing feature in many applications, e.g., imaging and positioning. Compared to electronic scanning enabled by phase-shifters, frequency scanning (FS) can provide a cost-effective solution in certain systems. Leaky-wave antennas (LWAs) are commonly used for FS. However, LWAs suffer an exponentially decaying aperture due to their travelling-wave nature, which limits the size of the effective aperture. In reflectarrays, although edge tapering [1] is intentionally introduced for radiation performance, the aperture size can be greatly increased because of the spatial feed.

In order to implement FS in reflectarrays, sufficient phase progression needs to be generated between reflective elements. Conventional delay lines would take up too much space to achieve the required phase variation, especially for a large field-of-view (FOV). A FS reflectarray using composite right/left-handed (CRLH) delay lines has been investigated in [2], in which lumped elements are used to constitute the CRLH structure. As we move towards higher frequencies in applications, the suitable lumped components are more expensive and potentially more lossy compared to their low frequency counterparts. A fully distributed CRLH delay line can be developed for such applications. However, the accumulated loss in the elements with long CRLH delay lines is still an issue. Such a limitation can be removed by amplification. More importantly, the introduction of amplifiers opens up the opportunity of amplitude control across the reflectarray surface. The use of amplifiers in reflecting structures for signal enhancement is explored in [3]–[5] but all these works consider cross-polarized elements, which makes the dual-pol operation difficult to be implemented. On the other hand, amplifying co-polarized elements face the challenge of instability and potential oscillation, as discussed in [3]. This work presents a distributed CRLH delay line terminated by a reflection-type amplifier. It supports amplified co-polarized reflection without the oscillation issue. The reflection gain and phase of the delay lines are verified through measurement. FS with amplification is demonstrated by full-wave simulation.

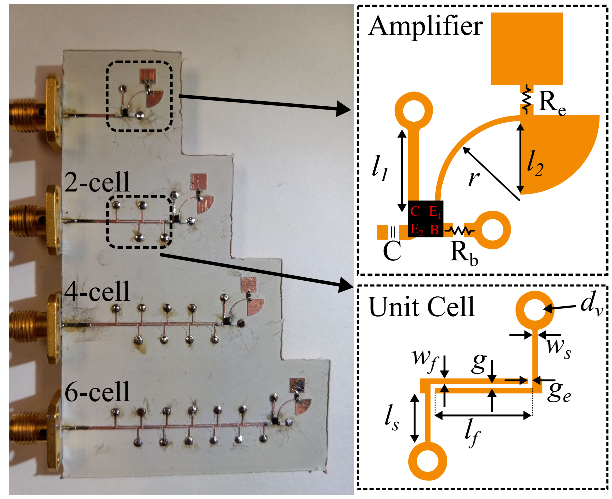


Fig. 1. Fabricated active delay lines. $l_1 = 3.43\,\text{mm}$, $l_2 = 3.1\,\text{mm}$, $r = 3.4\,\text{mm}$, $R_e = 100\,\Omega$, $R_b = 330\,\Omega$, $C = 1.5\,\text{pF}$, $d_v = 0.8\,\text{mm}$, $w_s = 0.2\,\text{mm}$, $w_f = 0.2\,\text{mm}$, $g = 0.2\,\text{mm}$, $g_e = 0.2\,\text{mm}$, $l_s = 2.0\,\text{mm}$, and $l_f = 4.0\,\text{mm}$. The unit-cell length is 5 mm. Substrate is RO3010 25 mil.

## II. Design and Measurement of Amplifying CRLH Delay Line

The transistor used in the amplifier is an Infineon BFP840FESD. The base is grounded through a high frequency 330 Ω resistor (CH0402-330RGFTA), and the collector is inductively loaded. Without any matching network, the amplifier

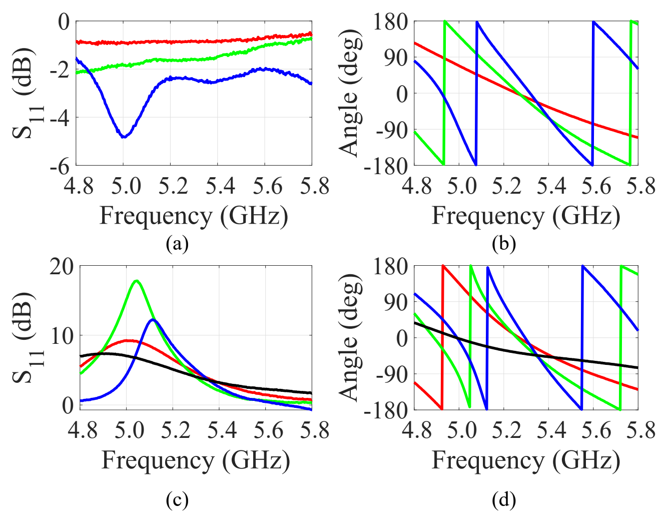


Fig. 2. Measurement results for the passive 2-, 4-, and 6-cell amplitude (a) and phase (b), and the active 0-, 2-, 4-, and 6-cell amplitude (c) and phase (d). The 0-cell (amplifier only) results are denoted by the black traces, 2-cell by red, 4-cell by green, and 6-cell by blue.

