A Recapitulate Fractal Pleated Hairpin Bandpass Filter Utilizing Adaptive-Radiation Algorithm

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Abstract: In recent decades, the hairpin topology uses parallel-coupled lines and behaves like a band-pass filter used to isolate the bandwidth's frequencies from parasitic signals. It takes up relatively low board space and is quite easy to build compared to other band-pass microstrip topologies. Despite significant size reduction, existing hairpin bandpass filters exhibited forged harmonics and substantial circuit size, uneven modal imbalance, and faulty outputs. To decipher these issues, a novel Methodical Hairpin Bandpass Filter Design is proposed. Initially Recapitulate Fractal Embracement is adopted in which the fractals are generated using Recapitulate Function System (RFS) for effectively curbing the harmonics. Moreover, the substantial filter size can be reduced by a Pleated hairpin bandpass filter design which deploys pleating the open-end arms symmetrically inwards. This size reduction of the hairpin bandpass filter may tend to the generation of erroneous reflection and transmission coefficients. To tackle this, Adaptive-Radiation Algorithm (ARA) optimization exploiting the vigor functionisproposed. It utilizes a vigor function that appraises the S-parameter in the passband and generates an optimal solution. Consequently, the level of a harmonic of greater than 36 dB is curbed and a size reduction of 28% is obtained thus designing an efficient hairpin bandpass filter.

Keywords: Recapitulate Fractal Embracement, Pleated design, Adaptive-Radiation Algorithm, Vigor function, Forged harmonics.

I. INTRODUCTION

Wireless Communication is the fastest growing and most vibrant technological areas in the communication field. Wireless Communication is a method of transmitting information from one point to another, without using any connection like wires, cables, or any physical medium through various technologies [1].Generally, in a communication system, the data from sender to receiver is typically conveyed down along a well-characterized frequency band [2]. With the help of Wireless Communication, the transmitter and receiver can be placed anywhere between few meters (like a T.V. Remote Control) to a few thousand kilometers (Satellite Communication).

Some of the commonly used Wireless Communication Systems in our day – to – day life are Mobile Phones, GPS Receivers, Remote Controls, Bluetooth Audio, and Wi-Fi, etc. The need for wireless connectivity has increased without-bound in the recent era. They provide a whole automated and intelligent network that offers an utterly immersive experience [3]. It improves the channel capacity and permits various users to access the system at the same time. It facilitates multiple access techniquesthat allow multiple users to use shared communication media [4].

During this situation of a global crisis of epidemic diseases, the function of wireless communications in making people connected and functioning has been phenomenal. Major of this is simply down to being the backbone that permits streaming media, social networking, and video conferencing to ramp up to new levels of activity. All these crucial applications depend on reliable and high-speed communication networks, resulting in tremendous pressure on wireless networks [5].Another use of such wireless communication systems is the effective tracing of potential COVID-19 contacts whereabouts by deploying cellular network type of localization techniques and provide disease management via integrated personalize mobile applications. Besides they can help small and medium-sized enterprises respond efficiently to the global crisis [6].Similar nature of localization techniques can be utilized to implement social distance measures which are considered as an effective solution to stop the spread of epidemic diseases [7].

Wireless communication uses different filters in simple arithmetic operations to complex circuits. Different topologies are adopted for the design of filters [8]. Numerous non-flexible transparent filters are designed by researchers for dual-band applications. Recently several filters are designed for wide-band applications [9]. A matched filter is not only used in modern digital communications but also involved in the detection of gravitational waves. The optimal waveform used to transmit an encoded message regarding these matched filters possesses determinism and sensitive dependence. Another filter type, an infinite impulse response (IIR) filter exhibits a confused matching waveform [10]. Bandstop filters (BSF) can also act as resonators and are widely used in the improvement of electromagnetic resonant coupling-based wireless power transfer systems. But these filters are not explored to a full extent [11]. Low pass filters are used to combine or select microwave frequencies within the low limit. They are utilized for the systems' communication in the wireless mode [12].They have an ultra-wide passband with high return loss, low insertion losses, and a low ripple. Also, they exhibit a large stopband with a high rejection level [13].

