A Series-fed Microstrip Patch Array with Interconnecting CRLH Transmission Lines for WLAN Applications

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***Abstract*—In this paper, a design of a series-fed microstrip array with composite right-/left-handed transmission lines (CRLH-TLs) is being proposed. To ensure that each element in the array is driven with the same voltage phase, dual-band CRLH-TLs are adopted instead of meander-line microstrip lines to provide a compact interconnect with a zero phase-constant at the frequency of operation. The simulation results of the proposed array are verified by measurements done in an anechoic chamber. A bandwidth of 24 MHz was experimentally determined with a center frequency of 2.45 GHz. The proposed array would be useful for 2.45 GHz WLAN applications.**

***Index Terms*—Series-fed array; Composite right-/left-handed transmission line**

I. INTRODUCTION

Microstrip patch antenna arrays are currently used in satellite communications and wireless systems for their attractive features such as light weight, small size, low cost, improved directivity and obtaining a desired pattern which is not achievable in single element configurations [1]. In particular, series-fed antenna arrays have the advantage of simple geometries, compact feed networks and low feed line losses [2]-[8]. Typically a series-fed array consists of a single feed point and the radiating elements are connected in series with a feed network which consists of transmission lines that are a particular factor of wavelength of the operating signal. In some instances, this factor can be achieved using meander-lines to excite all of the elements in the array with the same voltage phase to achieve broadside radiation. However, the size of the overall meander-line feed network becomes larger and more complicated as the frequency is reduced. One way to overcome this size problem is to incorporate composite left-/right-handed (CRLH) transmission lines (TLs) in the feed network of the series-fed array [9]-[13].

The objective of this work is to investigate the design procedure of embedding the CRLH-TLs reported in [13] into series-fed microstrip arrays. An image of the proposed series-fed array with the CRLH-TLs interconnecting each element is shown in Fig. 1. The role of the CRLH-TL in the array will be introduced in the next section. This will then be followed by simulations and measurement validations.

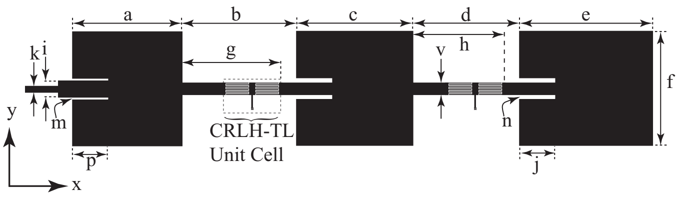


Fig. 1. Layout of the cascaded CRLH RH series-fed array.

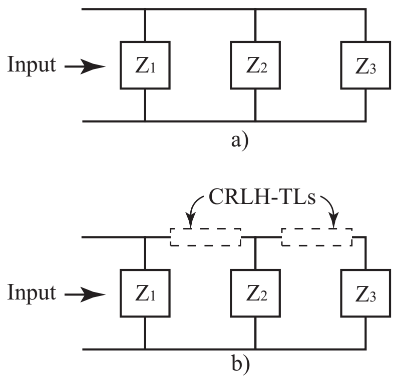
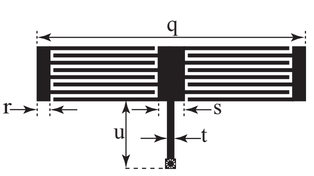


Fig. 2. a) Circuit representation of a 3-element series-fed array with conventional microstrip interconnects and b) circuit representation of a 3-element series-fed array with interconnecting CRLH-TLs.

II. ZERO PHASE SERIES-FED ARRAY

A series fed antenna array is classified as a standing wave array. The equivalent circuit of a series fed array is shown in Fig. 2a) [8]. Here, the array is fed from the left and Z_1, Z_2 and Z_3 represent the input impedance of the radiating elements along the length of the array. To achieve a good match at the input port, the impedance of each antenna element and interconnecting transmission lines must be chosen appropriately [4]. Furthermore, to achieve broadside radiation each element can be fed with the same voltage phase. This can be done be either designing the length of each interconnect to be a factor of the source wavelength or to introduce CRLH-TLs that have a zero phase-constant at or near the operating



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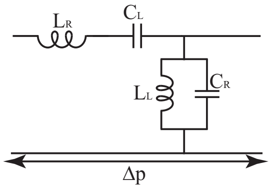


b)

Fig. 3. a) Layout of the CRLH-TL unit-cell and b) the equivalent circuit of the CRLH-TL unit-cell (q = 11.56 mm, r = 0.1 mm, s = 1.0 mm, t = 1.0 mm, u = 7.26 mm, finger length = 5.0 mm and the finger gap = 0.18 mm).

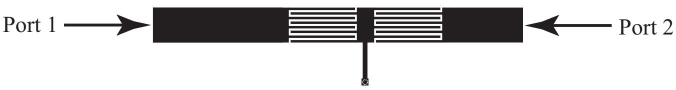


Fig. 4. Layout of the CRLH-TL interconnect between the elements in the series fend array with a length of 40.59 mm.

