Frequency Scanned Antenna Array Using a Suspended Stripline Negative Index Transmission Line

Wolfgang Menzel, Madhumathy Sathiaseelan

Microwave Techniques, University of Ulm, D-89069 Ulm, Germany
Phone +49-731-5026350, Fax +49-731-5026359, E-mail: wolfgang.menzel@ieee.org

Abstract — **In suspended stripline, series capacitors can easily be realized by overlapping strips on opposite sides of the substrate, and shunt inductances by thin strips to ground, increased with some amount of inset. In this way, negative index or left-handed transmission lines can be realized. Such a structure then is used as a feeding line for an antenna array which can be frequency-scanned from endfire to backfire over a wide range of angles. A first antenna array based on this principle with six dipole antennas was designed and tested successfully. Following this and using a different point of view on this type of antenna, an improved scanning antenna is designed using band-pass filter type in this technique, resulting in a scanning range from -60° to +60°.**

I. INTRODUCTION

In the last years, a transmission line approach for negative index (or "left-handed" (LH)) materials has gained interest for the reduction of component size or to realized novel functions like a leaky wave antenna scanning from backfire to endfire [1 - 3], even including electronic control of beam direction and beam shape [4]. Such lumped element transmission line structures are composed of series capacitors and shunt inductors (in contrast to the normal transmission line equivalent circuit with series inductors and shunt capacitances). To allow the operation at sufficiently high frequencies, the involved lumped elements must be as small as possible, typically using interdigital or MIM capacitors, and shorted shunt stubs as inductances. With microstrip lines, the latter requires vias making the fabrication of LH transmission lines somewhat complicated.

Suspended stripline (SSL), on the other hand, is often used for filters. It exhibits low loss, and if both sides of the substrate are used, quasi-lumped elements of all kinds can be realized easily [5] including series capacitors and shunt inductances (Fig. 1). Capacitance is controlled by the overlapping length, inductance by the inset depth.

Combining these two, a unit cell for a NL transmission line can be realized. As the structure includes finite physical line lengths as well, a composite right/left handed (CRLH) transmission line results by cascading such unit cells. This contribution describes the design and results of a frequency scanned antenna array using the dispersive behavior of such a SSL CRLH transmission line as well as an improved antenna based on band-pass type elements in the same technique.

II. FIRST CIRCUIT CONCEPT

In a first step, the combination of several CRLH unit cells was designed. Both lumped element values and transmission performance were calculated using a 2½-D MoM simulator [6]. Fig. 2 shows the layout of a two-cell arrangement. The ground connection of the inductive stubs was done to alternating sides to avoid additional magnetic coupling [7].

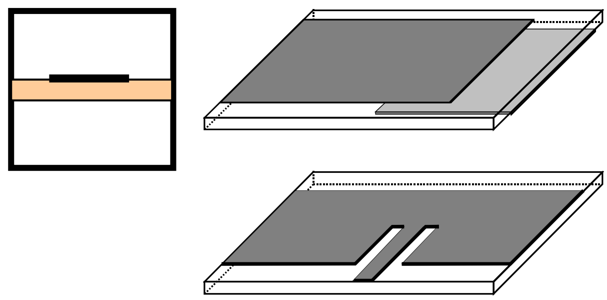

Fig. 1: Cross section (top left) and principle layouts of a series capacitor (top right) and a shunt inductor (bottom right) in suspended stripline

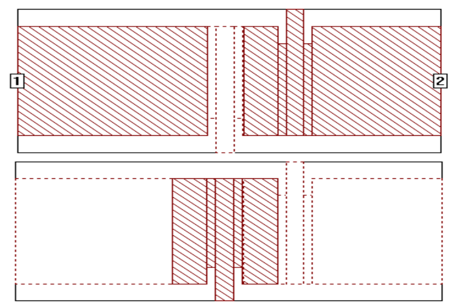

Fig. 2: Top and bottom layout of two-cell CRLH suspended transmission line arrangement.

Fig. 3 shows the insertion loss of such a structure with two and four cells. The typical high-pass behavior can be seen clearly. An increasing ripple occurs with increasing cell number at the band edge. This might be improved applying standard high-pass filter design principles. Finally, a four cell structure was combined with a T-junction to extract part of the power and to feed a $\lambda/4$ antenna dipole (with some additional matching of the junction), and six of these sub-structures were combined to form an antenna array (Fig. 4). The length of each structure is 16 mm. The CRLH transmission line was designed in such a way that each sub-structure has a transmission phase of 0° at about 10 GHz and therefore exhibits a broadside beam.

