Left-Handed Unit Cell Based on Hilbert Grounded Patch for Multi-Band Filtering Applications

Vasa Radonić, Nikolina Janković, Vesna Crnojević-Bengin

Abstract – **A new multi-band left-handed unit cell which uses Hilbert grounded patch is proposed and compared with the previously reported configuration which uses grounded square patch. The novel unit cell exhibits three distinct passbands and one deep pole. By changing specific geometrical parameters of the unit cell, three passbands can be independently positioned. The Hilbert patch provides an additional degree of freedom in the design of the unit cell: by varying line-to-spacing ratio and its orientation, the tuning range of the second passband can be increased in respect to unit cell with the square patch. To demonstrate the applicability of the proposed unit cell, a wideband bandpass filter of the third order is designed.**

Keywords – **Metamaterials, Hilbert patch, Bandpass filter.**

I. Introduction

As the number of different wireless systems and services is rapidly growing, frequencies are becoming less available. A solution to this problem is multi-band operation of the modern wireless communication systems. However, the conventional multi-band devices typically operate at harmonic frequencies, which is not in compliance with the spectrum allocations for modern wireless systems. New solutions are sought based on the application of metamaterials, artificial structures composed of a number of unit cells with sub-wavelength dimensions that exhibit electromagnetic properties generally not found in nature.

Apart from small size and backward radiation, metamaterials can be designed to exhibit multi-band operation at arbitrary, i.e. non-harmonic related, frequencies. Recently, the metamaterial concept was used to design multi-band devices with multiple left-handed passbands, [1]-[2].

In [3], a new unit cell for filtering applications has been proposed, based on grounded square patch. It exhibits three distinct passbands and one deep pole that can be independently positioned by changing some specific geometrical parameters of the structure.

In this paper, a new version of multi-band left-handed unit cell is proposed and it is compared with configuration that uses a square patch. In the novel design, square patch is replaced by Hilbert fractal patch. In this way an additional degree of freedom in the design is obtained. Due to their space-filling property, fractal curves allow the design of electrically long lines on a finite substrate area, and they have been applied for miniaturization of passive components, [4], and in the design of metamaterial unit cells, [5]. The influence of line-to-spacing ratio of fractal and its orientation to the performance of the unit cell are analyzed in detail. To demonstrate the applicability of the proposed unit cell, a wideband bandpass filter of the third order is designed.

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II. Configuration of the Unit Cell

The proposed unit cell consists of grounded Hilbert metal patch, capacitively coupled to the ring which is loaded with a grounded inductive stub, Fig. 1. Dimension g denotes the gap between the feeding microstrip line and the resonator, a is overall length of the side of the patch, s is distance between the patch and the metal ring, l and w_s denote length and width of the inductive stub, w is line width of the ring, and d denotes side dimensions of square vias positioned in the center of patch and at the end of the inductive stub. Line-to-spacing ratio of fractal curve, p, is defined as ratio between line width, w_H and spacing, g_H of Hilbert curve, $p = w_H / g_H$.

The unit cell is realized on a 1.27mm Taconic substrate, with ε_r=9.8 and dielectric loss tangent equal to 0.009. Conductor losses are modeled by using bulk conductivity for copper. To enhance the coupling and increase the inductance of the structure, the gap g, distance between the patch and the ring s, and the width of the ring w, are chosen to be the minimal available in standard PCB technology, i.e. equal to 100μm. The length of the side of the patch is a=4.9mm and stub dimensions are l=5.9mm and w_s=0.3mm. Initial width and spacing of Hilbert curve are 0.7mm. The overall dimensions of the proposed unit cell are equal to λ_g/10x λ_g/5 on a given substrate, where λ_g denotes the guided wavelength.

Simulated response of the proposed unit cell is shown in Fig. 2, obtained by EMSight, EM simulator in Microwave Office ver.4.0. The dispersion characteristic is shown in Fig. 3. The proposed unit cell exhibits three distinct passbands that are not harmonically related, positioned at 1.34, 2.84 and 5.66GHz and one deep pole between the first and the second passband positioned at 2.05GHz. First and second passpands are of left-handed nature, while the third is right-handed. The positions of all poles and the transmission zero can be changed independently by changing specific dimensions of the unit cell.

