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A Compact Metamaterial UWB Power-Divider Fed Wide-Band Array Antenna

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1. Introduction

In the development of a wide-band antenna, its radiator has become smaller by using slots and pins in a confined area, but the size of the antenna has not been effectively reduced in terms of the antenna system, because the conventional feeding structure is still used. When an array antenna is in need, as the feeding structure should have the power divider, the design becomes no more simple, and the size increases with the antenna feed.

While numerous methods have been introduced to keep the size of an antenna system from growing fast, Metamaterial technologies have emerged to overcome the limitations of the previous design methods in better performance and size-reduction. The CRLH transmission line(TL) was devised to show the possibility of miniaturization through zero phase variation and phase lead at microwave regimes, which imply frequency-independent resonance length and lower-frequency shorter-length, respectively[1]. Lin et al introduced the way to generate a nonlinear dispersion curve of the lumped element type metamaterial[2]. Multi-cell zero phase shift lines were realized as the lumped element type metamaterial[3]. The complementary split ring resonators(CSRRs) were substituted under the branches of the power divider, which has the narrow bandwidth[4].

Before the advent of the metamaterial type components for the antenna feed, the multi staged Wilkinson power divider or tapered line can be adopted to broaden its bandwidth, but this does not provide satisfactory miniaturization of the component(Its feed size is around 130mmX130mm)[5]. Instead of the 1-layer microstrip structure, two dielectric layers with oval slot coupling above and below metal broadside ellipses were introduced[6]. The parallel stripline shaped input port of the out-of-phase power divider is smoothly tapered and has a partial ground(Its entire footprint is about 30mmX40mm)[6].

A miniaturized metamaterial UWB bandpass filter, the power divider, and the array antenna will be designed. At first sight, the UWB filter looks like that of [7], but they are different, because the present filter is an asymmetric π type circuit facing unequal input and output impedance values. The design methodology is validated through the circuit and full-wave simulations and measurement of the fabricated power-divider and antenna. Importantly, the size reduction effect is addressed.

2. ZOR UWB Bandpass Filter and Power Divider

The one-cell metamaterial UWB filter is designed prior to the power divider. The equivalent π type circuit is as follows.

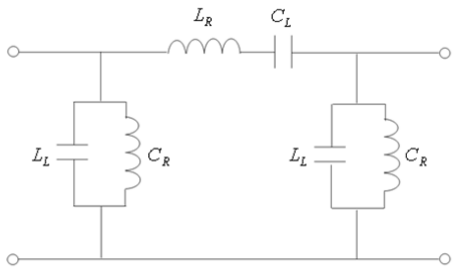


Fig. 1. Equivalent circuit of the proposed one-cell CRLH UWB bandpass filter

Solving the equations in [7] by setting f_L, $f_0(=f_{se}=f_{sh})$, and f_R at 3.1GHz, 5.4GHz and 10.8GHz, respectively, we can find L_L=1.362nH, L_R=1.273nH, C_L=0.617pF, C_R=0.594pF as the circuit elements. Using these values, the scattering parameters S_{21} and S_{11} of the circuit are given as follow.

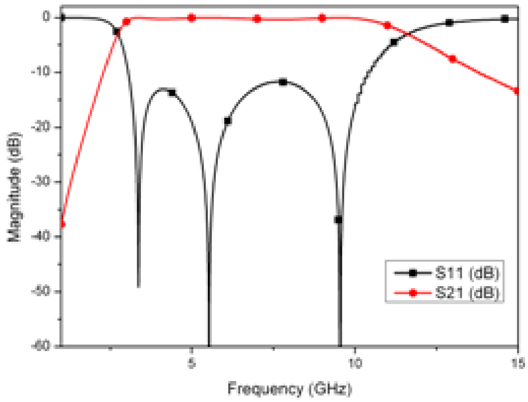
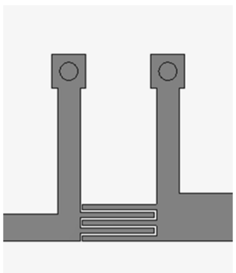
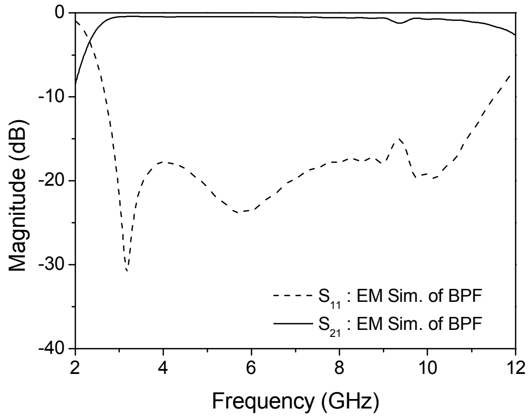


