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Study the Comparison between Un-Bended and Bended Broadband Parallel Coupled Microstrip Bandpass Filters Under Certain Angle

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Abstract

In this paper, design and simulation of broadband parallel-coupled microstrip bandpass filters used for modern wireless communication technology (Military & Industrial System such as Low Noise Block (LNB) in Television Satellite) are presented, Four designs of filters at 10GHz center frequency are proposed. The first design is parallel coupled microstrip filter, which modify by bending some of microstrip conductors in specific angle($\theta \approx 110^\circ$) as shown in the second design to modify the characteristics and results.

The third design is U-shape parallel coupled filter which modify by bending its stripes with the same angle as above as shown in the fourth design to obtain the best characteristics and results. All filters are simulated by using CAD (Microwave office 2000 version 3.22) and implemented on the Roger RT-duroid 6006, PTFE ceramic substrate with Dielectric constant(ε_r=10.2), loss tangent($\tan\alpha = 0.0023$) and substrate height(h = 0.635mm) .

Keywords: Broadband, Parallel-Coupled, Microstrip, Bandpass, Filter, Bending Angle.

الخلاصة

في هذا البحث تم التطرق الى تصميم ومحاكاة مرشحات امرارحزمي ذات حزمة واسعة لشرائح دقيقة متوازية الاقتران المستخدمة في تكنولوجيا الاتصالات اللاسلكية الحديثة (المنظومات العسكرية والصناعية مثل مستلم اشارات القنوات الفضائية التلفزيونية (LNB)) . تم عرض أربعة تصاميم من المرشحات عند تردد المركز (10GHz). التصميم ألاول هو مرشح ذو شرائح متوازية، تم تطويره بثني بعض من الشرائح المكونة للتصميم بزاوية ($\theta \approx 110^\circ$) كما موضح في التصميم الثاني للحصول على مواصفات ونتائج أفضل.

اما التصميم الثالث هو مرشح على شكل حرف U ، تم ثني بعض شرائحه بنفس الزاويه اعلاه كما موضح في التصميم الرابع والحصول على أفضل المواصفات والنتائج. تم اجراء المحاكاة باستخدام الحقيبة البرمجية مايكرويف (2000) النسخة (3.22) ، والتنفيذ على المادة نوع سيراميك (RT-duroid 6006) بسماحية (10.2) وسمك (0.635) ملم.

Abbreviations

Symbols	means & units
LNB	Low Noise Block
$\tan\alpha$	Loss tangent
CAD	Computer Aided Design
ε_r	Relative permittivity, Dielectric constant
h	Thickness of substrate, substrate height (mm)
BPF	Band Pass Filter
BPCF	Broadband Parallel Coupled Filter
FDTD	Finite Differences Time Domain
δ	Fractional bandwidth
f_2	Upper cut-off frequency (GHz)
f_1	Lower cut-off frequcey (GHz)
f_o	Center frequency(GHz)
f	Filter frequency (GHz)
f_c	Cut-off frequency (GHz)
f_i	The frequency at -40dB(GHz)
n	Order
g	Element value
j	Inverter
R	Ripple
Z_o	System characteristic impedance
Z_{oe}	Even characteristic impedance
Z_{oo}	Odd characteristic impedance
S	Gap between two strips

Introduction

The bandpass filter finds many applications in communication and microwave system. It serves well in reducing the noise and harmonics content of a system by limiting the band of frequencies seen by the system. Many times bandpass filters are placed at the front end of a receiver to decrease the out of band noise that can enter. They can be used to reduce or eliminate harmonics and spurious outputs generated within the system. A bandpass filter passes a specific band of frequencies and rejects frequencies below and above that band. The response curve for a bandpass filter is shown in figure (1), this response shows an area that is termed the passband which is the area where there is a minimum loss in the filter response [1].

Parallel-coupled lines are extensively used in microwave and millimeter-wave circuits for filters, impedance-matching networks, directional couplers, and combiners[2]. Since microstrip is easily incorporated in hybrid and monolithic microwave integrated circuits. Most currently designed microwave circuitry is based upon microstrip transmission line. The microwave circuit designer initially needs to know two main circuit parameters: the wavelength within the microstrip circuit and the characteristic impedance of the transmission line[3].