The position of the first passband is controlled by dimensions of the inductive stub, while at the same time, the second and the third passbands are almost unaffected. The position of the second passband can be changed by two mechanisms: by changing the dimensions of the patch via or by changing the dimension of the patch itself. Small changes in the dimensions of the patch via result in large changes of the second resonance, as well as in the position of the pole. By reducing via dimensions from 0.5x0.5mm to 0.1x0.1mm, reduction of more than 17% of the second resonant frequency is obtained. At the same time, there are no variations of the first and the third passbands. In the case of the square patch, [12] decreasing the patch size *a* results in shifting of the second passband and the pole towards higher frequencies. The length of ring influences only the third passband.

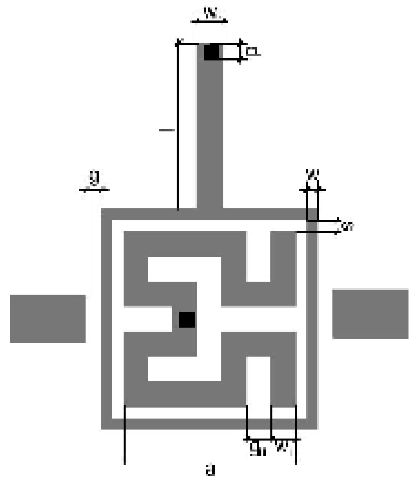


Fig. 1. Configuration of the proposed unit cell with all relevant geometrical parameters

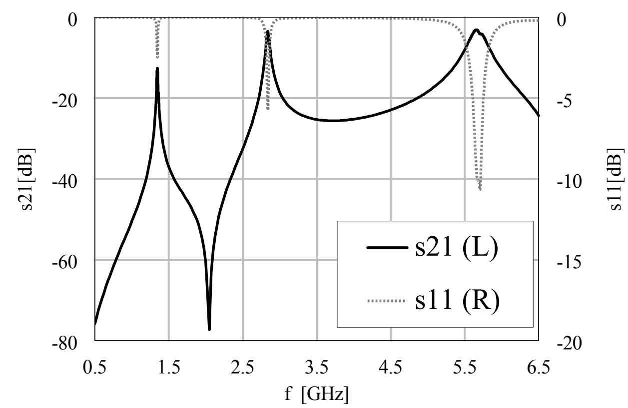


Fig 2. Simulated response of the proposed unit cell

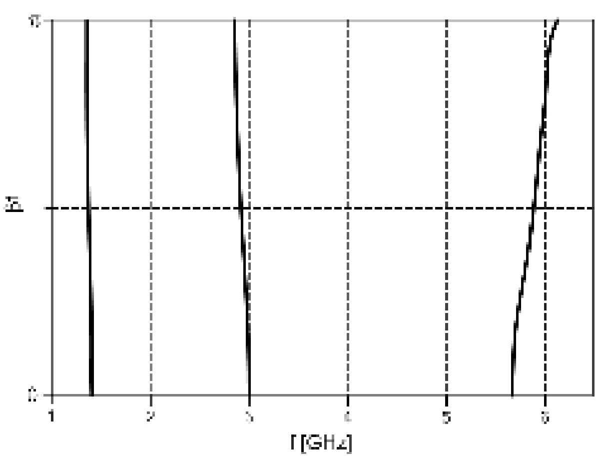
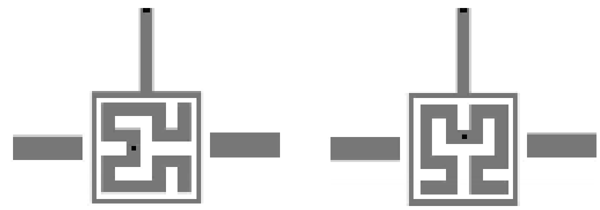


Fig. 3. Dispersion diagram of proposed unit cell

In this design, the square patch is replaced with the Hilbert fractal patch of the same overall dimensions. Two different orientations of the Hilbert patch are analyzed, Fig. 4. Obtained simulation results are compared in Fig. 5.



(a) (b)

Fig. 4. Proposed unit cell with orientations of the Hilbert patch: (a) orientation 1, (b) orientation 2

Unlike the case of the design of grounded fractal filters, where the orientation of the fractal curve plays a significant role, the orientation of the Hilbert patch within the proposed unit cell bears a very small influence to the performance. In the case of orientation 2, an additional eigen resonance of the Hilbert curve is excited. However, the insertion loss associated with this resonant mode is two large for this passband to have any practical significance. Therefore, we can conclude that the orientation of the Hilbert patch does not significantly influence the performance of the unit cell.