A bandpass filter (also known as a BPF or passband filter) is considered as a component thatpermits frequencies within a particular frequency range and rejects (attenuates) frequencies that are outside that range.These filters are employed in wireless communication transceivers to separate frequency spectrum in various bands [14].Bandpass filters are mainly utilized in advanced transparent electronic and wireless communication systems [15].They are obtained with the parallel connection of high pass and low pass filter thus forming another filter, which permits the signal within frequency range or band and rejects the signals whose frequencies are outside of this band. The Band Pass Filter utilizes two cutoff frequencies. The initial cutoff frequency is obtained from a high pass filter. This will decide the higher frequency limit of a band that is known as the higher cutoff frequency (fc-high). The second cutoff frequency is obtained from the low pass filter. This will decide the lower frequency limit of the band and that is known as lower cutoff frequency (fc-low).

While bandpass filters are commonly used, their increased size has been considered a major problem.Hairpin bandpass filters were introduced to address this issue.Its low space usage is considered to be the main advantage of the hairpin filter. Space is saved in the hairpin filter by folding the resonator that is half a wavelength long. Also, the design of the hairpin filter is simple than the other microwave filters. They eliminateunnecessary frequency components from the signal to improve the signal-to-noise ratio. They are consideredbeneficial in the radio UHF range, to eliminate unwanted transmissions and hence increase the receiver's relative sensitivity [16].

Despite these advantages, the application of the hairpin bandpass filter is limited for bandwidth frequency isolation in signal processing and RF/microwave communication due to the presence of forged harmonics and substantial circuit size. Though several topologies were adopted for designing compact hairpin bandpass filters and curbing harmonics, they exhibited little effect on attenuation level which leads to uneven modal imbalance. Along with this, significant interest in introducing techniques to reduce the size of the filter generated erroneous reflection and transmission coefficients resulting in faulty outputs. Hence a dimension optimization is required to generate better coefficients by minimizing or maximizing the coefficient values. Therefore, to accord to the above-mentioned concerns a novel methodical hairpin bandpass filter design is proposed. The main contributions of this design are,

- It adopts Recapitulate Fractal Embracement which exploits fractals using RFS for effectively curbing the harmonics.
- The substantial filter size can be mitigated by a pleated hairpin bandpass filter design which deploys the open-end arms to be pleated symmetrically inwards.
- ARA optimization isproposed which utilizes a vigor function that appraises the S-parameter in the passband and generates an optimal solution.

Thus a novel hairpin bandpass filter is designed which can effectively tackle the issues and generate improved results.

The structure of the paper is as follows: Section 2 discusses the literature survey that deals with the issues of hairpin bandpass filters. Section 3 describes the proposed methodology with the procedure and techniques used. Section 4 describes the experimental setup and comparison strategies. Section 5 concludes this paper.

II. LITERATURE SURVEY

Prasetya et al [17] compared bandpass filter design using hair-pin and square-open loop resonator. Both approaches have been used to achieve filter designs that can function with digital television group broadcasting systems.The bandpass filter was simulated and produced using epoxy FR-4 substrates using design software.The comparison aimed to allow researchers to choose the correct form of the filter when viewed in terms of filter dimensions, loss of insertion and return loss, VSWR, and fractional bandwidth.The BPF constructed using the Hairpin Line method had better output than the square loop for the return loss and VSWR parameters, although the value was not significantly different.But the insertion loss value obtained was high when the desired fractional bandwidth value is small.

Mohammed et al [18] introduced a new design of a cross-coupled microstrip bandpass filter (MBPF) based on hairpin defected ground structure (DGS) resonators utilizing accurate coupling matrix (CM) technique for microwave communication systems. Despite the presence of the slots interrupting the current in the ground layer, it was extracted from the analogous inductance and capacitance.Different external coupling systems influenced by the configuration of the feed were discussed.Using precise matrix technology for microwave communication systems, the hairpin-defected ground structure resonators were focused. The simulation results provided strong consistency with the theoretical results with a very compact size and a small stop band with two zero transmission zeros. However, after researching its various external coupling mechanisms along with harmonics, the feeding configuration significantly affected the filter response.

Tsukushi et al [19]realized a fourth-order flat passband bandpass filter (BPF) using proposed resonators and half-wave open-looped resonators. To prepare at least two types of resonators with high and low unloaded quality factors, the fourth-order flat passband BPF was required.The suggested resonator was configured with a parallel-connected resistor based on a half-wave hairpin-shaped resonator. It was considered as a resonator with a minimal unloaded quality factor. The advantage of the proposed resonator was a flexible adjustment of the unloaded quality factor by varying the value and setting the location of the resistor. Since it was operated in a single-mode, its functioning flexibility is restricted.

