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Design of a Compact Wideband Log Periodic Spur Line Bandstop Filter

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Abstract*— *A novel technique is introduced to design a wideband, compact bandstop filter (BSF). This filter consists of a numbers of spur line resonators arranged in a log-periodic manner. The stop band of the filter is centered at 5 GHz for wireless application. Using the proposed technique the fractional bandwidth is enhanced from 7% to 68% when the individual spurline resonators are applied as log-periodic filter. There is a good agreement between the measured and simulated performances. This kind of filter is very much compact in nature as compared to the shunt-stub or coupled-line bandstop filters since the spurline structure is confined to a transmission line.

Index Terms*— *Spur line, bandstop filter, log periodicity, wide band.

I. INTRODUCTION

With the advent in microwave integrated circuits an increasing demand has created for compact wideband bandstop filters since the effective suppression of spurious signals is highly desirable in wireless communication applications. The main problem of a conventional open circuited stub bandstop filter is the fabrication limit of high impedance lines required for the connecting lines [1]. There are various modified techniques [2-5] to design wideband BSFs apart from conventional shunt stub and coupled-line bandreject filters. However in most of those cases the circuit structures are large and complex enough.

In this paper a simple compact transmission line configuration is presented using log-periodically arranged spurline resonators to design a wideband bandstop filter with high skirt selectivity. The concept of the log periodicity, first applied to the design of wideband antenna by DuHamel [8,9] is used here to increase the stop band of the proposed filter. Spurline resonators with their inherently compact characteristic are suitable only for moderate rejection bandwidth (about 10%) applications however when cascaded as log-periodic array, provide wider stopband without any penalty of increasing size. Another feature of spurline is its significantly lower radiation loss than conventional shunt stub and coupled-line filters [6, 7]. Here first of all the development of a new bandstop filter using log-periodically arranged spur line elements is presented. Secondly an analysis has been made to achieve a wider stop-bandwidth by increasing the number of resonators for a fixed scale factor. Further improvement of bandwidth is achieved by changing the scale factor.

The proposed filter provides stop bands centered at 5 GHz and the absolute bandwidth is extended up to 3.4GHz with attenuation in rejection band more than -15 dB for a scale factor 0.8 and four numbers of resonators. It also provides ease of implementation since the structure only needs an area of a 50 ohm microstrip line to be incorporated with antenna, diplexer, mixers etc. Moreover the combination of log-periodic technique with spur line structures has not been attempted yet in realizing bandstop performance.

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II. BASIC THEORIES TO DEVELOP THE FILTER

In this paper, the presented BSF is designed based upon the design of conventional log-periodic antenna used for wideband. The proposed filters employ multiple units spur line sections cascaded in a log-periodic array. Fig. 1 shows a schematic diagram of such a model which describes arrangement of the spur line resonator elements along the microstrip line where l is the length of the resonators and s is the spacing between resonators. The adjacent lengths *(l)* and spacing *(s)* are related to each other by a scale factor (τ) given as, where n is an ordinal number and F is the frequency ratio.

$$\frac{l_{n+1}}{l_n} = \frac{s_{n+1}}{s_n} = \tau \qquad \text{............(1-a)}$$

$$\frac{l_{n+1}}{l_n} = \tau^n = \frac{f_{n+1}}{f_n} \qquad \text{............(1-b)}$$

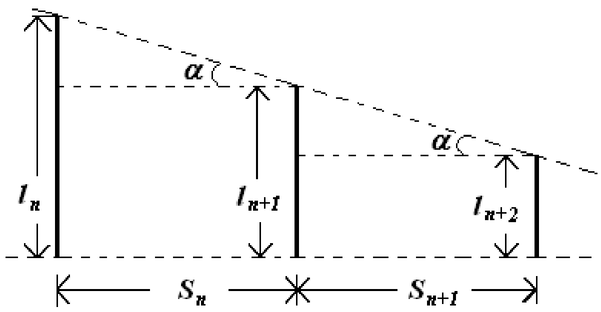

Fig.1: The model of arrangement of resonators of proposed filter with logperiodic geometry and spacing.

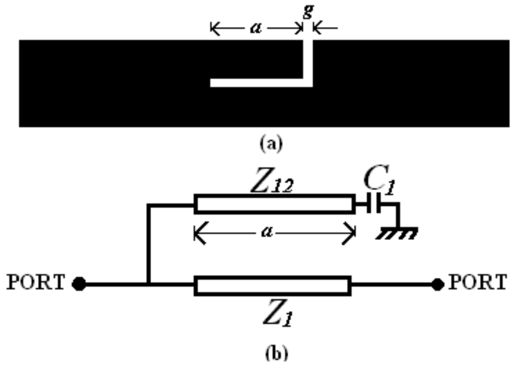

Fig.2: (a) The schematic diagram of spur line filter, proposed filter with logperiodic geometry and spacing.(b) equivalent circuit of the same.

Middle of these elements is chosen to be $\lambda_g/4$ long in order to create odd mode excitation where λ_g is the guided wavelength of the microstrip line at the center frequency of operation. From the geometry of Fig.1 it is clear that the dimensions of the elements in the proposed array structure are so developed that they gradually decrease with the scale factor (τ).

In this kind of filter structure the lengths and spacing between adjacent spur line resonators are such related that the resonant frequency will be repeated at all frequencies given by $\tau^n f$, where n is an integer. Each length *(l)* of the spur line sections is constituted of two parts, length a and gap g (i.e. $l=a+g$) as shown in Fig.2 (a). The unit spur line can be represented by a length of line of characteristic impedance Z_1 and an open circuited stub with characteristic impedance Z_{12} as described in Fig.2 (b) where Z_1 and Z_{12} are given by [7],

$$Z_1 = \frac{Z_{oe}}{Z_{oo}}\left(\frac{Z_{oe}+Z_{oo}}{2}\right) \qquad \text{.........(2-a)}$$

$$Z_{12} = \frac{Z_{oe}+Z_{oo}}{2} \qquad \text{.........(2-b)}$$

Where Z_{0e} and Z_{0o} are even mode and odd mode characteristic impedances respectively.

