A Compact Dual Band Band-pass Filter Using a New Topology of Transmission Line Metamaterial

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Abstract— In this paper, we introduce a dual-band band pass filter based on a transmission line metamaterial. The unit cell of this metamaterial was loaded with shunt inductor and series capacitor. Once simulated with HFSS, our band pass filter revealed two operational frequencies 5.8 GHz and 8.7 GHz, making it a good candidate for many microwave applications and especially for RADAR.

1. INTRODUCTION

Band pass filters are employed in wireless systems to remove signals from an undesired frequency or channel and we often find it before and after the mixer in many cases as revealed in Figure 1.

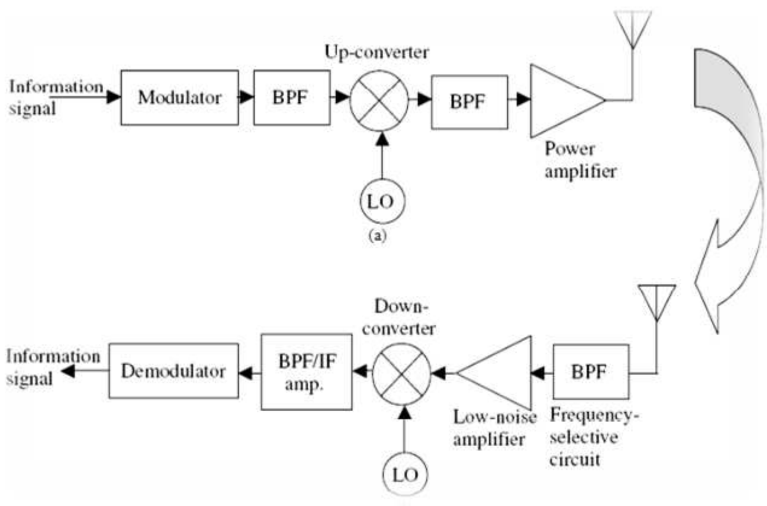


Figure 1: Transmitter/receiver block diagram for microwave communications.

With the rapid development of microwave and millimeter wave communication systems the demand on high performance band-pass filters with compact dimensions, low insertion loss and low cost was greatly stimulated. However, most of conventional band-pass filters are unsuitable for miniaturized realization demand of modern communication and electronic systems. In this study, we developed a novel compact dual band band-pass filter using a new type of transmission line metamaterial as depicted in Figure 2. The aim of using such type of metamaterial is the low cost and the easy achievement using the coupling method to synthesize such a filter.

Multiple studies showed that Metamaterial based on SRR, exhibit LH property only around the resonance frequency and this is called the resonant approach which permits only a narrow band and presents losses due to the requirement of operation near SRR resonance [1–3]. To overcome those drawbacks, we used Transmission Line metamaterial made by loading the conventional transmission line with discrete lumped inductors and capacitors with high quality factors to enable a good control and mitigate losses [5].

2. METAMATERIAL TRANSMISSION LINE UNIT CELL DESIGN

2.1. Unit Cell Design

The loading may be achieved using either discrete lumped elements or printed lumped elements as in the shunt NRI-TL structure. Discrete lumped elements have the advantage of permitting small structures at low frequencies and are easier to model.

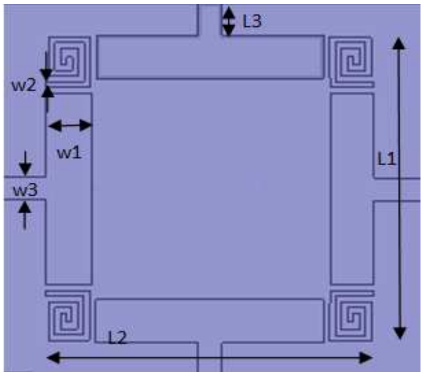


Figure 2: Unit cell of the MTM TL. $L_1 = L_2 = 5.5\,\text{mm}$, $W_1 = 0.788\,\text{mm}$, $W_2 = 0.1\,\text{mm}$, $W_3 = 0.4\,\text{mm}$, $L_3 = 0.5\,\text{mm}$.