Chen et al [20] designed a hairpin-shaped DGS which constituted a pair of slots that were tilted and placed with a separation angle of α. Two prototype microstrip lowpass filters were discussed and developed for microwave filter applications of such a type of DGS, by cascading the same unit cells and the scaled cells with a scale ratio of β, respectively.Demonstrations on the two produced prototypes, both from numerical simulations and from experimental examinations, showed anticipated responses.The DGS studied described simple architecture and developed a pole of attenuation and reflection near the cutoff frequency.Studies have shown that a wide stopband with a high degree of suppression can be approached by using cascaded scaled cells for microstrip lowpass filter demonstrations.For further integration with other microwave circuits, components, or modules for system applications, the presented DGS was considered attractive. Meanwhile, the simulation in-band matching was not so good that also contributes to the higher return loss from measurements.

Abdullah et al [21] presented a reduced size microstrip five poles hairpin band-pass filter using a three-layer structure for Ku-band satellites application. A significantly reduced filter size and expanded bandwidth were seen in the three-layer structure. In contrast to the remaining frequency bands, the band-pass filter limited the pass-band between some lower and upper-frequency limits in which the signal was attenuated, whether lower (band-pass) or higher (band-stop). The microstrip design method was chosen in which the model of parallel coupling lines was used to illustrate the filter's action on the multilayer substrate.The S-parameter outcomes obtained were still acceptable concerning the design requirements and multilayer filter structure differences. Some further dimension optimization was needed to achieve better coefficient values.

Yusoff et al [22] designed a compact hairpin bandpass filter thatrelied on the hairpin-line configuration and metamaterial of complementary split-ring resonator (CSRR) structure. For the compact framework design, the hairpin-line was used and easy to produce due to the existence of open-circuited ends that did not need grounding.The additional split-ring resonator structure was also simple to build and provided multi-band without affecting the filter size and output.To generate a multiple-band frequency response, the CSRR and hairpin bandpass filter were combined. However, the filter response for a single CSRR was not especially good.

Chatterjee et al [23] designed a conventional hairpin bandpass filter in which the characteristics have been improved and the second harmonic had been shifted to higher frequency due to the folding mechanism. Thus, the harmonic attenuation level remains almost unaffected.Square grooves with ideal dimensions and frequency were subsequently used on the outer edges of the coupled resonators to achieve phase velocity compensation between even and odd modes. Yet, the suppression of higher-order harmonics was not taken into account in this mechanism.

The related searches can be summarized as follows: [17] Obtained large insertion loss value when the desired fractional bandwidth value is small, while in [18] the feeding configuration affected significantly the filter response after having investigated its different external coupling mechanisms. [19] Operated in single mode, hence its functioning flexibility is restricted and [20] showed poor simulation in-band matching that also contributes to harmonics and higher return loss from measurements. [21] Depicted poor reflection and transmission coefficients which may result in the generation of erroneous outputs and in [22] the filter response for a single CSRR was not especially good. [23] Did not consider the suppression of higher-order harmonics.The proposed hairpin bandpass filter is designed to tackle these issues thereby generating improved compactness and harmonic suppression.

III. METHODICAL HAIRPIN BANDPASS FILTER DESIGN

In recent decades, the need for high-efficiency filters without interference is growing rapidly in different communication applications. Among them, bandpass filters are widely used in wireless transmitters and receivers providing the optimum bandwidth for communication. It minimizes the interference among signals and optimizes the signal-to-noise ratio. However, the design of compact bandpass filters is a confronting issue. For a wide-scale adoption of compact size filters, a hairpin bandpass filter is commonly used owing to low space consumption. The hairpin bandpass filter uses parallel coupled lines and isolates bandwidth frequencies consuming low board space. Despite significant size reduction attained by prior researches, the application of hairpin bandpass filter is limited for bandwidth frequency isolation in signal processing and RF/microwave communication due to the presence of forged harmonics and substantial circuit size. Though several topologies were adopted for designing compact hairpin bandpass filters and curbing harmonics, they exhibited little effect on attenuation level which leads to uneven modal imbalance. Along with this, significant interest in introducing techniques to reduce the size of the filter generated erroneous reflection and transmission coefficients resulting in faulty outputs. Hence a dimension optimization is required to generate better coefficients by minimizing or maximizing the coefficient values. Therefore, to accord to the above-mentioned concerns like forged harmonics, substantial circuit size, uneven modal imbalance, and faulty outputs, a novel strategy has to be proposed ensuring the design of a high-performance hairpin bandpass filter thereby expediting efficient communication.