The spur-length a is represented by [3],

$$a = \frac{c}{f_0\sqrt{k_{effo}}} - \Delta l \qquad \text{..............(3)}$$

where,

c= velocity of light

f_o= operating frequency

k_{effo}= odd mode effective dielectric constant

Δl = effective length extention due to gap g.

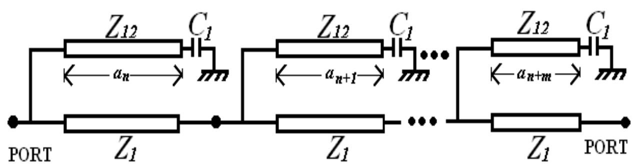

Fig.3: Equivalent circuit of the log-periodic spur line sections.

The equivalent circuit approach of more than one spur line resonator elements, cascaded in a log-periodic array is given in Fig.3. In the proposed log-periodic array variation of l is obtained by changing a keeping g at a constant value.

III. DEVELOPMENT OF FILTER

In order to achieve a wide stopband spur line sections are cascaded in a log-periodic array. The length of each spur is to be $\lambda_g/4$ long where λ_g is the guided wavelength at the corresponding resonant frequency. Spacing (s) between two adjacent spurs is chosen as $\lambda_g/2$. The total design procedure involves a few steps. First, the centre frequency at which the filter is to be designed and a scale factor (τ) close to 1 are to be selected. The next important parameter is the number of resonators, which itself along with the scale factor will determine the bandwidth of the filter. According to the center frequency of operation the length of the middle spur will be obtained using equation (3). By equation (1) other resonant frequencies and their corresponding spur lengths constituting the log-periodic array will be achieved. The schematic diagram of the proposed filter is shown in the Fig. 4. In this model the scale factor and numbers of resonators are chosen as 0.96 and 3 respectively. The center frequency of the filter is opted as 5GHz. The other resonant frequencies are calculated by equation (1) and listed in Table I. It is obvious from this table that there is a constant relationship between the resonant frequencies in logarithmic scale. Fig. 5 shows the photographic view of the proposed filter.

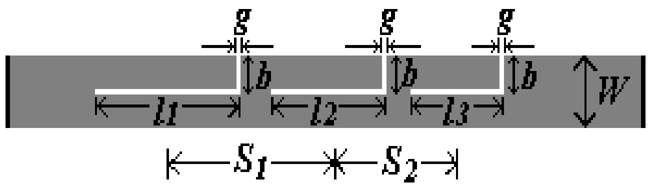

Fig.4: The schematic diagram of proposed filter with log-periodic geometry and spacing.

TABLE I
RELATIONSHIP BETWEEN FREQUENCIES.

Calculated resonant frequencies		Log of ratios of resonant frequencies	
f_1	4.8	*log (f2/f1)*	0.017
f_2	5.00	*log (f3/f2)*	0.017
f_3	5.2		

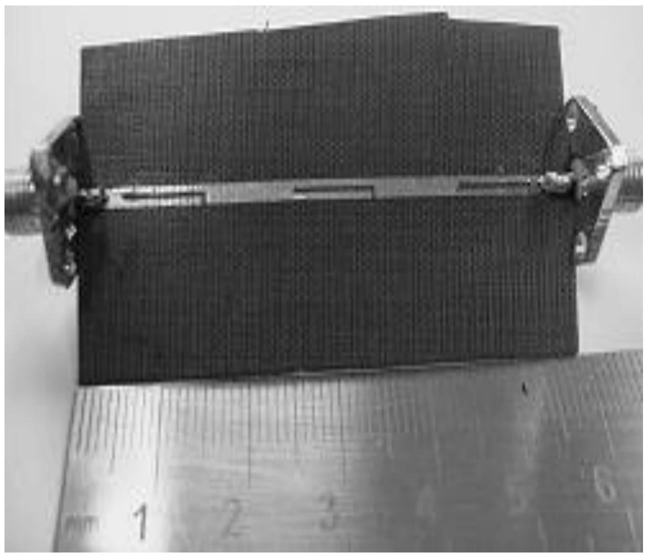

Fig.5 photographic view of the same

Firstly, the design is built on a substrate having dielectric constant 9.6 and thickness, h = 0.5mm. The different parameters to design the spur lengths at different resonant frequencies are shown in Table II [7]. The spur lengths are calculated using these parameters and equation (3). These lengths and spacing between them are given in Table III. Table IV shows that a constant relationship is held within adjacent spur lengths and also within the spacing between two nearby spurs as described in equation (1). Fig. 6 shows the simulation result of three-spur log-periodic filter, which provides three poles at 4.79 GHz, 5 GHz and at 5.19 GHz correspond to lengths a_1, a_2 and a_3 respectively as shown in Fig.4. The response of the proposed filter is similar to the additive responses of three individual spur line filters having same spur length as is evident from the simulated responses done in Fig.7.

TABLE II
OTHER DESIGN PARAMETERS.

Scale factor (τ)	0.96
ε_r	9.6
g (mm)	0.05
b (mm)	0.25
W (mm)	0.49
Z_o (ohm)	70.0
ε_{re}	6.088
Z_{oo} (ohm)	30.31
C_{oo} (pF)	0.0358
ε_{oo} for 4.8GHz	6.1263
ε_{oo} for 5GHz	6.1294
ε_{oo} for 5.2GHz	6.1329
v_{po} (m/s) for 4.8GHz	$1.2121\text{X}10^8$
v_{po} (m/s) for 5GHz	$1.2117\text{X}10^8$
v_{po} (m/s) for 5.2GHz	$1.2114\text{X}10^8$
Z_{12} (ohm)	70.7
Z_1 (ohm)	20.1

TABLE III
SELECTED AND CALCULATED VALUES OF RESONANT FREQUENCIES AND THEIR CORRESPONDING CALCULATED SPUR LENGTHS AND SPACING BETWEEN THE SPURS.

