Design of Hairpin Filter using Omega Metamaterial Substrate

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Abstract— **In this paper, a new innovation of omega structure as metamaterial substrate is implemented as a base construction of the hairpin bandpass filter has been proposed. A combination of RTD5880 and copper in omega structure has successfully performed the metamaterial behaviour. An investigation on the S-parameters has been carried out to determine the negative permittivity of the metamaterial. The results from the proposed method has been analyzed and compared with the conventional hairpin bandpass filter in terms of insertion loss, return loss and size. Based on the simulation results, the presence of metamaterial has improved the performance for return loss, insertion loss and also reduces 21 times the size of the filter. The details of design for the proposed method are presented and discussed.**

Keywords— Bandpass filter, metamaterial, microstrip, hairpin filter.

I. INTRODUCTION

Microwave systems have an enormous impact on modern society. Applications are diverse, from entertainment via satellite television, to civil and military radar system. In the field communication, microwave filters are vital components in huge variety of electronic systems, including cellular radio, satellite communication and radar. It is widely used in all these system in order to discriminate between wanted and unwanted signal frequencies [1].

Hairpin band pass filter is the one of the most popular filter configurations used in microwave frequencies. It is easy to manufacture because it has open-circuited ends that requires no grounding. In order to appreciate the concept behind the hairpin band pass filter, it would be helpful to have some background about parallel coupled filter. It is from the edge-coupled resonator filter by folding back the ends of the resonator into a "U" shape [2].

Materials with negative permittivity and permeability in certain frequency range or known as left-handed material (LHM) is the examples of metamaterial the material produce is new, may not be easily molded into minds. Negative permittivity means it is available in nature, physically unique and has unusual realizable response function. A metamaterial is a material which gains its properties from its structure rather than from its composition [3].

In this paper, an omega structure and substrate Rogers RTD5880 was used to construct the metamaterial substrate. The reason to used Rogers RTD5880 because the substrate can stable output for long time period and make accurate reading over relative narrow temperature spans. The proposed design was simulated and analyzed using Computer Simulation Technology Microwave Studio (CST MWS).

II. METHODOLOGY

A. Metamaterial Design and Its Determination

The first step is to determine the potential structure which can perform metamaterial behavior. The purpose of designing the metamaterial substrate is to choose reliable and potential structure design that can become metamaterial. Some of the famous structure is split-ring structure, symmetrical-ring structure, S structure and omega structure [4]. The comparison among different metamaterial substrate structure is in Table 1.

TABLE I
COMPARISON AMONG DIFFRENT METAMATERIAL SUBSTRATE [4]

Structure	Retrieval	Adjustment
Split-ring	Clean	Medium
Symmetrical-ring	Clean	Easy
S	Unclean	Medium
Omega	Unclean	Hard

For this paper, the omega structure is chosen as a metamaterial substrate design. Although omega structure is hard to adjustment and unclean to retrieval, it is used to try to prove that metamaterial substrate can improve the conventional substrate. Frequency domain solver was chosen to simulate the metamaterial construction in the CST MWS. Tetrahedral mesh was chosen and density mesh was fixed at 6 steps per wavelength with the advance volume method to obtain the accuracy in the simulation. The dimension of the omega structure is shown in Fig.1.

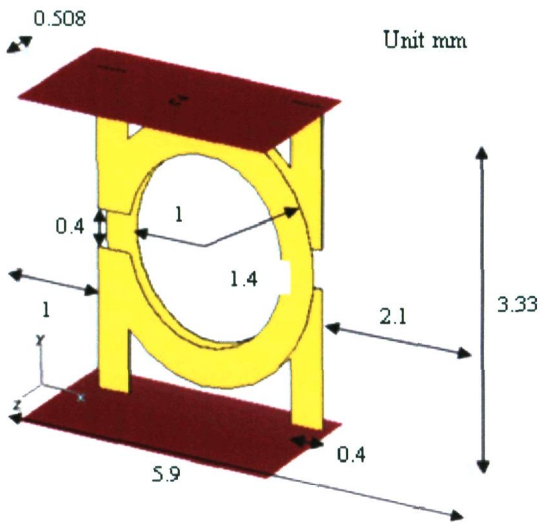

Fig.1: A unit cell of omega structure

The omega structure consists of substrate RTD5880 and two omega structures build by copper. The detail about RTD5880 shows at Table II:

TABLE II
RTD5880 SUBSTRATE PROPERTIES

Permittivity, ϵ	2.2
Loss Tangent	0.0001
Permeability, μ	1
Substrate Height, h	0.508mm

The CST Microwave Studio software is used to simulate and to obtain the S-parameters data. The boundary condition has been set as it has important consequences in the propagation of radiowave transmission. Transient solver is used to simulate the metamaterial construction in the CST Microwave Studio software and S-parameter data were obtained for further analysis to determine the permittivity of metamaterial.