Fig. 2. Circuit simulation result of the proposed one-cell CRLH UWB bandpass filter

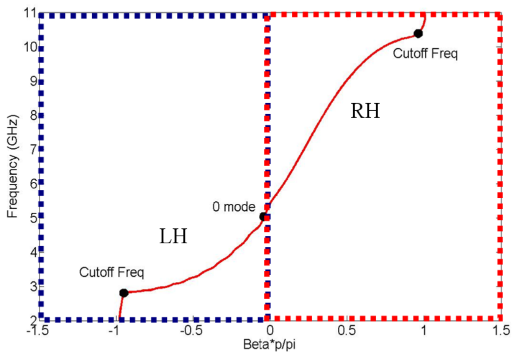
Checking S_{21} and S_{11}, it is shown that the UWB passband is obtained. The return loss is above -15dB at present(circuit level), but this will be enhanced in the following physical implementation. The physical dimensions are found by the process from the initial circuit elements vs. approximate sizes to iterative full-wave simulations for fixing the sizes, in the same manner as [7, 8]. The final sizes will be provided with those of the proposed UWB power divider. Currently, we present the full-wave simulated scattering parameters of the metamaterial bandpass filter along with its geometry.



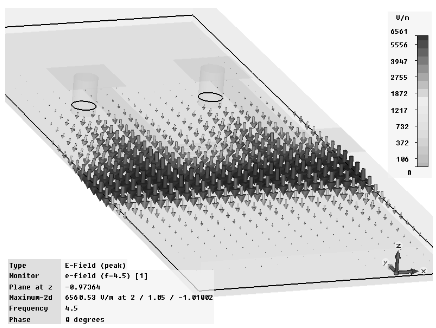
(a)



(b)



(c)

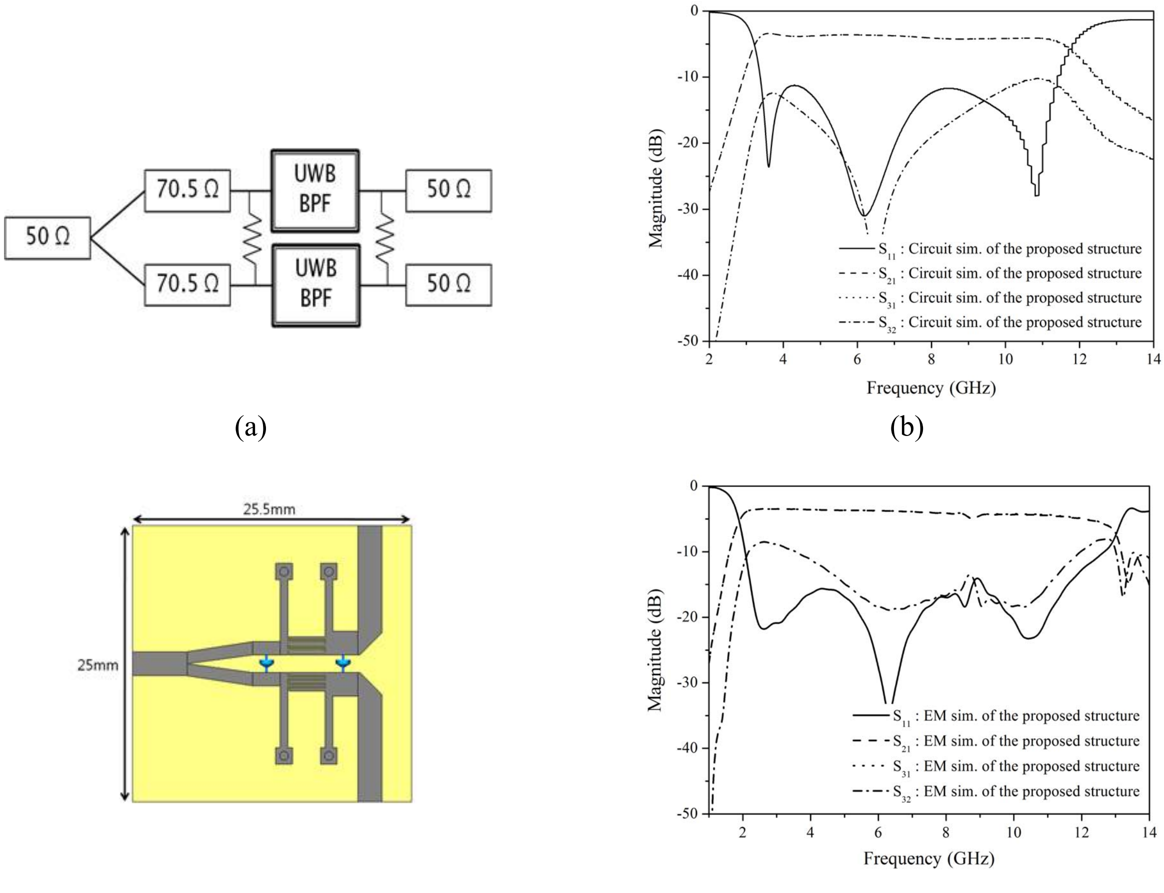


(d)