Operating frequencies (GHz)		Calculated Spur lengths (mm)		Calculated spacing (mm)	
f_1	4.800	a_1	6.31	S_1	12.62
f_2	5.000	a_2	6.05	S_2	12.11
f_3	5.208	a_3	5.81		

TABLE IV
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.96	S_2/S_1	0.96
a_3/a_2	0.96		

This leads to the fact that by cascading spurs in a log-periodic manner does not affect the poles but increase its bandwidth. Table V describes the comparison between simulated resonance frequencies of individual spurs and while they are cascaded log periodically. The proposed log-periodic filter yields a stopband of 0.9 GHz (4.6-5.5 GHz) at rejection level of –20dB. The 3 dB cutoff frequencies are obtained at 3.4 GHz and 6.3 GHz while the pole frequencies are at 4.79, 5 and 5.19 GHz. Such log-periodic arrangement of spurs has increased the fractional bandwidth to 18% as compared to around 7% of the individual spurs. The comparison between the calculated and simulated frequency ratios is given in Table VI. However the main drawback for this specific design is its poor sharpness factor of 15.8 dB/GHz.

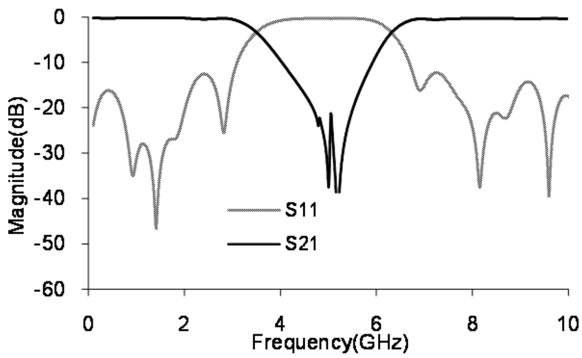

Fig.6: Simulated responses of proposed three-resonator log-periodic filter with scale factor 0.96.

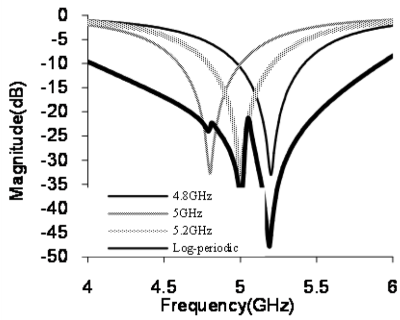

Fig.7: Comparison of simulated responses of proposed filter and three individual spur line filters having same dimensions as it taken for the proposed design.

TABLE V
COMPARISON BETWEEN SIMULATED RESONANCE FREQUENCIES OF INDIVIDUAL SPURS AND WHILE THEY CASCADED LOG PERIODICALLY.

Simulated resonant frequencies (GHz) of Individual spurs		Simulated resonant frequencies (GHz) of Log-periodically arranged spurs	
f'_1	4.798	f_{p1}	4.79
f'_2	4.999	f_{p2}	5.00
f'_3	5.199	f_{p3}	5.19

TABLE VI
COMPARISON OF CALCULATED AND SIMULATED VALUES OF LOG OF RATIO OF FREQUENCIES.

Calculated		Simulated	
$\log(f2/f1)$	0.017	$\log(f2/f1)$	0.018
$\log(f3/f2)$	0.017	$\log(f3/f2)$	0.016

Fabrication process with w/h<0.5 and g/h<0.2 for this kind of filter needs greater accuracy and the cost of the substrate used is very high. Thus a comparatively cheaper PTFE substrate with lower dielectric constant has been chosen as the novel work in this presentation. But the chosen substrate has w/h ≈1 and for the limitation of fabrication process s/h=0.3 mm is taken.

A three-spur resonators log-periodic filter with the same scale factor (τ =0.96) as that of the previous one is designed on a substrate with dielectric constant 3.2 and thickness 0.79mm. The centre frequency of the filter is chosen as 5GHz and using equation (1) the other two frequencies are found. The spur lengths ($a = \lambda_g/4$) corresponding to these frequencies are designed using the parameters listed in Table VII [7].

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TABLE VII
OTHER DESIGN PARAMETERS

Scale factor (τ)	0.96
ε_r	3.2
g (mm)	0.3
b (mm)	1.1
W (mm)	0.8
Z_o (ohm)	81.04
ε_{re}	2.409
Z_{oo} (ohm)	52.45
C_{oo} (pF)	0.034
ε_{oo} *for 4.8GHz*	2.4194
ε_{oo} *for 5GHz*	2.4203
ε_{oo} *for 5.2GHz*	2.4212
v_{po} *(m/s) for 4.8GHz*	$1.9287X10^8$
v_{po} *(m/s) for 5GHz*	$1.9284X10^8$
v_{po} *(m/s) for 5.2GHz*	$1.8280X10^8$
Z_{12} (ohm)	76.9
Z_I (ohm)	39.8

TABLE VIII
CALCULATED AND OPTIMIZED VALUES OF SPUR LENGTHS AND SPACING CORRESPONDING TO THEIR RESONANT FREQUENCIES.

Operating frequencies (GHz)	Calculated spur lengths (mm)		Optimized spur lengths (mm)	Calculated spacing between spurs (mm)	
4.800	a_1	10.04	9.61	S_1	20.08
5.000	a_2	9.64	9.19		
				S_2	19.28
5.208	a_3	9.25	8.77		

TABLE IX
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.96	S_2/S_1	0.96
a_3/a_2	0.96		

TABLE X
COMPARISON OF CALCULATED AND SIMULATED VALUES OF LOG OF RATIO OF FREQUENCIES.