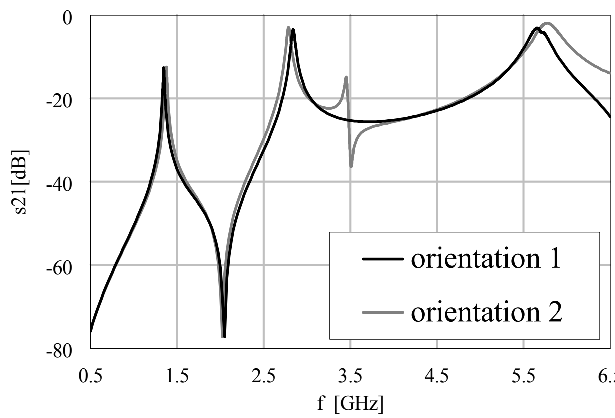


Fig. 5. Simulation results for different orientations of the Hilbert patch

Shifting of the second passband can also be obtained by changing line-to-spacing ratio of fractal curve for the fixed overall dimensions of Hilbert patch, equal to $4w_H+3g_H$=4.9mm. Simulation results for four different values of ratio *p*= 1, 0.364, 0.042 and 3.33 are compared in Fig. 6.

It can be seen that for lower *w*, the second resonance is shifted towards lower frequencies due to decreased inductance of the Hilbert line, while the first resonance is unaffected. As expected, wider lines on smaller spacing result in higher second resonant frequency and lower insertion loss. By changing ratio of the Hilbert curve, second resonance tuning range of more than 21% is obtained. Small ratio *p* results in a very weak coupling between the ring and the patch. Therefore, reducing *p* below a certain value has no effect on the performance.

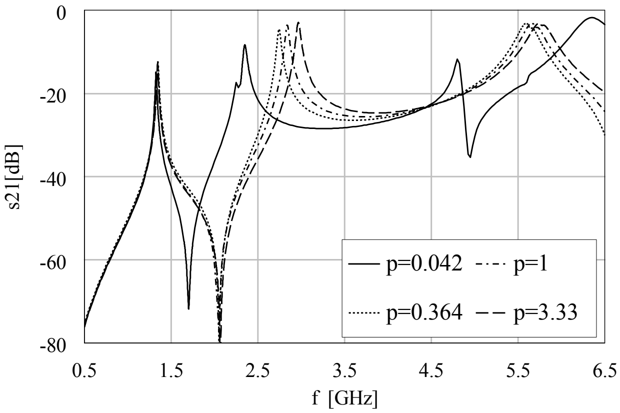


Fig. 7. Simulation results for different line-to-spacing ratio of fractal curve

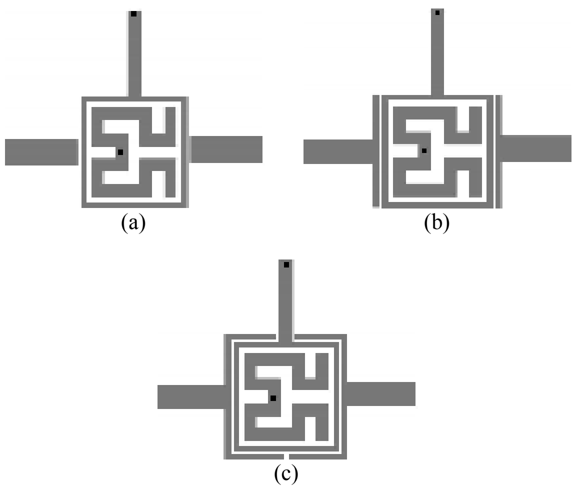


Fig. 8. Different coupling between the microstrip and the resonator: (a) edge coupling, (b) line coupling, (c) maximal coupling