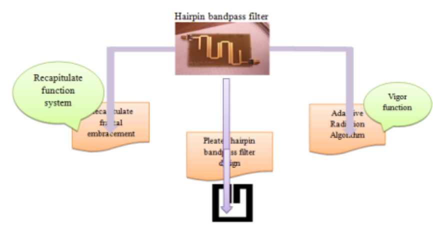

Figure 1. Schematic diagram of the proposed design

Figure 1. depicts the schematic diagram of the proposed design. In this proposed work, Recapitulate fractal embracement is adopted in which the fractals are generated using Recapitulate Function System (RFS) to curb the harmonics. Due to the space-filling property and recapitulation of the same geometric patterns with increasing iteration order, fractals are very effective in curbing harmonics. Moreover, the substantial filter size can be reduced by a Pleated hairpin bandpass filter design which deploys pleating the open-end arms symmetrically inwards. Due to the decreased coupling area, the coupled lines are agitated by the fractals to even up modal imbalance. This size reduction of the hairpin bandpass filter may tend to the generation of erroneous reflection and transmission coefficients. To tackle this, ARA (Adaptive-Radiation Algorithm) optimization exploiting vigor functionisproposed. It utilizes a vigor function that appraises the S-parameter in the passband. It increases the transmission coefficient and decreases the reflection coefficient thereby obtaining an optimal solution. Eventually, from the

proposed novel strategy, the major significant issues in hairpin bandpass filter inclusive of forged harmonics, substantial circuit size, uneven modal imbalance, and faulty outputs are eradicated which distinctly helps the design of high efficient hairpin bandpass filter.

A. Recapitulate fractal embracement

Hairpin bandpass filters are widely used due to their compact size but possess limited applications for bandwidth frequency isolation due to the forged harmonics. To reduce these harmonics, recapitulate fractal embracement is adopted. In this technique, fractals are generated using RFS which are efficient in curbing harmonics. They exhibit the property of space-filling and also recapitulate even geometric patterns with increasing iteration order. By adopting these properties, fractals can curb harmonics effectively.Among them, Recapitulate fractals are more effective because of their simple creation process and poor prickliness to design tolerances. These fractals are generated by RFS utilizing the transformation z which is given by,

$$z\begin{bmatrix}a_1\\a_2\end{bmatrix}=\begin{bmatrix}p & q\\r & s\end{bmatrix}\begin{bmatrix}a_1\\a_2\end{bmatrix}+\begin{bmatrix}t\\u\end{bmatrix}=Pa+c \quad (1)$$

Where, a_1,a_2= coordinates of the point a

p, q, r, s, t, u, v = control revolution and scaling

e, f = control linear conversion

c = plane conversion

The value of P is expressed as,

$$P=\begin{pmatrix}s_1\cos\theta_1 & -s_2\sin\theta_2\\ s_2\sin\theta_1 & s_2\cos\theta_2\end{pmatrix} \quad (2)$$

Here $s_1 = s_2 = s$, $0<s<1$, $\theta1= \theta2= \theta$, the transformation is considered to be a constrictive similitude in which s denotes the scaling factor and θ denotes the angle of rotation.

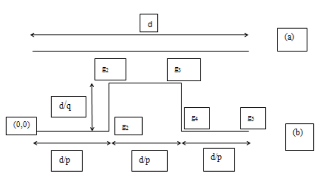

Figure 2. Generation of recapitulate fractal shape on a line (a) Primer for iteration n=0 (b) Generator geometry for n=1

Figure 2. indicates the production of recapitulate fractals in which d is considered as the primer length. The length of the horizontal, as well as vertical portions, is confirmed by the parameter values of p and q. In this recapitulate fractal, the RFS is practiced to the horizontal and vertical portions. Further,the Hutchinson operator is expressed in equation (3) considering a prime geometry G where i represents the index of line portions.

$$G(K)=\sum_{i=1}^{5} g_i[K] \quad (3)$$

The RFS transformation coefficients for the producer of recapitulate fractals consider the order of iteration as n=1. Table 1 represents theRFS transformation coefficients for the producer with iteration order n=1 which represents the normalization to a unit length where p_i, q_i, r_i, s_i, t_i, u_i denotes the values of P, Q, R, S, T, and U corresponding to the line portion i.