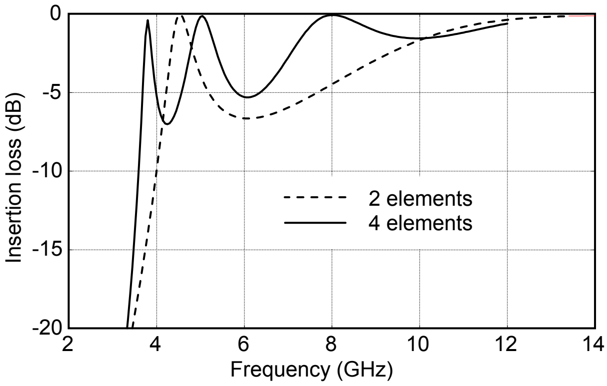

Fig. 3: Insertion loss of a two- and a four-cell CRLH suspended transmission line arrangements.

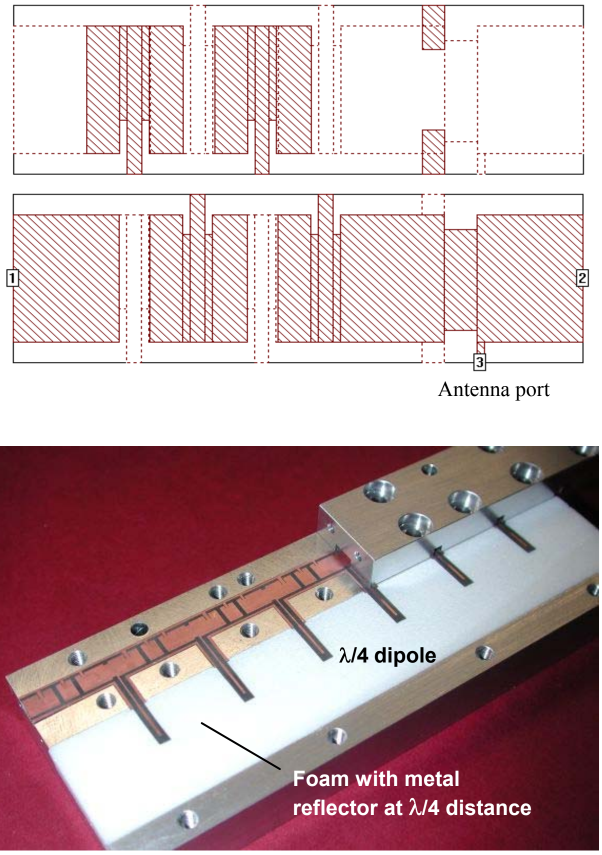

Fig. 4: Layout of an antenna sub-structure and photograph of the complete first antenna with opened mount.

III. First Results

The antenna array as described above was fabricated using a RT-Duroid 5880 material ($\varepsilon_r = 2.2$, substrate thickness 0.254 mm), and the SSL part of the CRLH transmission line was suspended in a mount of 5 mm width and 4.25 mm height. Input and output were connected to SMA connectors (one of these was connected to a 50 Ω load). Fig. 5 shows H-plane radiation diagrams for different frequencies. At 8 GHz, the antenna scans to nearly 60° endfire, and at 11.5 GHz, the main lobe points to about -25° backfire. In the E-plane, a broad beam results according to a quarter-wave dipole. Return loss of the antenna is 3 … 13 dB between 8 GHz and 11.5 GHz; some increased value results at the frequency for broadside radiation, as all reflected signals add up in phase. In the load at the end of the CRLH transmission line, about -5 dB of power are absorbed between 8 GHz and 9.5 GHz, quickly increasing above 9.5 GHz.

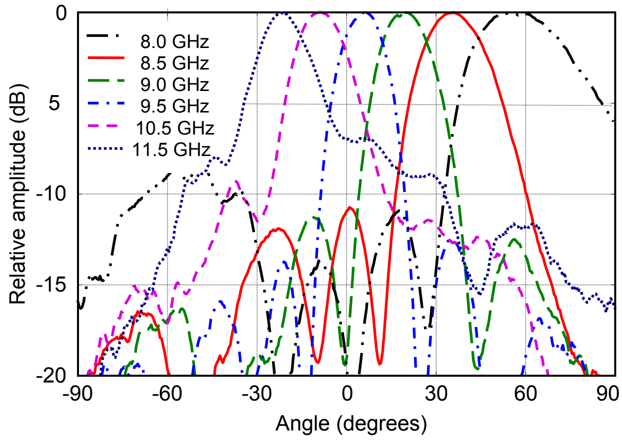

Fig. 5: H-plane radiation diagrams of the antenna array from 8 GHz to 11.5 GHz.