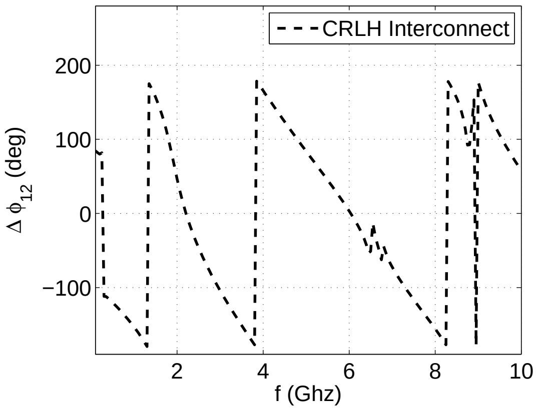


Fig. 5. Simulated S_{12} phase of the CRLH interconnect.

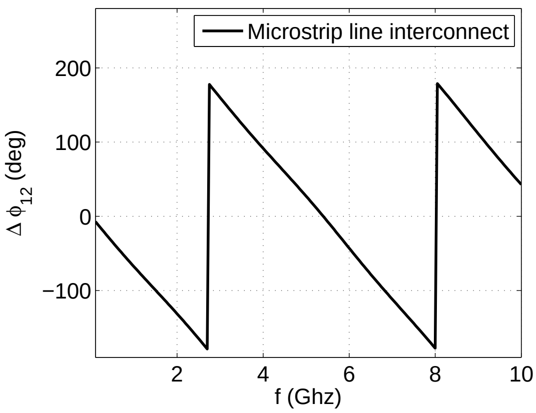


Fig. 6. Simulated S_{12} phase of the conventional microstrip transmission line interconnect.

frequency of interest [13]. Because of the compact size, the CRLH-TL unit-cell shown in Fig. 3a) will be used in the interconnects between the elements in Fig. 2b).

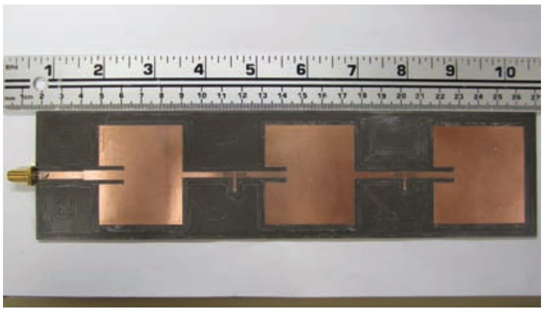
The equivalent circuit of the CRLH-TL is also shown in Fig. 3b). It consists of a series reactance (consisting of L_R and C_L) as well as a shunt reactance (consisting of L_L and C_R). C_R and L_R denote the right-handed capacitance and inductance, respectively. C_R represents the parasitic capacitance between the printed conductors on the top plane and the ground (reference) plane and L_R represents the parasitic inductance of the TL supporting wave propagation. L_L is introduced along the length of the TL with shunt stubs and C_L is implemented using inter-digital capacitors (as shown in the layout in Fig. 3a)). The benefits of introducing L_L and C_L are many [7]. The property of interest to this work is when the reactance of L_L and C_L are dominant for the frequencies of interest, a positive phase shift will be introduced by the CRLH-TL unit-cell of length q. This positive phase shift can then be used in the appropriate manner to develop an interconnect with a lower zero-phase frequency. Thus, by choosing the geometry of the CRLH-TL appropriately, each element of the array can be fed with the same voltage phase for broadside radiation and the use of meander-lines is not required.

To determine the layout of the array and achieve the required antenna impedances and interconnecting CRLH transmission line lengths, the simulation tool Momentum in the Advanced Design System (ADS) software [14] was used. The antenna was simulated on a Rogers RT/Duroid 5880 substrate with a thickness of $h = 1.57$mm ($\epsilon_r = 2.2$, $\tan\delta = 0.0009$). The conventional microstrip transmission line is used with the CRLH-TL as an interconnect between the patch elements in a manner similar to the dual-band lines reported in [13]. The layout of the interconnect on the 5880 substrate is shown in Fig. 4. The dimensions of the CRLH unit-cell are shown in the caption of Fig. 3 and the S_{21} phase of the total interconnect is shown in Fig. 5. The first zero-phase frequency crossing occurs at f = 2.2 GHz, which is near our operating frequency of interest. For comparison, a microstrip TL with the same width at the CRLH-unit cell and length as the interconnect in Fig. 4 was simulated for the same frequencies. The phase introduced by this microstrip interconnect is shown in Fig. 6. The first zero-phase frequency occurs at 5.39 GHz. The zero-phase frequency of the CRLH interconnect is approximately 60 % lower than the mircorstrip interconnect. This illustrates the usefulness of the compact CRLH interconnects.

Next, the interconnect (shown in Fig. 4) was added to the of the series fed array show in Fig. 1. The design was again simulated on the Rogers 5880 substrate and manufactured for testing. The manufactured prototype array is shown in Fig. 7a) with the dimensions outlined in the caption.