Table 1: RFS transformation coefficients for n=1

w_i	p_i	q_i	r_i	s_i	t_i	u_i
w_1	1/p	0	0	1/p	0	0
w_2	0	-1/q	1/q	0	1/p	0
w_3	1/p	0	0	1/p	1/p	1/q
w_4	0	1/q	-1/q	0	2/p	1/q
w_5	1/p	0	0	1/p	2/p	0

Consider the case in which the impedance ratio K= 1, the modal frequencies are obtained as

For odd output mode, $\theta_o = (2n-1)\pi$

$$f_0 = \frac{(2n-1)c}{2d\sqrt{\varepsilon_{re}}} \quad (4)$$

Where n=1,2,3,….

For even output mode, θe = 2nπ

$$f_e = \frac{nc}{d\sqrt{\varepsilon_{re}}} \quad (5)$$

where n=1,2,3,…….

and ε_{re} = effective dielectric constant of the substrate and d is the length of the line.

Equation (4) and (5) denotes that the odd and even modal resonant frequencies move towards to the lower frequency region.But, the attenuation level at 2*f*0 shows a linear decrease more than that at *f*0 due to the fractal's band stop nature. A flat stopband denoting an attenuation level of 9 dB is generated between *f*0 and 2*f*0 because of the fractal's modal phase velocities compensation by the fractals. From this, it can be concluded that the fractals tend to efficiently curb the harmonics level. In addition to curbing harmonics, filter compactness is also to be considered which is dealt with in the next section.

B. Pleated hairpin bandpass filter design

The hairpin bandpass filter is one of the most famous microwave frequency filters which are widely utilized owing to its compact size and it doesn't utilize grounding and hence they are considered to be compact structures. The concept of the hairpin filter is similar to parallel-coupled half-wavelength resonator filters. The main attraction of hairpin filter when compared to end coupled as well as parallel-coupled microstrip is its minimal space usage. In the hairpin filter, space is conserved due to the pleating of the resonator which is half-wavelength long. Also, the hairpin design is simple when compared to other microwave filters. These filters aretheoreticallyattained by pleating the resonators of parallel-coupled, half-wavelength resonator filters.Hairpin bandpass filters are widely used due to their compactness yet the techniques adopted to develop compact hairpin bandpass filters are challenging. The proposed methodical design generates a compact hairpin bandpass filter and its substantial filter size is reduced by adopting a Pleated hairpin bandpass filter design which deploys pleating the open-end arms symmetrically inwards. The proposed design is shown in figure 3.

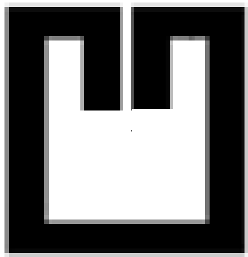

Figure 3. Pleated filter design

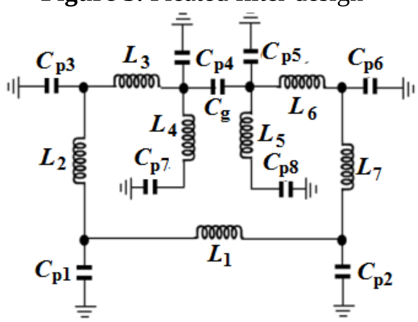

Figure 4. Equivalent L-C circuit connection diagram

Figure 4. illustrates the equivalent LC circuit diagram of the unit filter design. The *L* values (nH) and *C* values (pF) are calculated as follows: *L*1 = 2.5989, *L*2 = *L*7 = 2.937, *L*3 = *L*6 =1.0665, *L*4 = *L*5 = 2.6265, *C*p1 = *C*p2 = 0.4834, *C*p3 = *C*p6 = 0.3564, *C*p4 = *C*p5 =0.3104, *C*p7 = *C*p8 = 0.2194 and *C*g1 = 0.0321. Similarly for the fourth order filter design the equivalent inductance and capacitance values are calculated as L1=2.6, L2=L7=3, L3=L6=1, L4=L5=2.5, Cp1=Cp2=0.5, Cp3=Cp6=0.4, Cp4=Cp5=0.33, Cp7=Cp8=0.22, and Cg1=0.03.