IV. Improved Design

An improved design of such an antenna can be derived if the problem is considered from a different point of view. A "normal" frequency scanned antenna with broadside beam results if the phase difference between the antenna ports is 0°, e.g. [8]. This is true, too, for the antenna under investigation here as can be seen approximately from the phase simulation of a single antenna LH transmission line cell, Fig. 6. This structure basically is a high-pass configuration, but without proper return loss design. Phase angle slope, and therefore the variation of the antenna beam direction is largest close to the corner frequency of the high-pass filter structure. The phase angle slope gets flatter for higher frequencies, resulting in an unsymmetrical scanning performance as is seen from the previous results.

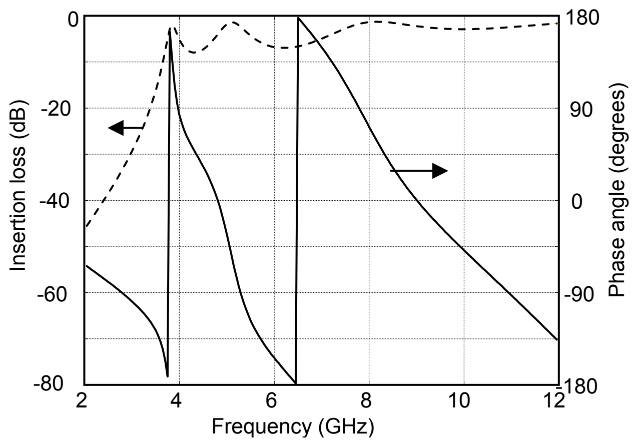

Fig. 6: Insertion loss and phase angle of a unit cell of the LH antenna structure (see Fig. 4, top).

A much better, symmetric, and even steeper phase angle slope can be achieved using a band-pass filter as a frequency dependent phase shifting element. Once again, SLL is well suited to realize low-loss bandpass filters, and with a proper filter design, even a good return loss of each cell can be achieved.

In a first approach, a SSL four resonator bandpass filter as described in [7] was taken as such a phase shifter cell (Fig. 7) without adding any matching element for the antenna port. This bandpass filter has a center frequency of 8.5 GHz, a bandwidth of about 1.2 GHz, and it shows an experimental insertion loss of 0.7 dB *including* losses of 0.3 dB due to 18 mm additional line length and transitions to coax at each port (Fig. 8). (A filter designed for even lower loss presently is under development). The length of the four resonator filter is smaller than 16 mm, so five such filters could be integrated into the mount for the first antenna. A photograph of part of the new antenna is given in Fig. 9.

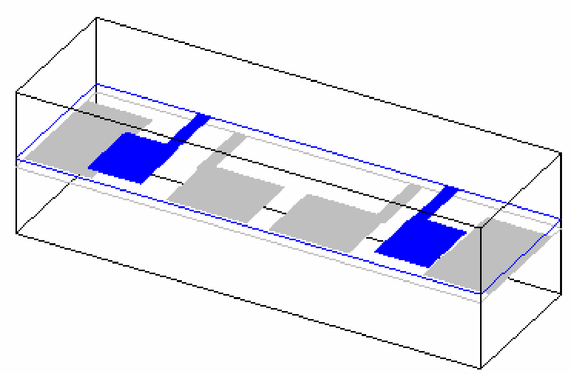

Fig. 7: Basic structure of a four resonator band-pass filter according to [7].

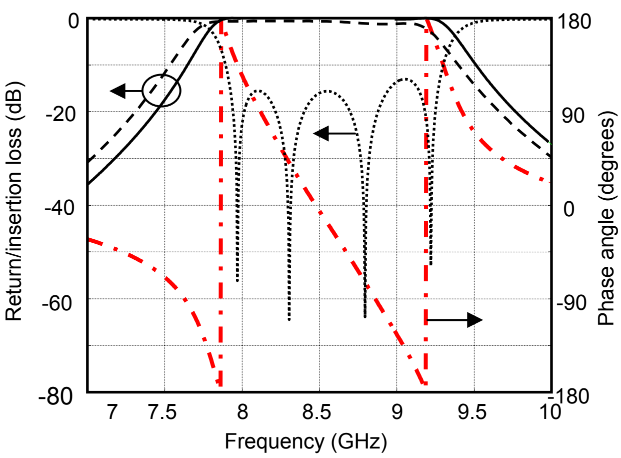

Fig. 8: Return and insertion loss and phase angle of the band-pass filter according to Fig. 7. The solid line gives simulated, the dashed line the experimental insertion loss of this filter. (Dotted line: return loss, dash-dotted line: phase angle).