III. Measurement and Simulation Results

The simulated S_{11} and radiation pattern values for E_θ in the x-z plane are shown in Figs. 8 and 9, respectively. The simulated BW was determined to be 30 MHz with a center frequency of 2.425 GHz. All of the S-parameter and radiation pattern measurements were then performed in an anechoic chamber. A picture of the antenna being measured in the anechoic chamber is shown in Fig. 7b). The results in Fig. 8 show the measured S_{11} values and good agreement



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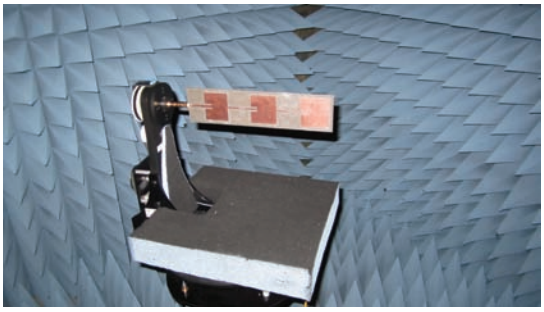


b)

Fig. 7. a) Picture of the manufactured prototype (a = 41.2 mm, b = 40.59 mm, c = 44.3 mm, d = 40.66 mm, e = 47.3 mm, f = 49.44 mm, g = 31.35 mm, h = 31.46 mm, i = 4.86 mm, j = 10.7 mm, k = 3.65 mm, m = 1.98 mm, n = 2.65 mm, p = 12.4 mm and v = 2.7 mm) and b) picture of the manufactured prototype being measured in the anechoic chamber.

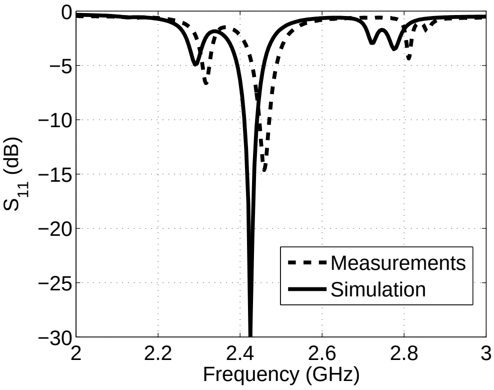


Fig. 8. Simulated and measured S_{11} values.

with simulations can be observed. The measured BW was 24 MHz with a center frequency of 2.45 GHz. Next, the radiation pattern in the x-z plane was measured and compared to simulations. These results are shown to agree in Fig. 9 and a broadside radiation pattern can be observed. Finally, for illustration the 3D pattern and currents on the radiating elements were computed in the simulation tool Momentum and are shown in Fig. 10. It is shown that at the resonant frequency, the direction of the surface currents on the patches are aligned indicating that the currents are the same (i.e., each element is fed with the same voltage phase).

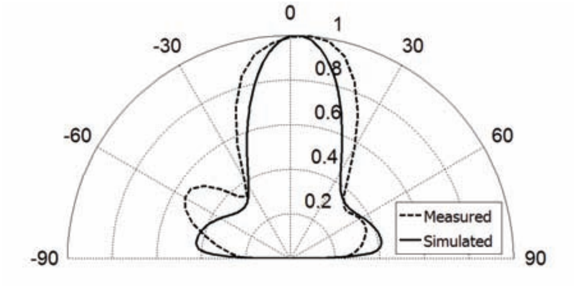
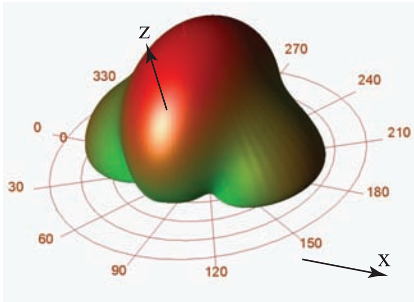
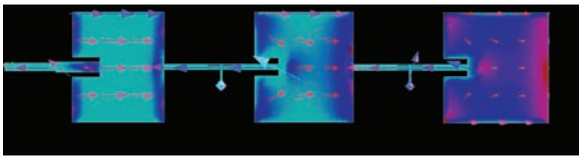


Fig. 9. Measured and simulated E_θ in the x-z plane at 2.45 GHz



a)



b)

Fig. 10. a) Simulated 3D radiation pattern at 2.45 GHz and b) simulated surface current direction on the radiating elements at 2.45 GHz.

IV. Conclusion

A design for a microstrip series-fed antenna array with CRLH unit-cell interconnecting lines has been presented. The array prototype was simulated in Momentum, manufactured and tested in an anechoic chamber. The measured results agree well with the simulated values and an impedance match can be observed at 2.45 GHz. The radiation pattern of the array has also been measured and agrees well with simulation results. Finally, the surface currents were simulated and plots show that the currents on each antenna element are in phase. Overall, the use of CRLH unit-cells in this series-fed array results in a compact design.

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