Calculated		Simulated		Measured	
log (f2/f1)	0.017	*log (f2/f1)*	0.018	*log (f2/f1)*	0.016
log (f3/f2)	0.017	*log (f3/f2)*	0.016	*log (f3/f2)*	0.022

The calculated and optimized lengths of the spurs and spacing (s= $\lambda_g/2$) between them are shown in Table VIII. Other dimensions are: *b*=1.1mm, *g*=0.3mm and, W=1.9mm for 50 ohm line. Fig. 9 shows the simulation result of three-spurs log-periodic filter provides three poles at 4.789 GHz, 4.989 GHz and at 5.209 GHz with rejection levels at –31.8dB, 40.3dB and 57.3dB respectively. The cut off frequencies are obtained at 3.1 GHz and 6.6GHz. This design yields –20dB bandwidth of 1.5GHz (5.7GHz-4.2GHz) with skirt selectivity of 17.16dB/GHz. Also shown in the same figure a comparison of the simulated and measured results. In measurement result corresponding pole frequencies are 4.85GHz, 5.03GHz and 5.3GHz with rejection levels at –23.8dB, 31.1dB and 45.7dB respectively.

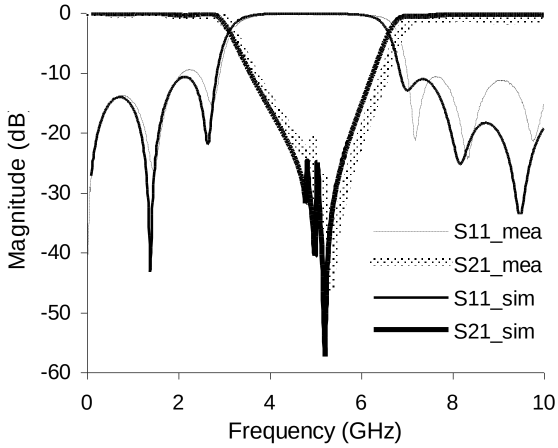

Fig.8: Comparison of simulated and measured responses of proposed three-resonator log-periodic filter with scale factor 0.96.

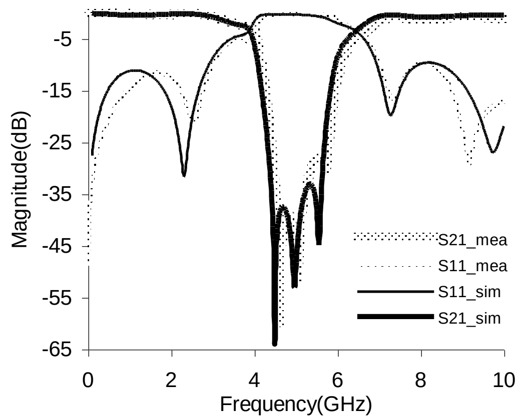

Fig. 9: Simulated s-parameter responses of bandstop filter with 3 log-periodic resonators having scale factor 0.9 and comparison of simulated and measured responses of the same.

It is clear from the simulation and measured results that there is a good agreement between them. The spacing between the spurs in this design is taken as $\lambda_g/2$ at the corresponding resonant frequency, however, causes poor sharpness factor. For such an array of spurs with lower frequency ratio and half wavelength spacing between them causes cascaded pole frequencies rather separated. This results in poor selectivity. Thus there is a problem of controlling the bandwidth of proposed filter with lower scale factor and with half wavelength spacing between the spurs. Another problem may occur in this kind of design while increasing the scale factor for broadening the bandwidth with the spacing between adjacent spurs chosen as $\lambda_g/2$. In order to widen the bandwidth in this way causes rejection level to be decreased, although pole frequencies get separated. This deteriorates the performance of this filter as a bandreject filter. In the following section a filter is presented with a higher scale factor of 0.9 and spacing of $\lambda_g/4$ between the spur-elements. If the spacing is taken as $\lambda_g/4$ at the corresponding resonant frequency with increased scale factor then the problems of poor skirt selectivity and degradation of bandwidth are overcome. This kind of log-periodic filter results in cascaded poles but the response has well-accepted depth in rejection level.

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Thus this design of the filter with quarter wavelength spacing provides a band rejection response with broad bandwidth, deeper rejection level and higher skirt characteristics than that of the filter with half wavelength spacing.

Hence a design is carried out with three spur lines arranged in a log periodic (τ=0.9) manner with quarter wavelength spacing between them. The centre frequency is chosen as 5GHz as the earlier ones. Two other resonant frequencies (eqn.1) and their corresponding calculated spur lengths (eqn. 3) are listed in Table XI.

TABLE XI
CALCULATED AND OPTIMIZED VALUES OF SPUR LENGTHS AND SPACING CORRESPONDING TO THEIR RESONANT FREQUENCIES.

Operating frequencies (GHz)	Calculated spur lengths (mm)		Optimized spur lengths (mm)	Calculated spacing between spurs (mm)	
4.50	a_1	10.71	10.29	S_1	10.71
5.00	a_2	9.64	9.19	S_2	9.64
5.55	a_3	8.68	8.14		

The calculated lengths of spur in this bandstop filter are: l_1=11.01mm, l_2=9.94mm, l_3=8.98, a_1=10.71mm, a_2=9.64mm, a_3=8.68mm, width of the transverse slot, b=1.1mm, g=0.3mm, s_1=10.71mm, s_2=9.64mm, 50 ohm width of the line, W=1.9mm. The ratio of adjacent spur lengths and spacing are given in Table XII. The simulated -20dB rejection band of the filter is 1.5GHz (5.75-4.25) as shown in Fig. 9. The cutoff frequencies of the filter are at 3.86 GHz and 6.51GHz and pole frequencies are at 4.49GHz, 4.96GHz, 5.5 GHz respectively. The comparison of the calculated, simulated and measured values of log of the ratio of the frequencies are available in Table XIII.