V. Results of the Second Antenna

In a first step, insertion and return loss were measured with respect to the two SSL ports (Fig. 10). The band-pass characteristic clearly can be seen; overall losses amount to 5 dB and nearly 10 dB at the lower and the upper edge of the passband, respectively. Most of these losses are due to antenna radiation. Return loss is better than -10 dB.

The radiation diagrams of the antenna from 8.1 GHz to 9.3 GHz are plotted in Fig. 11. All curves are plotted with the same reference level, indicating, apart from slight changes of amplitude of the measurement system, their realistic amplitude. For these measurements, once again, the second SSL port was connected to a matched load. The scanning angles range from -60° to 60°, although at the maximum scan angles, an increased sidelobe comes up at the opposite side. Very good scanning performance is found in the -45° to 45° range. The scanning angle as a function of frequency is plotted in Fig. 12.

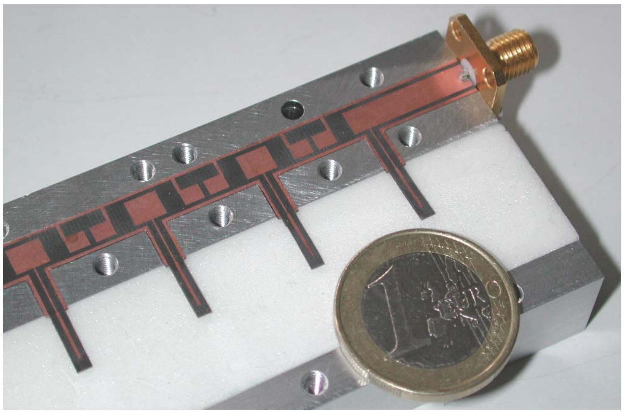

Fig. 9: Photograph of part of the test antenna using SSL band-pass filters as phase shifting elements.

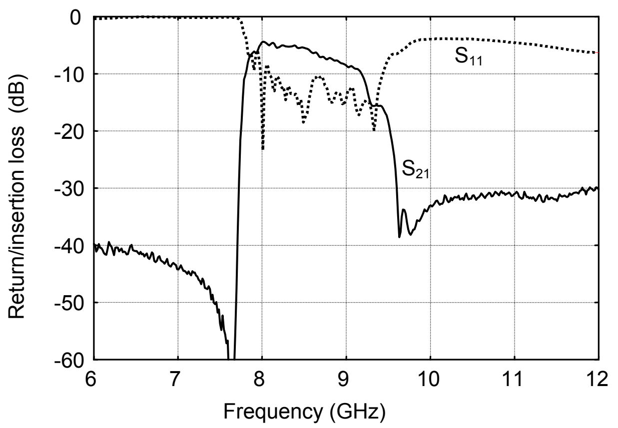

Fig. 10: Return and insertion loss of the test antenna using SSL band-pass filters as phase shifting elements.

VI. Conclusion

A frequency scanned antenna array has been demonstrated based on a composite right/left handed suspended stripline transmission line. The left-handed portion of this transmission line can easily be realized using overlapping strips as capacitors and thin lines to ground (with some inset) as inductors. With this arrangement, frequency scanning of the array is demonstrated from 60° (endfire) to -25° (backfire) over a frequency range from 8 to 11.5 GHz. With an improved antenna using band-pass structures as phase shifting elements, a scanning range from -60° to +60° is achieved.