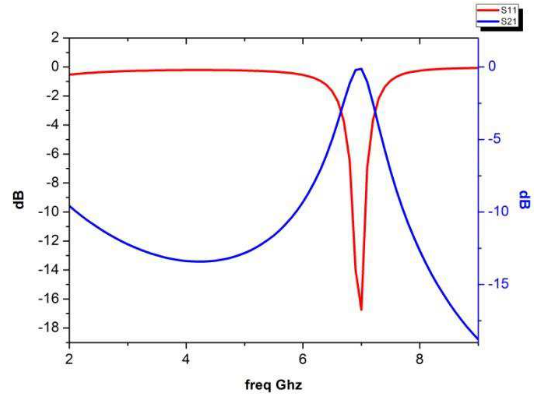


Figure 3: Scattering parameters of the simulated of the array of 3 unit cells.

On the other hand, printed lumped elements allow scalability and can lower the cost of fabrication significantly. In our case, we considered a design employing printed lumped capacitors and inductors rather than discrete elements. For the shunt inductive loading, we employed a strip of width w_3 connecting the coplanar-strip TLs, and, for the series capacitive loading, we propose the use of spiral strip capacitors with finger width w_2 with a distance between turns of about 0.2 mm. The resulting of the complete, printed planar unit cell is shown in Figure 2.

The loaded TL is printed over a Roger O3003 substrate with $\varepsilon = 3$ and at a height of about 1.5 mm. In addition the overall size of the super lens unit cell is a sub-wavelength size $\lambda/3$ which fulfills the condition of loss reducing mentioned before.

In an effort to find out the contribution of each load in the creation of NRI TL, and with analogy to the behavior of SRR and wire studied by Smith [4, 6], we will try to focus on the behavior of series capacitor and shunt inductor in response to electromagnetic excitation. When the TL is loaded with shunt inductors only or when rings are connected via the inductor strip to each other, the propagation is forbidden at low frequencies and this is explained by the fact that the inductive loading creates a continuous path at low frequency which cause the behavior of ground plane. We also noted that the permittivity of the medium is negative, below the effective plasma frequency ω_{ep}. When the host TL is loaded with series capacitors, the dispersion characteristic is similar to that obtained for an array of SRR. Thus we have a forbidden frequency band between resonance frequency ω_0 and magnetic plasma frequency ω_{mp} where the permeability is negative.

Once the host medium is loaded with series capacitors and shunt inductors, a region of left hand propagation is created inside the forbidden frequency band created by the series capacitor load and mentioned above [7].

2.2. Simulation Result

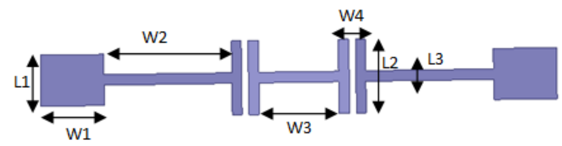
In order to study the behavior of the structure when responding to an electromagnetic excitation, an array of three unit cells with a period $p = 6.5\,\text{mm}$, was simulated with HFSS.

To do that, our structure is excited with an electric field polarized perpendicular to the ring and by a magnetic field lying in the ring plane which would excite the gap between rings and also the ring capacitors [10]. The return loss as depicted in Figure 3 is about $-17\,\text{dB}$ at 7 GHz as well as and the transmission coefficient S_{21} is about 0 dB which means that the incident wave is fully transmitted.

3. DUAL PASS BAND FILTER

Our purpose was to design a band-pass filter and after that we will manage to modify the filter structure so that we got a dual pass band filter. Our structure was printed over a Roger O3003 substrate with $\varepsilon = 3$ and at a height of about 1.5 mm.