TABLE XII
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.9	S_2/S_1	0.9
a_3/a_2	0.9		

TABLE XIII
COMPARISON OF CALCULATED, SIMULATED AND MEASURED VALUES OF LOG OF RATIO OF FREQUENCIES.

Calculated		Simulated		Measured	
log (f2/f1)	0.045	log (f2/f1)	0.043	log (f2/f1)	0.039
log (f3/f2)	0.045	log (f3/f2)	0.044	log (f3/f2)	0.053

From the simulated response, it is very much clear that three poles are obtained from three spur line resonators as usual. Since the gap widths g are narrow as 0.3mm, the high performance of skirt selectivity is observed which is about 113.4dB/GHz and 43.9dB/GHz for lower side and upper side of the stopband respectively. Therefore in comparison to the previous one (τ=0.96, s= $\lambda_g/2$) the response of the present structure is having the same bandwidth but far better skirt characteristics. Fig. 9 also shows that there is a very good matching between the simulated and measured response. In measurement data the pole frequencies are obtained at 4.6GHz, 5 GHz and 5.7 GHz. Measured phase response is given in Fig.10 (a), which describes that in the passband phase are changed linearly with frequency warranting its usage in a dispersionless condition. Thus it is evident from the above discussion that design of the filter with quarter wavelength spacing is more advantageous than the half wavelength spacing from the point of view of bandwidth and sharpness factor. The photographic view of this filter is given in Fig. 10 (b).

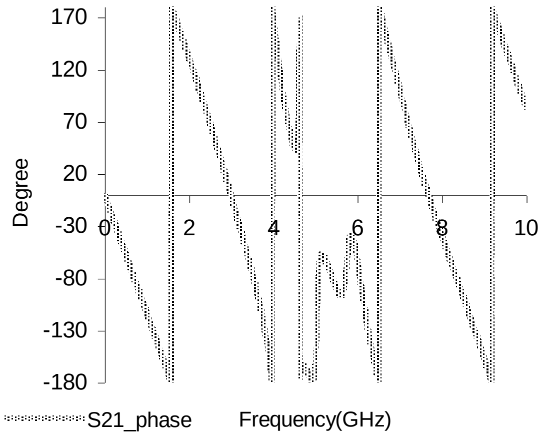


Fig.10 (a): Measured phase responses of proposed three-resonator log-periodic filter with scale factor 0.9.

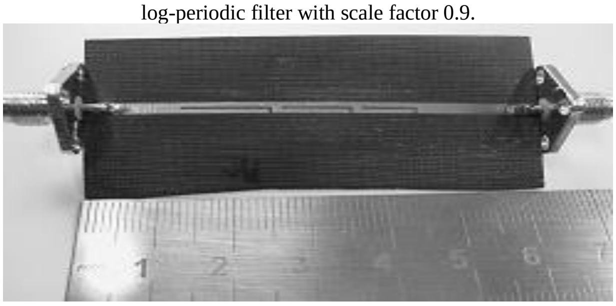
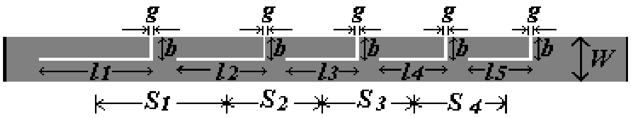
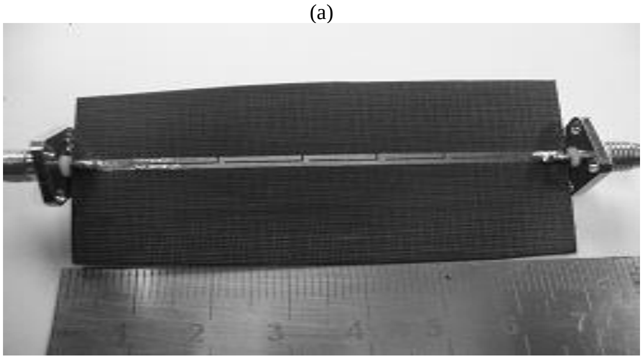


Fig.10 (b): The photographic view of proposed three-resonator filter with scale factor 0.9.

If the numbers of resonators is increased to 5 with the same scale factor (i.e. τ=0.9), an enhancement of fractional bandwidth of 22% is achieved due to addition of extra transmission zeros. This filter is designed for the centre frequency of 5GHz. Other resonant frequencies are obtained by equation (1), from which the lengths of the spurs are calculated by equation (3) like previous ones. The schematic of a 5-resonator log-periodic bandstop filter is depicted in Fig. 11(a) and the photographic view is given in Fig. 11(b). The calculated frequencies and spur lengths are listed in Table XIV.



(a)



(b)

Fig.11 (a): The schematic diagram of proposed five resonator filter with log-periodic geometry and spacing, (b) photographic view of the same.

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TABLE XIV
CALCULATED AND OPTIMIZED VALUES OF SPUR LENGTHS AND SPACING CORRESPONDING TO THEIR RESONANT FREQUENCIES.

Operating frequencies (GHz)	Calculated spur lengths (mm)		Optimized spur lengths (mm)	Calculated spacing between spurs (mm)	
4.05	a_1	11.91	11.6	S_1	11.91
4.50	a_2	10.71	10.29	S_2	10.71
5.00	a_3	9.64	9.19		
5.55	a_4	8.68	8.14	S_3	9.64
6.17	a_5	7.80	7.20	S_4	8.68

TABLE XV
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.9	S_2/S_1	0.9
a_3/a_2	0.9		
a_4/a_3	0.9	S_3/S_2	0.9
a_5/a_4	0.9	S_4/S_3	0.9

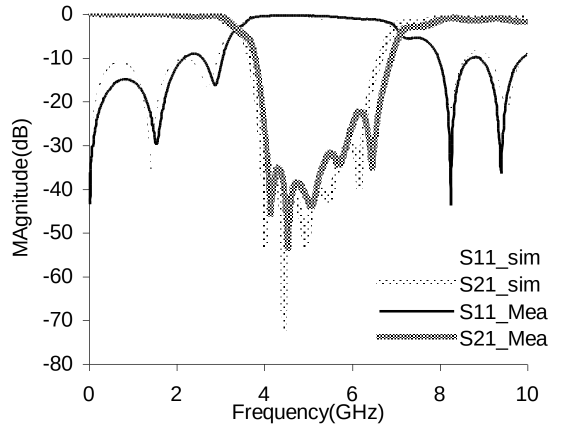

Fig. 12: Simulated s-parameter responses of 5-resonators filter with log-periodic geometry and spacing having scale factor 0.9 and Comparison of simulated and measured responses of the same.