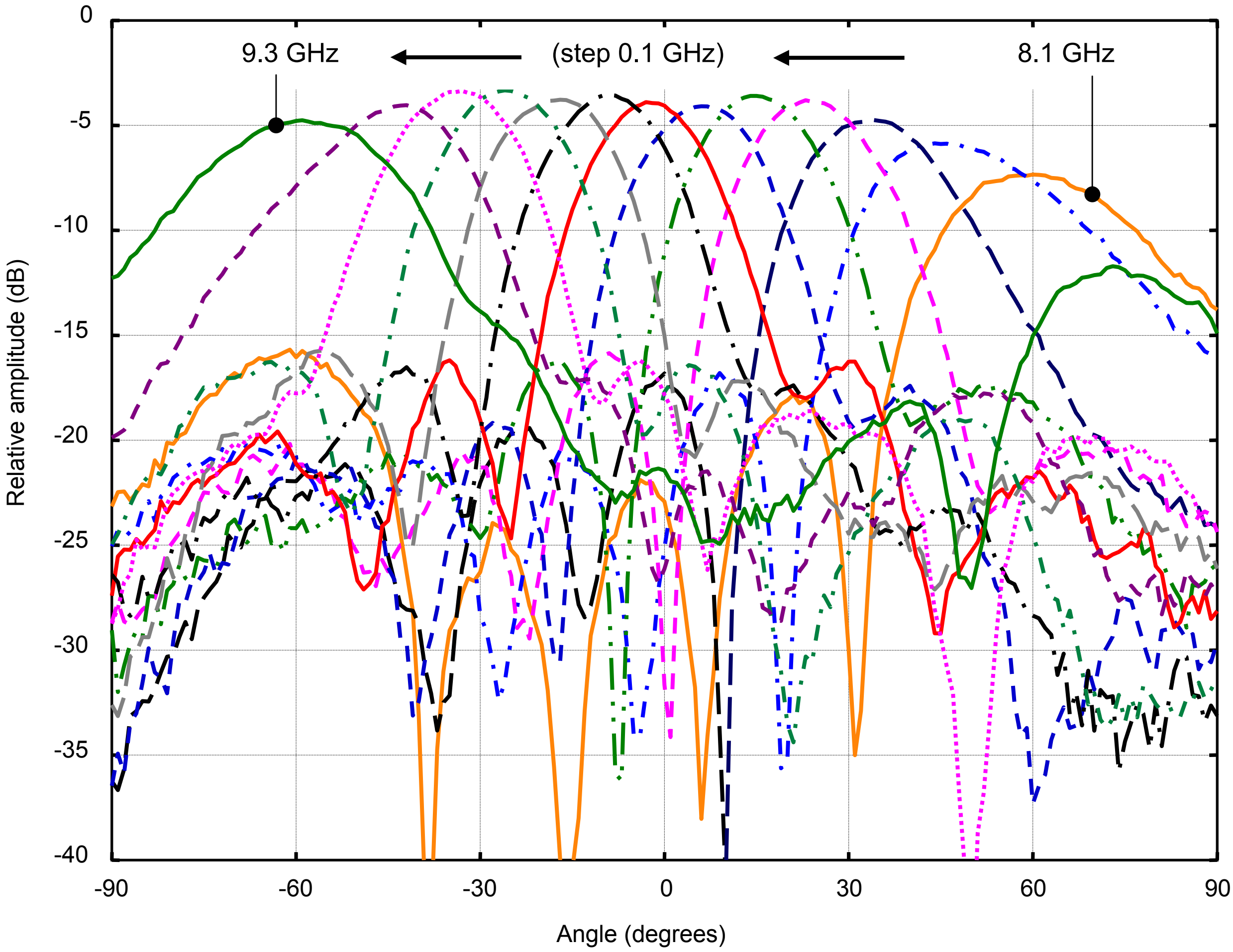

Fig. 11: Beam angle of the test antenna using SSL band-pass filters as a function of frequency.

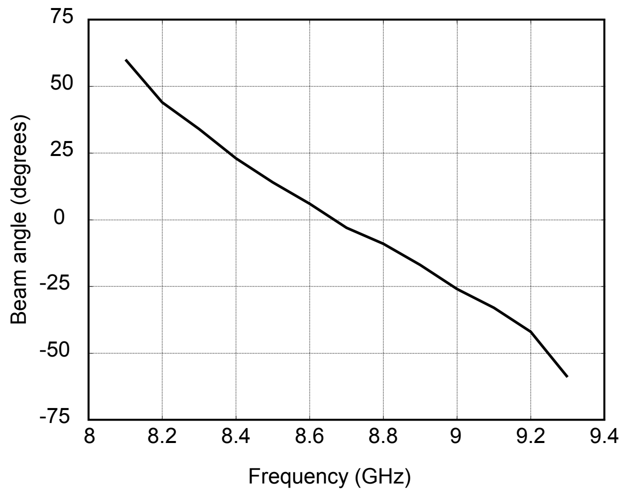

Fig. 12: Beam angle of the test antenna using SSL band-pass filters as a function of frequency.

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