The filter was simulated with HFSS and excited using two coupled microstrip lines associated to a taper line which permits to achieve good matching input impedance for the desired band. To modify the bandwidth of the filter we have to adjust the lengths of the H structure. After the



W1	W2	W3	W4	L1	L2	L3
4.7	9.5	5.92	0.5	3.8	5.5	0.788

Figure 4: The bandpass filter structure (dimensions are in mm).

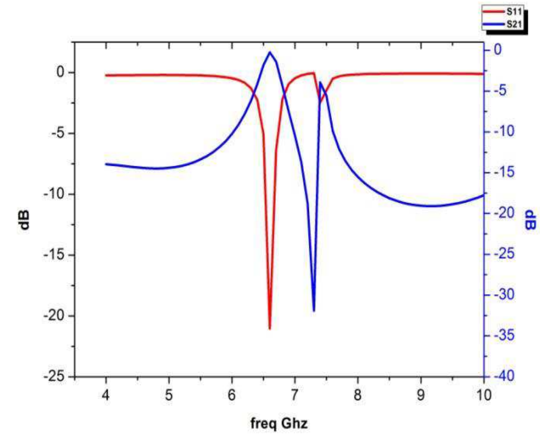


Figure 5: S parameters of the H filter structure.

optimization of this structure we have obtained a band-pass filter centered at 6.8 GHz with an S_{11} of about -21 dB.

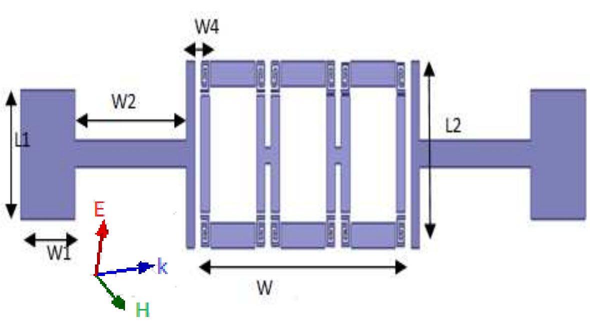
After the validation and the simulation of the H filter, we conducted a study to improve the response of the structure and realize a dual band band-pass filter using a new topology of transmission line metamaterial as described in the first section.

As depicted in the above structure, the load is ensured by an array of three unit cell with an overall length of $w = 17.5$ mm. The filter has dimensions of $48.35 \times 24\,\text{mm}^2$.

It's important to note that we have kept the same dimensions of the microstrip lines and the feeder to maintain the impedance mach. The filter was excited by an electromagnetic wave where E is perpendicular to the structure and according to z direction while H is according to x direction. The simulation was made using HFSS and it showed a dual-band band pass filter and the first frequency was 5.8 GHz and the second frequency was 8.7 GHz with a return loss of about -22 dB for the first and -27 dB for the second. Those results are showed in the Figure 7 below.

The Figure 8 presents the current distribution for the two filtered band frequency the first around 5.8 GHz and the second around 8.7 GHz. The exchange of energy between resonators can be concluded from the coupling coefficient, nevertheless the use of sub-wavelength resonators provide a significant reduction in the planar area of microwave filter [8, 9].

The dual band operation is an important issue in band-pass filter design and it answers the demand in conception of band-pass filter in many in many RADAR applications ensuring miniaturization, low cost and fulfill the ISM band (Industrial , Scientific and Medical) thanks to the



W1	W2	W	W4	L1	L2
4.7 mm	9.5 mm	17.5 mm	0.5 mm	3.8 mm	5.5 mm

Figure 6: The novel band pass filter topology.

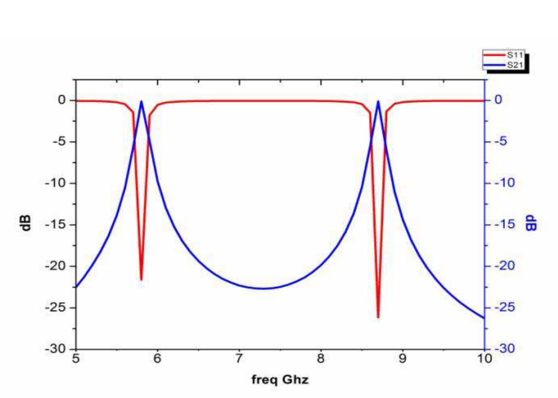


Figure 7: The simulation results of the band pass filter.