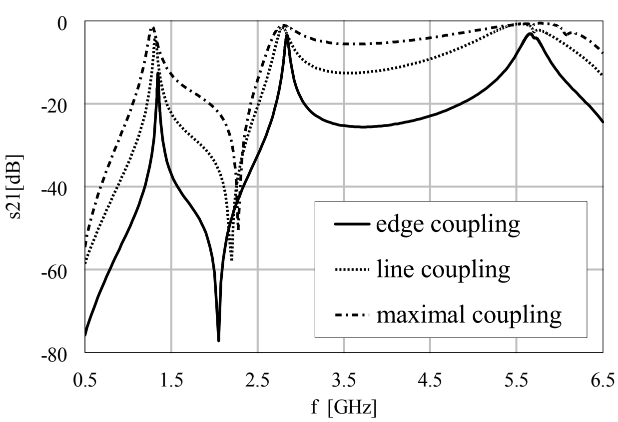


Fig. 9. Influence of the coupling between the feeding lines and the resonator on the transmission coefficient

With the aim to reduce losses in the passbands and/or to modify the shape of the transmission characteristic, coupling between the microstrip and the resonator can be changed. Three different coupling geometries that use the same gap equal to g=100µm are analyzed, Fig. 8. The responses are compared in Fig. 9. Apart from the reduced losses, increased coupling results in changed shape of the transmission characteristic. By a proper choice of the dimensions, the second and the third passband could be merged to form a very wide passband.

III. Filter design

To demonstrate applicability of the proposed unit cell, a very wideband bandpass filter of the third order is designed. Layout of the filter is shown in Fig. 10. Optimized dimensions of the unit cell are d=0.1mm, a=4.9mm and w=0.1mm. Two stubs on the opposite sides of every unit cell are used instead of just one, to control the position of the first passband and insertion losses. In this case, resistive losses are connected in parallel which results in smaller insertion loss of the whole structure. By optimizing inductive stub length, the first passband can be suppressed and the second and the third passbands can be merged forming one very wide passband, Fig. 11.

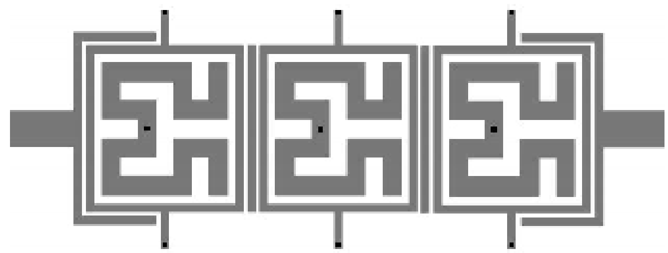


Fig. 10. Wide-band bandpass filter of the third order

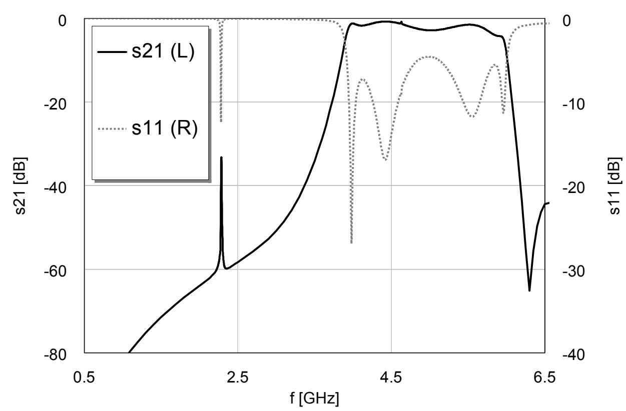


Fig. 11. Optimized response of the wideband bandpass filter

For optimized length of the inductive stub equal to 1mm, the first passband is suppressed for more then 30dB. At the same time, the filter exhibits 40% 3dB fractional bandwidth centered at 5GHz. Proposed filter has 2dB ripple in the passband that can be decreased by optimizing dimensions of each Hilbert patch individually or changing a position of each patch via. The proposed filter can be used in modern wireless communication systems that operate according to IEEE 801.11a and HyperLanII standards.

IV. CONCLUSION

Novel LH unit cell with multi-band characteristics has been presented. It has been shown that each passband can be independently controlled by varying specific dimensions of the unit cell. In comparison to the unit cell that uses grounded square patch, unit cell with Hilbert patch offers 20% greater tuning range of the second resonance. To illustrate the potential of the proposed unit cell, bandpass filter of the third order has been designed, which exhibits 40% fractional bandwidth at 5GHz. This filter could be used in IEEE 801.11a and HyperLanII systems.

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