The ratio of the power delivered from source to load with and without a two-port network inserted in between is known as the insertion loss of that two-port network. It is generally expressed in dB. The fraction of the input power that is lost due to reflection at its input port is called the return loss. The ratio of the power delivered to a matched load to that supplied to it by a matched source is called the attenuation of that two-port network [4]. Selinda[5] was designed and optimized of a parallel-coupled bandpass filter have passband (2.4 - 2.4835)GHz with minimum attenuation of -25dB at 2.5GHz and passband ripple of 0.2dB. The filters are implemented on Roger 4003C substrate with dielectric constant of 3.38, loss tangent of 0.0021 and substrate height of 0.508mm.

Cornelis[6] design a wideband RF filters and illustrates this with the design of a 5 resonator filter with a 50% bandwidth at 1GHz center frequency. The design technique produces filters with a remarkable accuracy, so that one-iteration filter designs can be produced reliably. H.L.Gan[7] is presented an optimized design method to compensate for the open-end effect in parallel-coupled microstrip bandpass filters. The analysis of the relationship between center frequency deviation and microstrip open-end effect is given.

Maher[8] design of parallel-coupled microstrip bandpass filters without spurious resonance, two different techniques are used to eliminate this response at twice the passband frequency. Suspended substrates and shorting of the coupled microstrip lines are used. The finite differences time domain(FDTD) with the perfect layer is used in the analysis. In this paper, four broadband parallel-coupled filters(BPCFs) designs at 10GHz center frequency with reduction in size and optimum performance comparing with the previous designs are proposed.

The filters are simulated by using CAD (Microwave office 2000 version 3.22) and implemented on the Roger RT-duroid 6006, PTFE ceramic substrate, relative permittivity (ε_r=10.2), loss tangent($\tan\alpha = 0.0023$) and thickness(h = 0.635mm). The first design is a basic parallel-coupled filter used to design other filters. In the third design, the U shape resonator is chosen to connect between two parallel coupled lines. The elegant technique using the bending strips in optimum angle ($\theta \approx 110^\circ$) will execute in the second and fourth designs. The designed filters can be used in satellite television receivers[9].

Required Specifications

The required specifications of broadband filter are given in table (1). The designs of filters are implemented on Roger RT-duroid, PTFE substrate with dielectric constant of ε_r=10.2, loss tangent is $\tan\alpha = 0.0023$ and substrate height of $h = 0.635$mm.

Design Steps with Related Theory

The first step is examining filter prototype specification which meet the insertion loss requirements. The family of curves shown in figure (2) apply to Chebyshev prototypes given at -0.01dB passband ripple. Notice that the independent variable has been adjusted for convenience to achieve on the normalized frequency which is given as $|f/f_c| - 1$. For ripple amplitude R > 0.01dB, only odd order designs are permissible, ensuring that $g_o = g_n = 1.0$ accurately. The equations for calculation of element values are given below [5]:

$$g_1 = \frac{2}{\gamma}\sin(\frac{\pi}{2n}) \qquad (1) \text{ ---}$$

$$g_i = \frac{1}{g_{i-1}} \frac{4\sin\left[\frac{(2i-1)\pi}{2n}\right]\sin\left[\frac{(2i-3)\pi}{2n}\right]}{\gamma^2 + \sin^2\left[\frac{(i-1)\pi}{n}\right]}$$

for i = 2,3, ---------,n

$$g_{n+1} = \begin{cases} 1.0 & for \quad n \quad odd \\ \coth^2(\frac{\beta}{4}) & for \quad n \quad even \end{cases} \qquad \text{--- (3)}$$

where

$$\beta = \ln\left[\coth\left(\frac{R}{17.37}\right)\right]$$

$$\gamma = \sinh\left(\frac{\beta}{2n}\right)$$

The second step is to determine the fractional bandwidth (δ) [10]:

$$\delta = \frac{f_2 - f_1}{f_o} \qquad \text{--- (4)}$$

The frequency transformation from the low-pass prototype filter to the band-pass microwave filter is [10]:

$$\frac{f}{f_c} = \frac{2}{\delta}\left(\frac{f_i - f_o}{f_o}\right) \qquad \text{--- (5)}$$