Other dimensions are: width of the transverse slot, b=1.1mm, g=0.3mm, 50 ohm width of the line, W=1.9mm. A constant relationship is maintained between adjacent spur lengths and spacing described in Table XV. The simulated response of a 5-resonator filter shown in Fig.12 having the cutoff frequencies at 3.3 GHz and 7 GHz with the insertion loss in passband is less than -0.5dB. The resulted –20dB bandwidth is (6.4GHz-3.8GHz) 2.6 GHz and the transmission zeros are obtained at 4.04, 4.45, 4.95, 5.46 and 6.17 GHz. Maximum attenuation level is at –30dB and sharpness factor is 67.3dB/GHz at lower side and 44.3 dB/GHz at upper side of the stopband. The comparison of responses of 3 resonators and 5 resonators BSF with scale factor 0.9 is given in Fig.13, which clearly shows the enhancement of stopband with the increment of numbers of resonators. Fig.12 shows that there is a good matching between the simulated and measured responses.

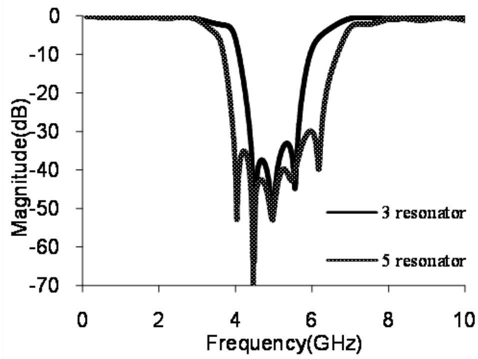

Fig.13: Comparison of simulated responses of transmission characteristics of proposed three and five resonators log- periodic filter with scale factor 0.9.

TABLE XVI
COMPARISON OF CALCULATED, SIMULATED AND MEASURED VALUES OF RATIO OF LOG OF FREQUENCIES.

Calculated		Simulated		Measured	
log (f2/f1)	0.045	*log (f2/f1)*	0.043	*log (f2/f1)*	0.043
log (f3/f2)	0.045	*log (f3/f2)*	0.046	*log (f3/f2)*	0.051
log (f4/f3)	0.045	*log (f4/f3)*	0.042	*log (f4/f3)*	0.050
log (f5/f4)	0.045	*log (f5/f4)*	0.053	*log (f5/f4)*	0.050

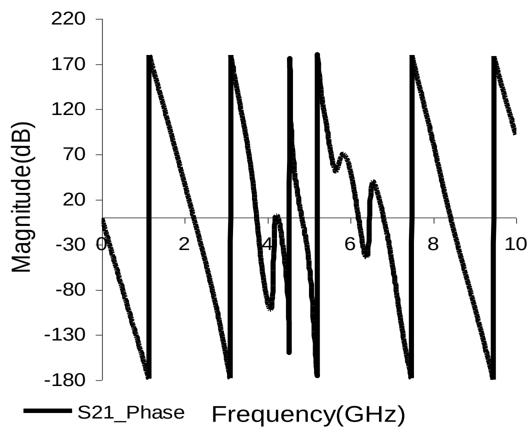

Fig.14: Measured phase responses of proposed five-resonator log-periodic filter with scale factor 0.9.

The measured pole frequencies are available at 4.07GHz, 4.5GHz, 5.07GHz, 5.7GHz and 6.4GHz. A negligible difference occurs at higher poles due to fabrication error. Another comparison is made in Table XVI which shows calculated, simulated and measured values of frequencies ratio. Measured phase response of the proposed filter is given in Fig.14 where it is seen that phase is linearly changed with frequency in passband.

TABLE XVII
CALCULATED AND OPTIMIZED VALUES OF SPUR LENGTHS AND SPACING CORRESPONDING TO THEIR RESONANT FREQUENCIES.

Operating frequencies (GHz)	Calculated spur lengths (mm)		Optimized spur lengths (mm)	Calculated spacing between spurs (mm)	
4.00	a_1	12.06	11.74	S_1	12.06
5.00	a_2	9.64	9.19	S_2	9.64
6.25	a_3	7.70	7.27		

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TABLE XVIII
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.8	S_2/S_1	0.8
a_3/a_2	0.8		

To achieve a significant stopband improvement the scale factor is increased to 0.8. In the design process three numbers of resonators are considered first. Here the centre frequency is same i.e. 5GHz as the earlier designs. Other resonant frequencies and their corresponding spur lengths are listed in Table XVII. Transverse slot width *b* is taken as 1.1mm, gap width, *g*=0.3mm, 50 ohm line width, W=1.9mm.Relation between adjacent spurs and spacing between the spurs are given in described in Table XVIII. The calculated frequencies and spur lengths are listed in Table XVII.