The filter size is reduced to $0.28\lambda_0*0.10\lambda_0$ and subsequently, the filter size reduction of 28% is obtained. In the pleated design of the hairpin bandpass filter, the odd mode and even mode coupling existed between the nearer coupled arms. Considering the case of f_0 odd-mode coupling overcomes even-mode coupling while in the case of $2f_0$ even-mode coupling overcomes odd-mode coupling. Thus the hairpin bandpass filter size is reduced thus designing a compact hairpin bandpass filter and this compactness may result in a non-even modal imbalance which is tackled in the section below.

C. ARA optimization exploiting vigor function

Pleated hairpin bandpass filters are designed for compactness and curbing harmonics. Though several topologies were adopted for designing compact hairpin bandpass filters and curbing harmonics, they exhibited little effect on attenuation level which provokes uneven modal imbalance.To overwhelm this issue Adaptive Radiation Algorithm (ARA) exploiting vigor function is proposed. It utilizes a vigor function that appraises the S-parameter in the passband. In this proposed work, the Adaptive Radiation Algorithm(ARA) is utilized for designinga bandpass filter with efficient performance. The ARA-optimization method exploits a vigor function that estimates the S-parameters in a passband. The vigor function is specified in such that itimproves transmission coefficient and degrades reflection coefficient.

1) Vigor function

The vigor function utilized for reflection coefficient and transmission coefficient is denoted by the expression below,

$$V = \{\frac{S_{21}(dB)}{S_{[11]}(dB)}\} \tag{6}$$

The above vigor function is obtained for the frequency range between 2.5 GHz and 4.5 GHz. Reflection coefficients (S_{11}) of the filter are selected since it denotes the impedance matching further indicating the ability of the filter to utilize the power which is given by the feed. The transmission coefficient (S_{21}) of the filter is selected since it indicates the ability of the input power obtained at the resultant port without attenuation. It requires the maximum value of transmission co-efficient and minimum value of the reflection coefficient. Due to this, thevigor function is increasedfor the passband for obtaining an optimal result.

2) Adaptive Radiation Algorithm

The flowchart for the proposed algorithm is shown in figure 5. Using ARA, the cells are extracted consistently from the resonator with the estimation of vigor function. These vigor function values are compared with the initial parameters and the process continues till the required iteration. As the final solution, an efficient optimized output is obtained.

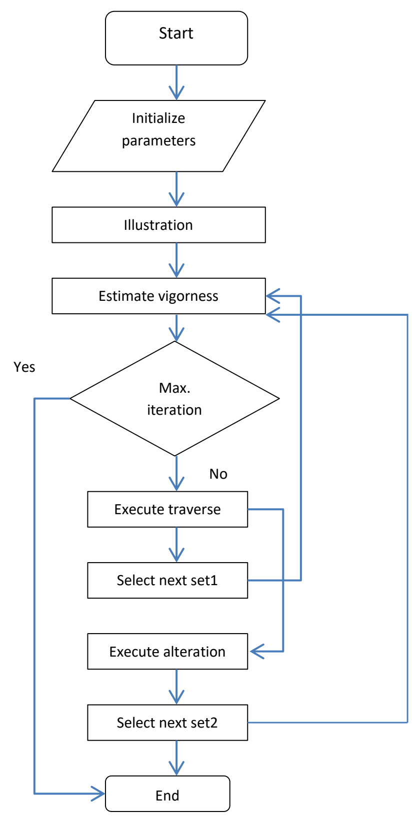

Figure 5. Flowchart of the proposed algorithm

The ARA-optimization method employed in this approach follows the process involving illustration, traverse, and alteration. The traverse is implemented for correlating the parameters into two sets for the generation of new outputs. The initial parameters give away the traverse outputs considering the utilization of two sets. The traversed values are altered to obtain optimal solutions. Alteration is considered to be more efficient because it possesses the ability to give birth to generate unique values as outputs. Consequently, the optimal solution is obtained in the output. The algorithm for the proposed flowchart is given below,

Step 1: Initialize the input parameters

Step 2: Perform illustration of the parameters

Step 3: Estimate the vigor function

Step 4: Check for the maximum iteration. If the maximum value is obtained conclude the process else go to the next step.