The third step is to calculate the inverter admittances (normalized for a 50 Ω impedance system) and hence coupled-line impedances use the following equations for N=3 (four coupled line sections) [11]:

$$Z_o J_1 = \sqrt{\frac{\pi\delta}{2g_o g_1}} \qquad \text{...(6)}$$

$$Z_o J_n = \frac{\pi\delta}{2\sqrt{g_{n-1} g_n}} \qquad \text{...(7)}$$

for n = 2,3,---, N

$$Z_o J_{n+1} = \sqrt{\frac{\pi\delta}{2g_n g_{n+1}}} \qquad \text{...(8)}$$

$$Z_{oe} = Z_o\left[1 + JZ_o + (JZ_o)^2\right] \qquad \text{...(9)}$$

$$Z_{oo} = Z_o\left[1 - JZ_o + (JZ_o)^2\right] \qquad \text{...(10)}$$

In parallel coupled microstrip filter design, the characteristics impedances can be defined as [12]:

$$Z_o \approx \sqrt{Z_{oe} Z_{oo}} \qquad \text{... (11)}$$

Results and Discussions

From step (1) of design, a fractional bandwidth of 0.36 and transformation ratio of -4.756 will be obtained. Figure (2) shows the relationship between the attenuation and normalized frequency which is equal to 3.756 at -40dB for $n = 3$. Using equations (3, 4 and 5) to find the elements value (g_n) which indicate in table (2), then calculate the values of even and odd characteristic impedances (Z_{oe}, Z_{oo}) from equations (9, 10) to get the values of Z_o for each elements that is indicated in table (3). Table (4) shows the dimensions of layout design of parallel-coupled broad BPF, and figure (3) shows the layout design. Figure (4) shows the frequency response and return loss for the band (8.35-11.7)GHz at -3dB point, and the return loss equal -24dB at center frequency (10GHz) . Figure (5) shows the phase angle diagram with respect to frequency for BPCF. Figure (6) shows the scattering parameter S_{11} with respect to frequency that is implemented on smith chart.

The modified design (bending angle PCF) has the same dimensions of elements and spacing but reduced layout dimensions as a modified shape, which is shown in figure (7). Figure (8) shows the response of bending angle PCF, where the insertion loss at 10GHz equal to -30dB and the band limited frequency at -3dB are (8.32-11.8) GHz with (3.48GHz) band width. Figure (9) shows the phase diagram of bending angle PCF, where the phase at 10GHz equal to 55°. Figure (10) shows the scattering parameter S_{11} implemented on smith chart for bending angle PCF. The separation of the U-shape resonator is chosen with the aid of Microwave Office optimization function, this design shown in figure (11). If the separation is chosen to be too small, there will be a lot parasitic reactance, but if the separation is too high, losses will be great. Therefore a balance between the two has to be met [7]. The dimensions of the modified filter (U-shape BPCF) are (8mm X 4.4mm). The frequency response and return loss of U-shape BPCF are shown in figure (11) and the phase diagram of the U-shape filter is shown in figure (13). The scattering parameter S_{11} with respect to frequency of this filter is shown in figure (14).

Figure (15) shows the fourth design which is modified from third design. In this design the strips are bending by ($\theta = 110^\circ 10'$) but all dimensions of strips have the same lengths of strips in previous design, Table (7) indicate the dimensions of this design. The angle is found by using trial and error method, and represents a better angle which gives better results.

The overall dimensions of the modified filter (bending angle U-shape BPCF) are (7.32mm x 4.4mm). The filter response and phase diagram for this modified filter are shown in figures (16) and (17) respectively. Scattering parameter S_{11} with respect to frequency of modified filter is shown in figure (18). Table (8) indicates the comparisons between all designed filters for Bandwidths, Phase Angle, Insertion Loss and Dimensions of filters.

Conclusion

In this paper, four kinds of broadband parallel coupled microstrip bandpass filters have been presented. The designs are carried out by analysis and simulation using Microwave office. From the results of this work, the following conclusions can be obtained:

1. Numerical results show that a rejection level at passband frequency can be obtained when using a substrate material of RT-duroid 6006, ε_r=10.2, $\tan\alpha$ = 0.0023, h=0.635mm.
2. From the comparison indicated in table(8):
   - **a-** The bandwidth of U–shape PCF is smaller than other filters.
   - **b-** The phase diagram of all filters designs is changed with respect to degree of bending on strips, where in first design the phase in center frequency equal 0° but in other designs shifted with respect to bending angle.
   - **c-** The Insertion Loss at center frequency is increased in the fourth filter design with respect to other designs, so the reflection coefficient will be reduced.
   - **d-** The layout dimensions in the second and fourth designs are reduced with respect to the first and third designs.
3. From above, the second and fourth filters designs are the best designs and there modified from first and third designs.