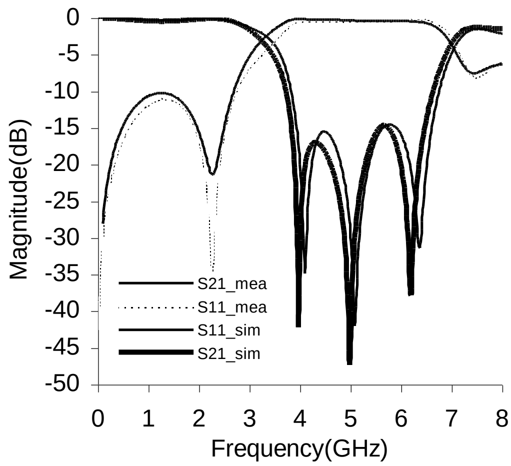


Fig.15: simulated s-parameter response of proposed filter with log-periodic geometry and spacing having scale factor 0.8 and comparison of simulated and measured responses of the same.

Fig.15 draw simulated response of the proposed filter consists of three log-periodically arranged spur line resonators with scale factor 0.8. Simulated result shows a wide band bandstop filter with –15 dB stop bandwidth of 4.2 GHz. The cutoff frequencies are obtained at 3.2 GHz and 7 GHz. The pole frequencies are at 3.98GHz, 4.99GHz and 6.2GHz. The pass band insertion loss is less than -0.5 dB. The fractional bandwidth and the sharpness factor are 54% and 52.3dB/GHz respectively. –15 dB bandwidth of the filter is 2.7GHz (3.8-6.5). It is observed that –15dB rejection band has extended about 24 % when the scale factor is chosen 0.8 rather than 0.9 for three spur resonators. Measurement result shows pole frequencies at 4.09GHz, 5.09GHz, 6.3GHz. In Fig.15 it is observed that there is a good matching between simulated and measured response of the proposed filter. Measured phase response is given in Fig. 16.

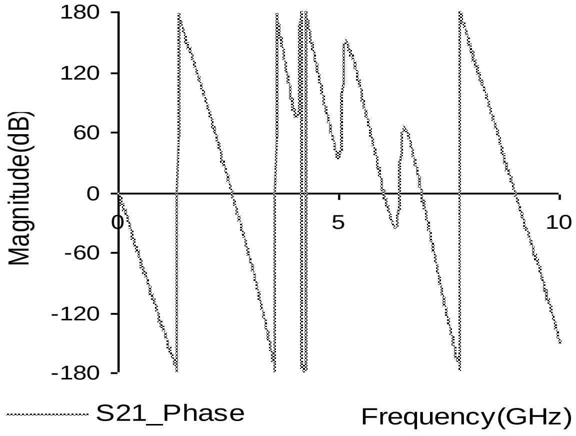
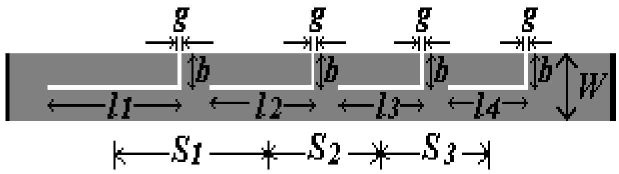
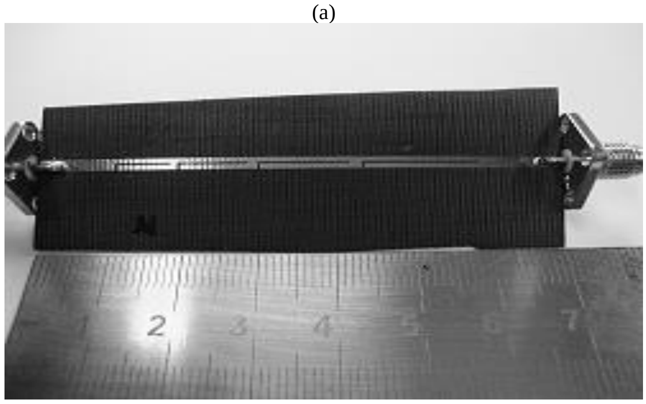


Fig.16: Measured phase responses of proposed three-resonator log-periodic filter with scale factor 0.8.



(a)



(b)

Fig.17 (a): The schematic diagram of proposed four resonator filter with with scale factor 0.8, (b) photographic view of the same.

A gradual improvement of stopband can be achieved by increasing the numbers of resonators by one. When the numbers of resonators are considered to be four then the approximated lengths are taken as: l_1=mm, l_2=12.36mm, l_3=9.94mm, l_4=8mm, width of the transverse slot, b=1.1mm, g=0.3mm, 50 ohm width of the line, W=1.9mm. The schematic diagram and photographic view of four resonator bandstop filter with scale factor 0.4 is given in Fig. 17 (a) and Fig.17 (b) respectively.

TABLE XIX
CALCULATED AND OPTIMIZED VALUES OF SPUR LENGTHS AND SPACING CORRESPONDING TO THEIR RESONANT FREQUENCIES.

Operating frequencies (GHz)	Calculated spur lengths (mm)		Optimized spur lengths (mm)	Calculated spacing between spurs (mm)	
3.2	a_1	15.07	14.89	S_1	15.07
4.00	a_2	12.06	11.74	S_2	12.06
5.00	a_3	9.64	9.19	S_3	9.64

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6.25	a_4	7.70	7.27		

TABLE XX
RATIO OF ADJACENT SPUR LENGTHS AND SPACING.

Ratio of adjacent spur lengths		Ratio of spacing between spurs	
a_2/a_1	0.8	S_2/S_1	0.8
a_3/a_2	0.8		

Calculated frequencies and spur lengths are listed in Table XIX. Table XX shows that a constant ratio is maintained between adjacent spur lengths and spacing. The simulated result from Fig. 18 clearly shows four transmission zeros at 3.19GHz, 3.99GHz, 5GHz and 6.14GHz. The cutoff frequencies are at 2.7GHz and 6.9GHz and maximum passband insertion loss is about -0.4dB. The –15dB bandwidth is 3.4GHz (6.4-3) with a skirt selectivity of 100 dB/GHz at lower side and 42.8dB/GHz at upper side of the band. Measured transmission zeros shown in the same figure, are obtained at 3.3GHZ, 4.1GHz, 5.09GHz, and 6.28GHz and measured result shows a very good resemblance with the simulated one.