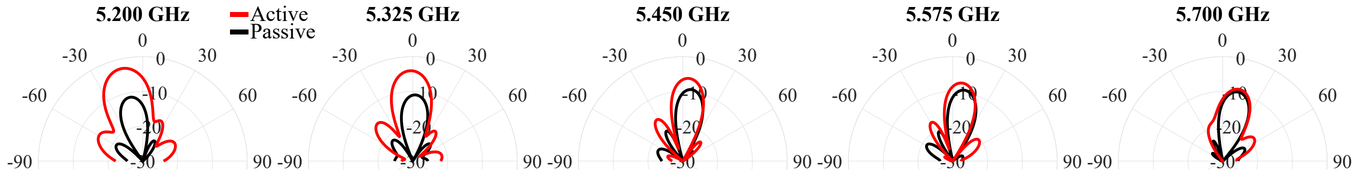


Fig. 3. Simulated radiation patterns in the XZ plane for the active and passive arrays. The increase in gain for the listed frequencies are 8.56 dB, 6.93 dB, 3.12 dB, 1.93 dB, and 0.81 dB, respectively.

response can still be tuned over a wide range by changing the loading on these two terminals. A reference impedance of $50\,\Omega$ is used to measure the amplifier response shown in Fig. 2(c) and (d). The gain and the linearity of the phase response are sufficient for later integration into the reflectarray. Therefore, the CRLH delay line and the radiating element are both designed to $50\,\Omega$. In general, the reference impedance is chosen such that the desired reflection gain can be achieved.

The CRLH unit-cell has a series interdigital capacitor and two shunt stub inductors in a symmetric geometry for improved matching. The transition frequency is $5.2\,\mathrm{GHz}$.

The fabricated active circuit is shown in Fig. 1. TRL calibration is used to deembed up to the amplifier/delay line. The passive/active measurement results are plotted in Fig. 2. While maintaining the progressive phase relation between the delay lines, the active cases show clear reflection gain compared to the passive cases. The difference in gain between the active cases is due to the fact that the Bloch impedance of the unit-cell is not perfectly $50\,\Omega$ throughout the measurement range. If the Bloch impedance is very close to the reference impedance, the gain should be almost the same as the pure amplifier response and independent of the number of cells.

## III. Frequency Scanning Reflectarray using Amplifying CRLH Delay Line

In order to demonstrate both frequency scanning and amplification, the measured S-parameters of the passive and active CRLH delay lines are applied in respective reflectarray simulations in ANSYS HFSS. The simulated structure is a $4 \times 4$ array, as shown in Fig. 4. A plane wave along the -z direction is used to illuminate the structure, emulating a distant source.

The radiating element is an aperture-fed patch antenna. The $-10\,\mathrm{dB}$ bandwidth is from $4.9\,\mathrm{GHz}$ to $5.8\,\mathrm{GHz}$. At the end of the transmission line in each radiating element, a circuit element is attached to include the measured S-parameters. The X dimension of the element is set to $30\,\mathrm{mm}$ to prevent grating lobes. The Y dimension is relaxed to be $45\,\mathrm{mm}$ since the array is not designed to scan in the YZ plane. The Y dimension is large enough to incorporate the 6-cell active CRLH delay line, which has a length of $39.3\,\mathrm{mm}$. For larger arrays, different CRLH unit-cell designs can be used for more compactness and the CRLH delay line can be meandered. In addition, multilayer board structures can be used to greatly increase the maximum number of cells.

The simulated patterns in the scanning plane are plotted in Fig. 3. From $5.2\,\mathrm{GHz}$ to $5.7\,\mathrm{GHz}$, gain enhancement is achieved while covering a similar FOV from $-15°$ to $+15°$

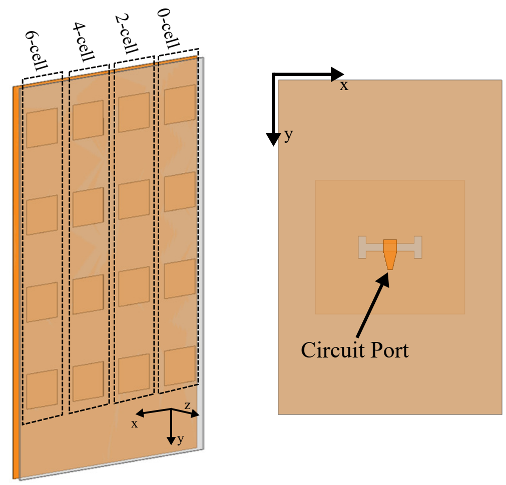


Fig. 4. Simulated array and its radiating element.

compared to the passive array. Below $5.2\,\mathrm{GHz}$, the large variation of gain will cause more pronounced side lobes, making the operation in that region undesirable.

## IV. Conclusion

The amplifying CRLH delay line is verified through measurement and its application to reflectarrays is demonstrated by full-wave simulation. The presented design has a relatively simple structure, which is suitable for scaling into much larger sizes. Future work will include designing the CRLH delay line with broadband amplification and for amplitude control over the aperture for improved side lobe levels, as well as measuring the reflectarray equipped with such delay lines.

## Acknowledgement

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