Table (1) Broadband Pass Filter Design Specification

Filter specifications	Values
Center frequency, f_o	10 GHz
Upper cut-off frequency, f_2	12 GHz
Lower cut-off frequency, f_1	8.5 GHz
Bandwidth	3.5 GHz
Minimum attenuation	-40 dB at 2 GHz

Table (2) Elements Value Of Filter

g_o	g_1	g_2	g_3	g_4
1.0	1.031	1.147	1.031	1.0

Table (3) Parameters Of Parallel Coupled Filter (PCF)

n	$Z_o J_n$	$Z_{oe}(\Omega)$	$Z_{oo}(\Omega)$	$Z_o(\Omega)$
1	0.730	113.145	40.145	67.39
2	0.505	88.000	37.501	57.44
3	0.505	88.000	37.501	57.44
4	0.730	113.145	40.145	67.39

Table (4) Dimensions Of BPCF Shown In Figure (3)

Element number	Width(W) mm	Length(L)mm	Space(S)mm
Ports(1=8)	0.75	1.9	-
Strips(2=3=6=7)	0.266	3.4	S1=S2= 0.073
Strips(4=5)	0.58	2	S3=0.072

Table (5) Dimensions Of Bending Angle BPCF Shown In Figure (7)

Element number	**Width(W) mm**	**Length(L)mm**	**Space(S)mm**
Ports(1=8)	0.84	1.5	-
Strips(2=3=6=7)	0.266	3.4 (1.7 x 2)	S1=S2= 0.058
Strips(4=5)	0.667	2	S3=0.03

Table (6) Dimensions Of U-Shape BPCF In Figure (11)

Elements number	**Width(W) mm**	**Length(L)mm**	**Space(S)mm**
Ports(1=5)	0.75	1.9	-
Strips(2=3=6=7)	0.188	3.46	s1=s2=0.055
Strips(4=8)	0.617	2	s3=s4=0.1
Strips(9=10)	0.187	2.68	
Strip(11)	1.34	0.15	s5=0.965

Table (7) Dimensions Of Bending Angle U-Shape BPCF In Figure (15)

Elements number	**Width(W) mm**	**Length(L)mm**	**Space(S)mm**
Ports(1=5)	0.75	1.9	-
Strips(2=3=6=7)	0.188	3.44(1.72 x 2)	s1=s2=0.055
Strips(4=8)	0.617	2	s3=s4=0.1
Strips(9=10)	0.187	2.68	
Strip(11)	1.34	0.15	s5=0.965

Table (8) Comparison Between All Designed Filters

Characteristic	Parallel Coupled Filter	Bending Angle Parallel Coupled Filter	U-shape Parallel Coupled Filter	Bending Angle U-shape Parallel Coupled Filter
BW(GHz) at -3dB	3.35	3.48	2.87	3.55
BW(GHz) at-10dB	5.0	5.0	4.64	4.6
Phase at 10GHz (degrees)	0.0	55	-155	- 100
Phase at Lower frequency (degrees)	158	55	-20	55
Phase at Upper frequency (degrees)	- 158	90	-20	0
Insertion Loss(dB) at 10GHz	-23	-30.5	-31	-45
Dimensions (mm x mm)	12.6 x 3	10.55 x 3	8 x 4.4	7.32 x 4.4

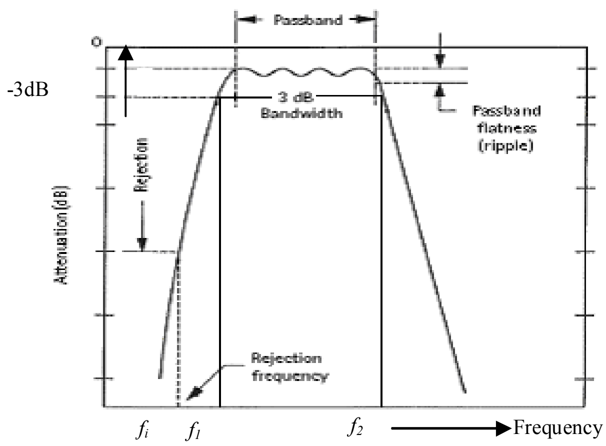

Figure (1) Band Pass Filter Response (BPF),[1]