B. Conventional Bandpass Filter Design

After the suitable structure for metamaterial is chosen and negative permittivity or permeability is proven, the structure of conventional hairpin band pass filter is designed. To design hairpin band pass filter, the center frequency (f_c) of the filter must be similar to the frequency where the negative permittivity is located. The design used the Chebyshev technique and 20% fractional bandwidth. The center frequency of bandwidth is 10.5GHz which approaches the value of the frequency at negative permittivity and pass band ripple is 0.5dB. The value of low cut-off frequency is 9.5GHz and high cut-off frequency is 11.5GHz. Table III shows the normalized element values from g1 to g3 for Chebyshev response.

TABLE III
NORMALISED ELEMENT VALUE

g_1	g_2	g_3	g_4	g_5
1.5963	1.0967	1.5963	1	0

The filter designed based on method described by R.N. BARAL, P.K. SINGHAL [5]. The coupling coefficient, Z is related as in equation (1);

$$Z_0 J_{n,n+1} = \sqrt{\frac{\Delta\pi}{2g_n g_{n+1}}} \quad (1)$$

Where

$$\Delta = \frac{w_u - w_l}{w_0} \quad (2)$$

After calculating the impedance values or value of Z, the next step is to calculate the even and odd characteristic line impedance for each coupling. The formula for both even and odd line impedance are;

For even (Z_{0e})

$$Z_{0ei,i+1} = Z_0\left[1 + Z_0 J_{i,i+1} + \left(Z_0 J_{i,i+1}\right)\right] \quad (3)$$

For odd (Z_{0o})

$$Z_{0ei,i+1} = Z_0\left[1 - Z_0 J_{i,i+1} + \left(Z_0 J_{i,i+1}\right)\right] \quad (4)$$

Where

$$Z_0 = 50\Omega \quad (5)$$

Then, the electrical parameter must be determined, where the electrical parameter consists of;

$$Z_0 = \sqrt{Z_{0e} Z_{0o}} \quad (6)$$

And

$$\text{Coupling} = 20\log_{10}\left|\frac{Z_{0e}-Z_{0o}}{Z_{0e}+Z_{0o}}\right| \qquad (7)$$

Then, include the values of electric parameter in Line Cal program to calculate the coupler width (w), length (l) and spacing (s) of the filter.

From equation (8) and (9) the tapped point can be calculated [6].

$$Q_{sh} = \frac{R}{Z_0}\frac{\pi}{2\sin^2\phi_1} \qquad (8)$$

$$\frac{Q_{sh}}{\left(\frac{R}{Z_0}\right)} = \frac{\pi}{2\sin^2\left(\frac{\pi}{2l}\right)} \qquad (9)$$

After optimizing, the final dimension of the filter is obtained as shown in Fig.2 below.

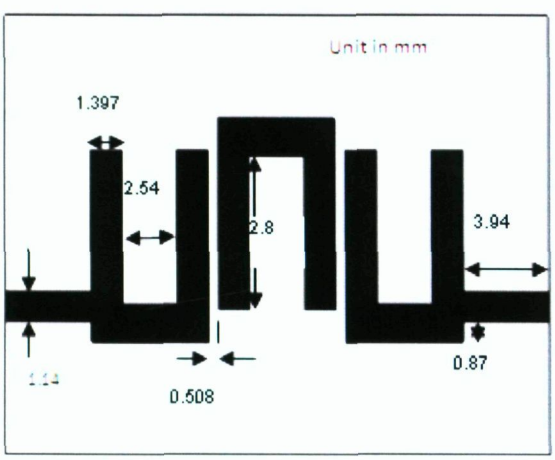

Fig.2: The dimension after last optimizing

The band pass filter structure as shown in Fig. 2 is a there pole hairpin bandpass filter. Each resonator with U-shape is a quarter-wavelength resonator. Roger RT/duriod5880 is used as a substrate for the conventional filter.

C. Metamaterial Bandpass Filter Design

The Fig.3 shows the hairpin band pass filter circuit using metamaterial substrate. The dimension circuit of conventional band pass filter is converted to the metamaterial substrate.

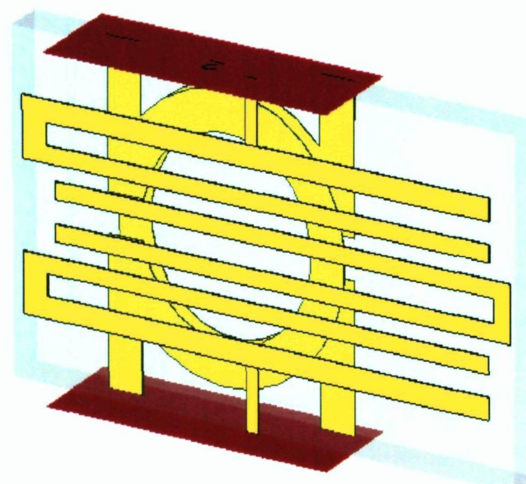

Fig.3: The hairpin filter using metamaterial substrate.