Fig. 3. Proposed 1-cell CRLH UWB bandpass filter for the power-divider and full-wave simulation results (a)Geometry (b)S-parameters (c)Dispersion diagram (d)ZOR E-field

Different from [1] and [7], the geometry Fig. 3(a) is an asymmetric configuration that takes into account the impedance matching with 75Ω of the input port and 50 Ω of the output port, since this metamaterial filter(< 3.7mm long) will be connected to the branches of the UWB power divider output ports. The physical geometry is a 1-layer microstrip line with FR4(ε_r=4.4, tanδ=0.02, thickness=50mil) as the substrate which is distinguished from the double layered strip line of [6]. The filter has been tuned to have lower return loss than the circuit simulation, and keeps the required bandwidth and poles. This structure needs investigation on the metamaterial ZOR properties. So, the dispersion diagram and the electric field at the ZOR frequency are plotted in Fig.'s 3(c) and (d). The dispersion diagram tells us that the balanced conditioned passband has the LH(phase lead), ZOR(zero phase variation), and RH(phase delay) regions of the CRLH. The ZOR point that crosses the 'β(propagation constant)=0' axis which means no phase variation which is shown by the electric field vectors in Fig. 3(d).

Next, we incorporate the UWB bandpass filter above to the paths of the power divider. The circuit of the proposed UWB power divider is schematized and is followed by the 3D-EM simulation.



(a) (b)

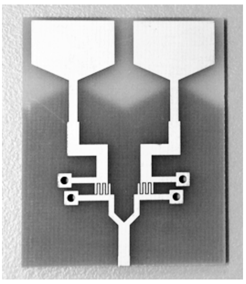
(c) (d)

Fig. 4. Circuit and EM simulated results of the proposed metamaterial UWB power divider (a)Schematic (b)S-parameters of the schematic (c)Geometry in EM simulation (d)EM data

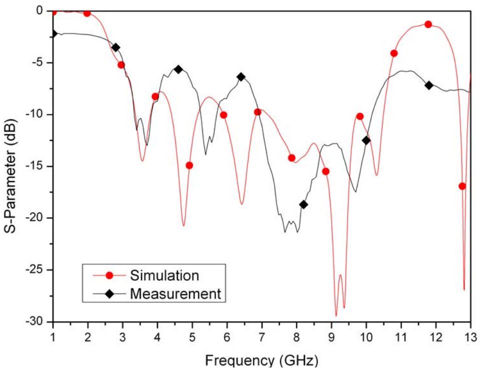
In Fig. 4(a), the UWB BPF blocks are connected to the branches of the power-divider. Fig. 4(b) shows the return loss(S_{11})<-15dB, the power-division(S_{21} and S_{31})=-3dB, the port isolation(S_{23})≈-15dB that meet the specs over the UWB. The schematic is realized physically in the 3D EM simulator with the length less than 3.7mm and simulated as in Fig. 4(c) to give the following results. S_{21} and S_{31} are exactly the same as 3dB, S_{11} < -15dB, and the required bandwidth for the UWB wireless communication. All the performances are better than [4-6]. This power-divider is used for a wide-band array antenna in the next section.

3. Array Antenna with the Proposed Power Divider

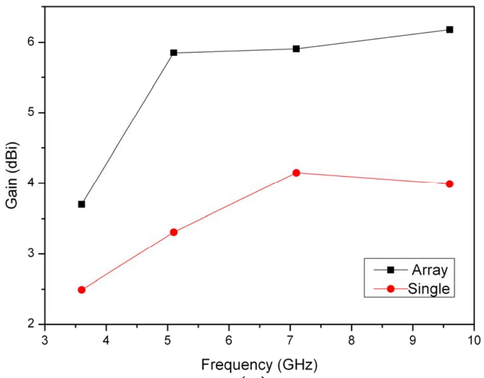
We have implemented a two element array antenna employing the proposed power divider by fabricating and its frequency response is measured.



(a)



(b)



(c)

Fig. 5. Fabricated array antenna, return loss and antenna gain with the proposed metamaterial UWB power divider

Fig. 5(a) is the photo of the fabricated the prototype antenna. The return loss of the antenna looks degraded from the original BW of the UWB in Fig. 5(b), attributed by impedance mismatch between the radiators and power divider(But it can use the 7GHz~10GHz as a wide-band compact array antenna). And Fig. 5(c) shows the gain enhancement over the wide-band by arraying .

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