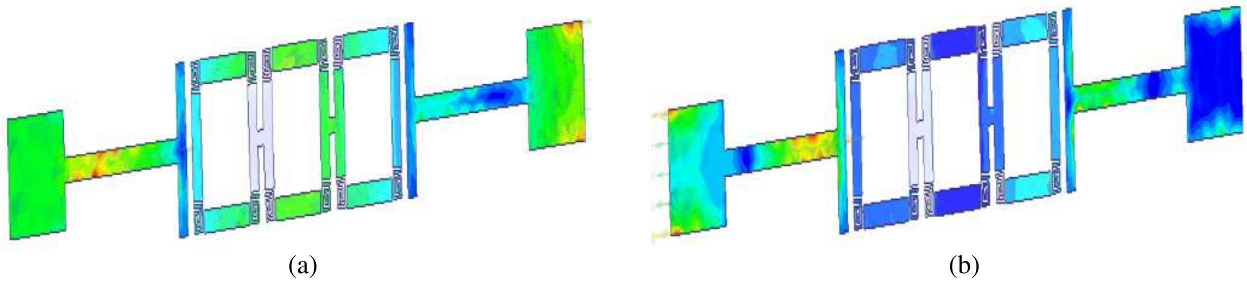


Figure 8: The current distribution at (a) 5.8 GHz and (b) 8.7 GHz.

planar micro strip technology. Meanwhile we should mention that a dual band band-pass filter with highly selective response in conjunction with lower insertion loss and wide stop band still a challenge in microwave applications. Practically, we can use our filter in Weather RADAR applications operating at 5.8 GHz and in the same time for RADAR applications operating in X band.

4. CONCLUSION

In this study we are proposing a dual pass band filter using a new type of metamaterial transmission line. The structure was compact and low cost thanks to MTM TL and it can be used in many applications related to RADAR.

REFERENCES

1. Veselago, V. G., "The electrodynamics of substances with simultaneously negative value of ε and μ," *Soviet Physics Uspekhi*, Vol. 10, No. 4, Jan. 1968.
2. Pendry, J. B., A. J. Holden, D. J. Robbins, and W. J. Stewart, "Low frequency plasmons in thin-wire structures," *J. Phys. Cond. Matter.*, Vol. 10, 4785–4809, 1998.
3. Pendry, J. B., et al., "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, Nov. 1999.
4. Shelby, R. A., D. R. Smith, and S. Schultz, "Experimental verification of negative index of refraction," *Science*, Vol. 292, 77–79, May 2001.
5. Eleftheriades, G. V. and R. Islam, "Miniaturized microwave components and antennas using negative-refractive-index transmission-line (NRI-TL) metamaterials," *Metamaterials*, Vol. 1, 53–61, 2007.
6. Smith, D. R., et al., "Composite medium with simultaneously negative permeability and permittivity," *Physical Review Letters*, Vol. 18, 4184–4187, May 2000.
7. Iyer, A. K. and G. V. Eleftheriades, "Volumetric layered transmission-line metamaterial exhibiting a negative refractive index," *J. Opt. Soc.*, Vol. 23, No. 3, Mar. 2006.
8. Baral, R. N. and P. K. Singhal, "Miniaturized microstrip bandpass filter using coupled metamaterial resonators," *International Journal of Microwave and Optical Technology*, Vol. 4, No. 2, Mar. 2009.
9. Benmostefa, N., et al., "Metamaterial tunable filter design," *Journal of Electromagnetic Analysis and Applications*, No. 5, 250–254, 2013.