Each width (w), length (l), spacing (s) and feeder size of the conventional hairpin bandpss filter is converted to metamaterial substrate using area ratio of conventional substrate and metamaterial substrate. The Fig.4 below shows the dimension of hairpin bandpass filter on metamaterial substrate.

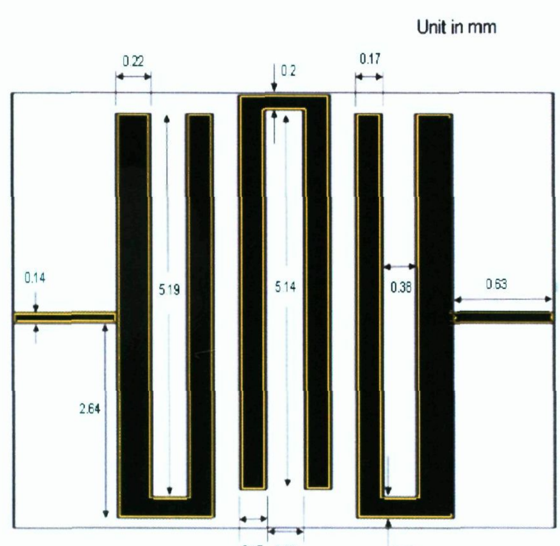

Fig.4: The dimension hairpin on metamaterial substrate

III. RESULTS AND DISCUSSION

Fig.5 shows a plot of the permittivity that has been extracted from S-parameters. The graph indicates that the metamaterial has a negative permittivity at the targeted frequency of 10.5GHz with value of -3.653.

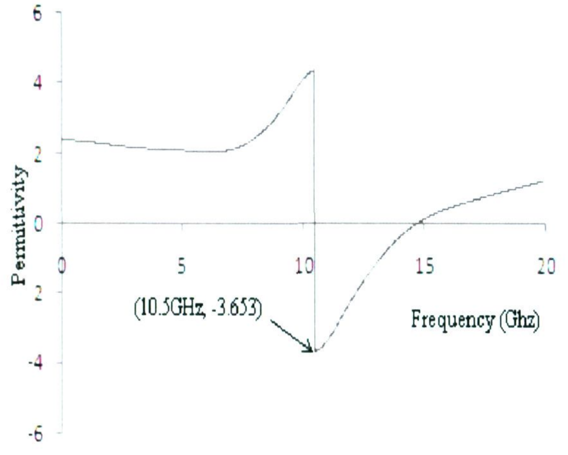

Fig.5: A Graph permittivity versus frequency

The best dimensions of both filters were obtained after optimization processes. The size of metamaterial filter was approximately **21 times smaller** than the conventional that operate at the same frequency of 10.5GHz. Comparisons of dimensions from both conventional and metamaterial filters were shown in Table IV.

TABLE IV
COMPARISON BETWEEN CONVENTIONAL AND METAMATERIAL SUBSTRATE

Description	Conventional	Metamaterial
Length	24.89mm	3.33mm
width	17.14mm	5.9mm
Area	426.65mm^2	19.467mm^2

The graph in Fig.6 shows the response of S21 or insertion loss. The solid line represents conventional of S21and broken line represents metamaterial of S21. The average passband insertion loss for the conventional is -0.64dB and -0.5026dB for conventional, that's mean using metamaterial is closed to ideal condition equal to 0dB. For stopband at low cut-off frequency, conventional is better than metamaterial because conventional is closed to ideal shape. At high cut-off frequency metamaterial is more perform better than conventional because the value of stopband for the metamaterial is less than -20dB. From the graph, it can be seen that the design is a wideband filter with bandwidth of 2GHz or equal to 20%.

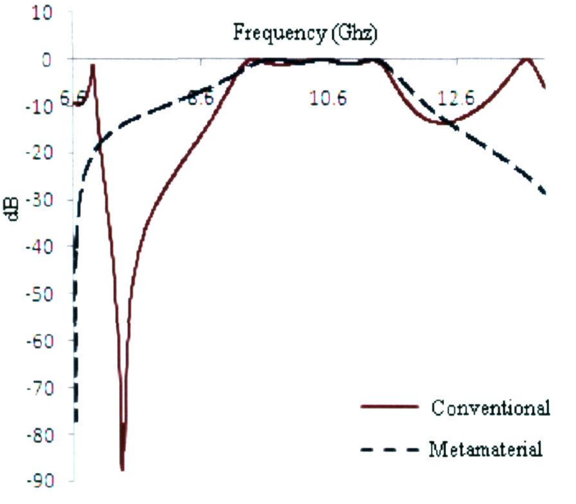

Fig.6: The graph of S21 for conventional and metamaterial filter

The graph in Fig.7 shows the response of S11 or return loss. The solid line represents conventional of S11 and broken line represents metamaterial of S11. Both of graphs have 3 corner edges, similar like resonator "U" shape at the circuit hairpin bandpass filter. From Fig.7 also can determined value metamaterial of S11 is less compared value of conventional. A small return loss of metamaterial bandpass filter correspond precisely the power being delivered to the load. A high return loss of conventional bandpass filter correspond the power being reflected from the load and returning to the source.