Step 5: Execute traverse operation

Step 6: Select the next set

Step 7: Execute alteration process

Step 8: Select the next set and check the vigor function

Step 9: Repeat the process until the maximum iteration is obtained

Thus the proposed ARA-optimization efficiently tackles the modal imbalance concern and generates optimal results by outputting accurate transmission and reflection coefficients.

Henceforth, the proposed methodical hairpin bandpass filter design effectively curbs the harmonics and provides the compact design by pleating technique. Moreover, the hindrance of faulty outputs is tackled by eradicating modal imbalance and generating accurate transmission and reflection coefficients. Utilizing the pleating approach and vigor function, the proposed approach generates efficient outputs which are discussed in the below section.

IV. RESULTS AND DISCUSSION

This section provides a comprehensive description of the implementation results and the performance of our proposed system.

A. Experimental Setup

This work has been implemented in MATLAB/SIMULINK in the working platform of MATLAB with the following system specification and the simulation results are discussed below

Platform : MATLAB 2018b

OS : Windows 8

Processor : Intel Core i5

RAM : 8GB RAM

B. Performance metrics

1) Fractional bandwidth

Fractional bandwidth (FBW) is defined as the bandwidth of a device divided by its center frequency. It is given by,

$$FBW= 2\frac{(f_H - f_L)}{(f_H + f_L)}$$

Where f_H = upper band frequency

f_L = lower band frequency

2) Stopband rejection level

Stopband rejection level (SRL) is defined as the level at which a range of frequencies are rejected or attenuated. It is measured in dB.

3) Stopband rejection bandwidth

Stopband rejection bandwidth (SBW) is defined as the bandwidth in which a range of frequencies are rejected or attenuated. It is measured in GHz.

C. Simulation outputs

This section effectively describes the simulation outputs of the proposed methodical hairpin bandpass filter design flowingly:

1) Fractal effect on even and odd mode frequencies

Figure 6. indicates the effect of fractals on even mode frequencies and odd mode frequencies. It depicts that both the even and odd resonant mode frequencies migrate towards the minimal frequency portion as indicated in equations (4) and (5).

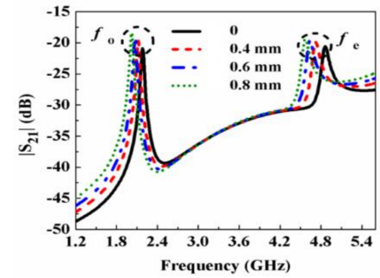

Figure 6. Fractal effect on even and odd resonant mode frequencies

2) Coupling coefficients

The resonant frequencies advance each other which results in the nonlinear degradation of coupling coefficients. The coupling coefficient values corresponding to the coupling gap are given in table 2. Figure 7 illustrates that when s12=s23=0.45mm, the coupling coefficient M= 0.0864 and when s12=s23= 0.77, the coupling coefficient M= 0.0634. The graph depicts that the coupling coefficients gradually decrease with the increase in the coupling gap.

Table 2: Coupling coefficient values

Coupling gap,s(mm)	Coupling coefficient,M
0	0.22
0.1	0.21
0.3	0.18
0.5	0.135
0.7	0.11
0.9	0.10
1.1	0.075
1.3	0.065

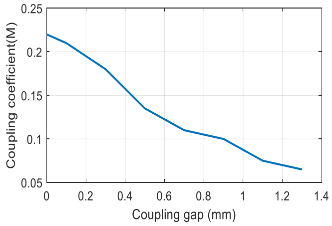

Figure 7. Output curve for the coupling coefficient

3) S-parameter for pleated filter

The S-parameter plot for the pleated filter is depicted in figure 8. From the graph, it is clear that the skirt parameters of the pleated filer showed improved values with the shift ofharmonic frequencies at 0.35 GHz, 1 GHz, and 1.65 GHz.The shifting of harmonic frequencies mainly occurs because of the decrease of the effective coupling area between the nearer pleated-arms.