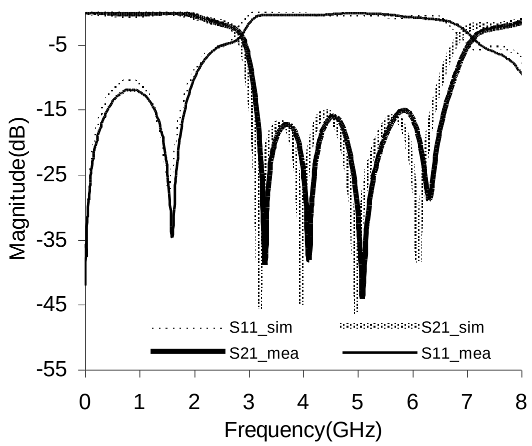

Fig.18: Comparison of simulated and measured s-parameter responses of 4-spur line filters with log-periodic geometry and spacing having scale factor 0.8.

Table XXI shows the comparison among calculated, simulated and measured values of frequencies ratio. A comparison is made to show the increment of bandwith in case of four-resonator filter with respect to three-resonator filter in Fig. 19. The measured phase response of the proposed four-pole log-periodic bandstop filter is given in Fig.20 and it is found that in passband phase is changed linearly with frequency. The improvement of the stopband of BSF in this work is because of introducing extra transmission zeros in the stopband by means of increasing scale factor and numbers of resonators.

TABLE XXI
COMPARISON OF CALCULATED, SIMULATED AND MEASURED VALUES OF LOG OF RATIO OF FREQUENCIES.

Calculated		Simulated		Measured	
log (f2/f1)	0.045	*log (f2/f1)*	0.043	*log (f2/f1)*	0.043
log (f3/f2)	0.045	*log (f3/f2)*	0.046	*log (f3/f2)*	0.051
log (f4/f3)	0.045	*log (f4/f3)*	0.042	*log (f4/f3)*	0.050

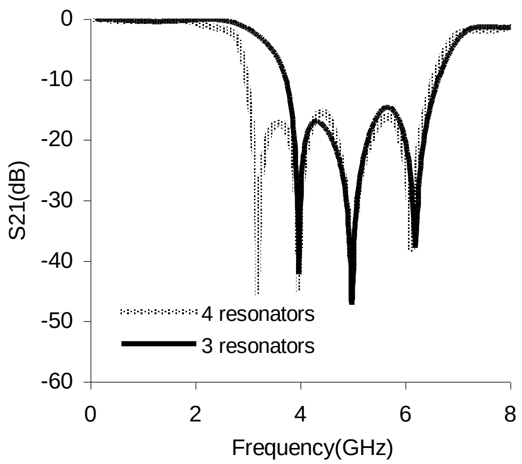

Fig.19: Comparison of simulated s-parameter response of proposed filter with three resonators and four resonators log-periodic filter having scale factor 0.8.

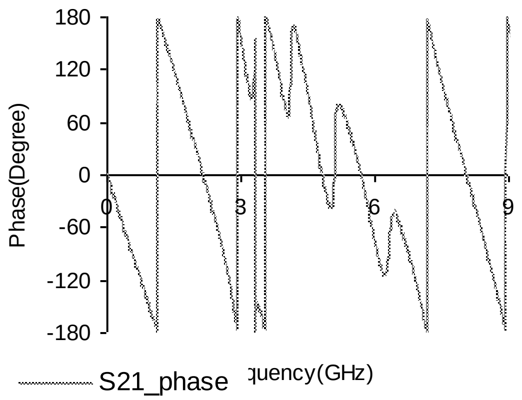

Fig.20: Measured phase responses of proposed four-resonator log-periodic filter with scale factor 0.8.

TABLE XXII
COMPARISON OF DIFFERENT SCALE FACTORS AND NOS. OF RESONATORS CHOSEN AND THEIR CORRESPONDING BANDWIDTH IMPROVEMENT AND SHARPNESS FACTOR.

Scale facror (τ)	Nos. of resonators	Rejection level (dB)	Bandwidth (GHz)	Sharpness factor (dB/GHz)
0.96	3	-20	1.5	17.2
0.90	3	-20	1.5	113.4
0.90	5	-20	2.6	67.3
0.80	3	-15	2.7	51.9
0.80	4	-15	3.4	100

A comparison is given in the above table (Table XXII) to show the enhancement of stopband of filter by applying same technique. It is observed that when scale factor is gradually increased from 0.96 to 0.8 an improvement of fractional bandwidth of 38% is obtained. The sharpness factor of the response is also advanced by controlling the spacing between the resonators. The rejection is better than 20 dB when scale factor is chosen as 0.9 and when increased to 0.8 the rejection is better than 15 dB.

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IV. CONCLUSION

In this paper the advantage of the proposed BSF over the conventional broadband BSF is its simple structure and compact size. It is noted that the filter has high skirt selectivity and wide bandwidth. The concept of log-periodic antenna is used to increase the stopband of the filter. The filter structure is simple and compact as it incorporates the spur line resonators without any increase in circuit dimension. It is observed that the filter shows high skirt selectivity (51dB/GHz –113.4dB/GHz) with wide stopband for different scale factors and numbers of resonators. The rejection bandwidth of the proposed filter is gradually improved in the range of from fractional bandwidth of 30% to 68% in comparison with 7% fractional bandwidth in case of single spur line by changing the scale factor and numbers of resonators. Therefore this technique increases the bandwidth about 61%. As a result this band stop filter can be used to suppress the higher harmonics of any type of bandpass filter. All the filters are built on PTFE substrates (ε_r=3.2 and h=0.79 mm.). The simulation process is performed by a commercial full-wave electromagnetic simulator IE3D and measurements are done by vector network analyzer.

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