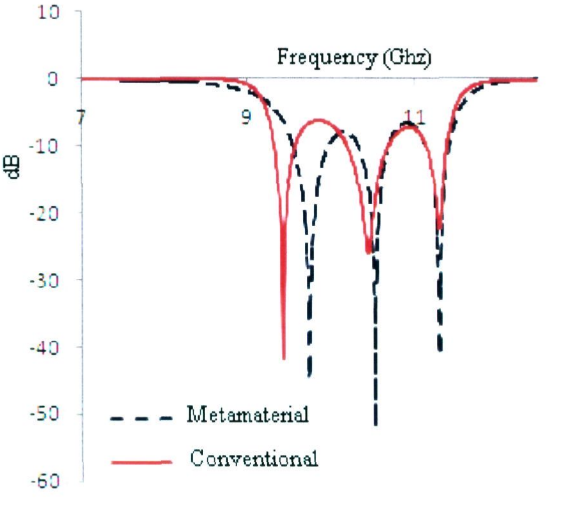

Fig.7: The graph of S11 for conventional and metamaterial filter

Table V shows the summarized data between the conventional bandpass filter and metamaterial bandpass filter. It is clearly shown that the presence of metamaterial has improved the performance for return loss, insertion loss and stopband attenuation loss. The bandwidth both conventional and metamaetrial hairpin bandpass filter is same value at same operating frequency.

TABLE V
COMPARISON RESULTS BETWEEN CONVENTIONAL AND METAMATERIAL BANDPASS FILTER

Description	Conventional	Metamaterial
S11	-40dB	-50dB
Insertion loss	-0.7dB	-0.5dB
Stopband13GHz)	-14.01dB	-20dB
Bandwidth	2Ghz	2GHz

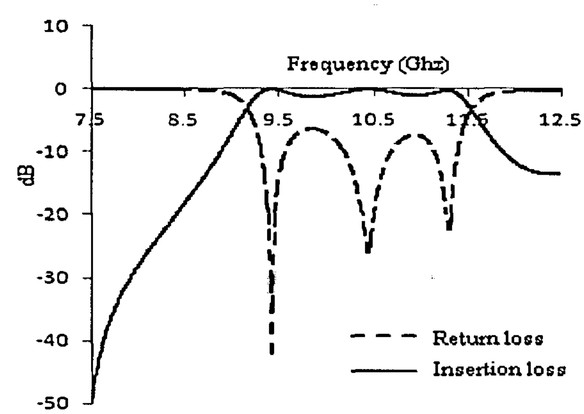

Fig.8: The graph of S11 and S21 for conventional

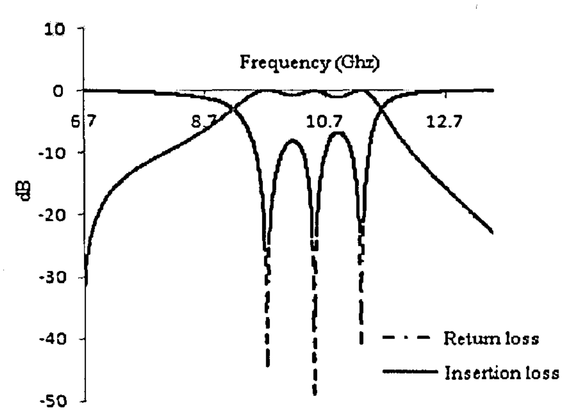

Fig.9: The graph of S11 and S21 for metamaterial July 200

From the Fig.8 and Fig.9 show the responses insertion loss (S21) and return loss (S11) both conventional and metamaterial hairpin bandpass filter. Even stopband at low frequency for conventional closed to ideal shape batter than metamaterial, but another specification metamaterial was improving the conventional filter.

IV. CONCLUSION

The properties of metamaterial have been proven by showing negative permittivity of the material at certain range of frequencies using CST software. The metamaterial Omega structure negative permittivity can be obtained.

Based on the results that have been obtained, it is proven that the metamaterial bandpass filter provides better results in terms of return and insertion losses and also reduce size

V. FUTURE DEVELOPMENT

From the results developed on this new research, the advantages from the project will bring into future technology. It is recommended that the metamaterial bandpass filter can be designed on different substrate with different properties and structure.

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