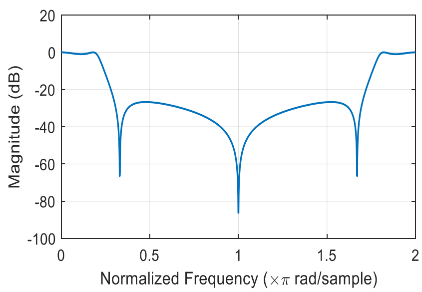

Figure 8. Output plot for S-parameter value for pleated filter

4) Frequency Vs S-parameter value

The proposed ARA-optimization has increased the values of transmission coefficients by minimizing the value of S_{11} and maximizing the value of S_{21}. Figure 9 shows the characteristic plot between frequency and S-parameter value. The frequency of the passband filter center is moved to 3.4 GHz with the S-parameter value equaling to S11= - 24.12dB and S21= - 0.51 dB.

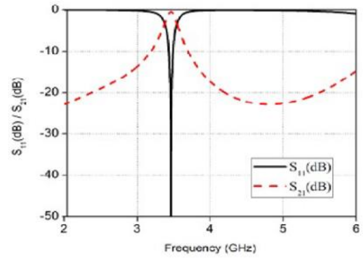

Figure 9. Frequency Vs S-parameter characteristics

5) Comparison strategies

The results of the proposed methodical hairpin bandpass filter design are compared with the existing bandpass filter designs like a four-pole cross-coupled filter, bandpass fractal filter, DMS integrated filter, microstrip bandpass filter, and compact bandpass filter. Table 2 shows the comparison values of the proposed hairpin bandpass filter design with the existing approaches. It indicates the significant size reduction of the proposed design compared to other approaches with the size of $0.28\lambda_0*0.10\lambda_0$ resulting in a significant size reduction of 28%. Moreover, it shows improved stopband rejection level such thatthe level of curbing harmonics equals 36 dB and improved stopband rejection bandwidth equal to 3.6 f_0. The fractional bandwidth value obtained is 4.2% and the corresponding resulted fromvalues are plotted in figure 10.

Table 3: Comparison of the proposed design with existing ones

Designs	FBW(%)	f_0(GHz)	SRL(dB)	SBW(GHz)	Size($\lambda_0*\lambda_0$)
Proposed	4.2	2.6	36	3.6 f_0	0.28*0.10
Four pole cross coupled	5	2.0	29	2.75 f_0	0.14*0.71
Bandpass fractal	20	1.0	29	2 f_0	0.25*0.19
DMS integrated	28.6	2.1	33	3.4 f_0	0.50*0.09
Micro-strip bandpass	25	1.0	30	2.8 f_0	0.34*0.19
Compact bandpass	28	2.5	33	2.2 f_0	0.45*0.12

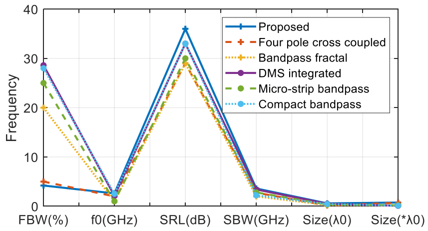

Figure 10. Comparison of the proposed design with existing approaches

This section clearly describes the efficiency of the proposed methodical hairpin bandpass filter design.The proposed designeffectively curbed harmonics and performed substantial size reduction which is considered to be the major challenging issue regarding the hairpin bandpass filter design. Besides, the proposed design generated accurate outputs by generating increased transmission coefficients and decreased reflection coefficients which in turn tackle the severe concern of modal imbalance.

V. CONCLUSION

In many RF/Microwave applications, filters play a significant role and are utilized to regulate frequency responses to overwhelm electromagnetic spectrum restrictions as well as permit the chance of sharing them. The methodical design of the hairpin bandpass filter is proposed which plays a major role in microwave applications for minimizing the interference and transmitting the required range of frequencies. Despite these advantages, hairpin bandpass filters face the presence of forged harmonics which is mitigated by adopting Recapitulate fractal embracement. It utilizes recapitulate fractal system which curbs the harmonics by generating fractals. The substantial size of the filter is also reduced by the pleated hairpin bandpass filter design which employs pleating of the open-end arms inwards. Moreover, hairpin bandpass filters may generate erroneous outputs that are tackled by the Adaptive Radiation Algorithm (ARA) optimization. It exploits a vigor function that outputs increased transmission coefficients and decreased reflection coefficients for an optimal solution. Therefore, the proposed methodical hairpin bandpass filter design exhibits a size reduction of 28% with curbing harmonics greater than 36 dB.

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