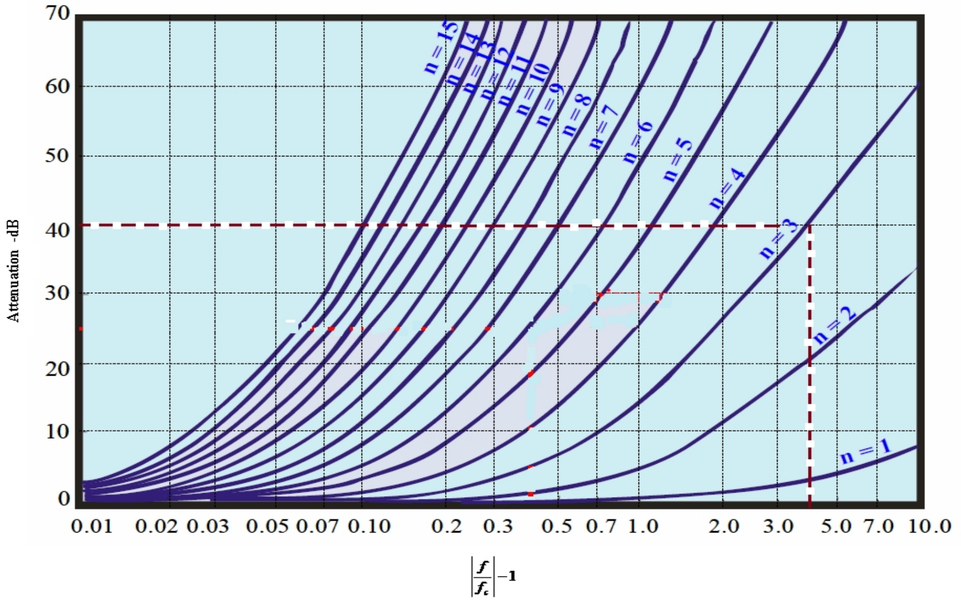

Figure (2) Attenuation Versus Normalized Frequency,[5]

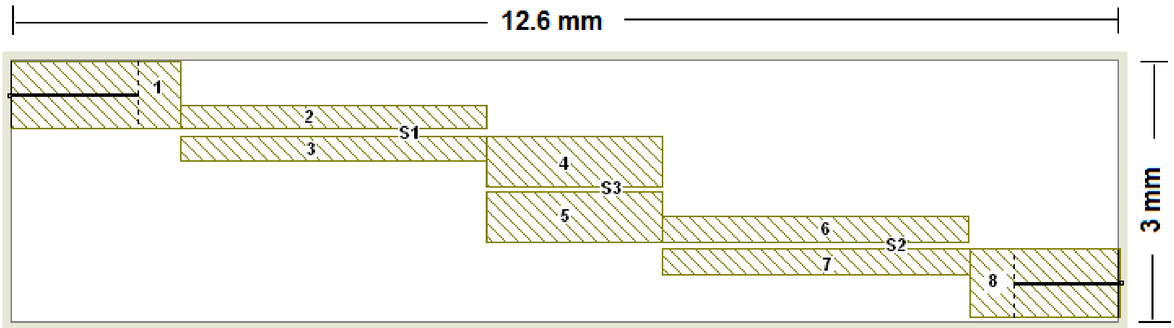

Figure (3) Broadband Parallel-Coupled Filter Design (BPCF)

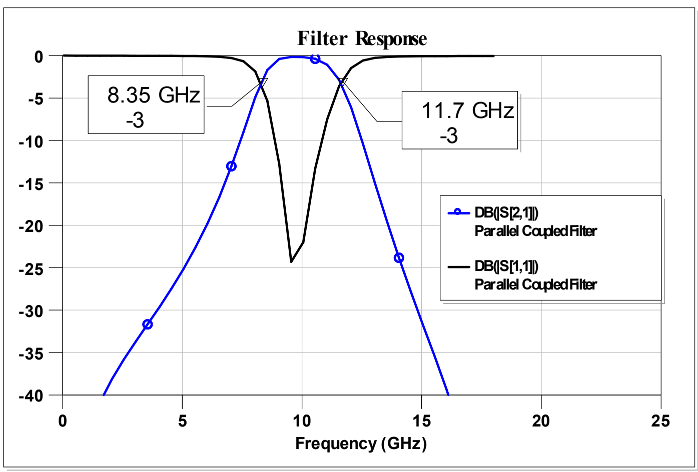

Figure (4) Filter Response Of Parallel Coupled Filter

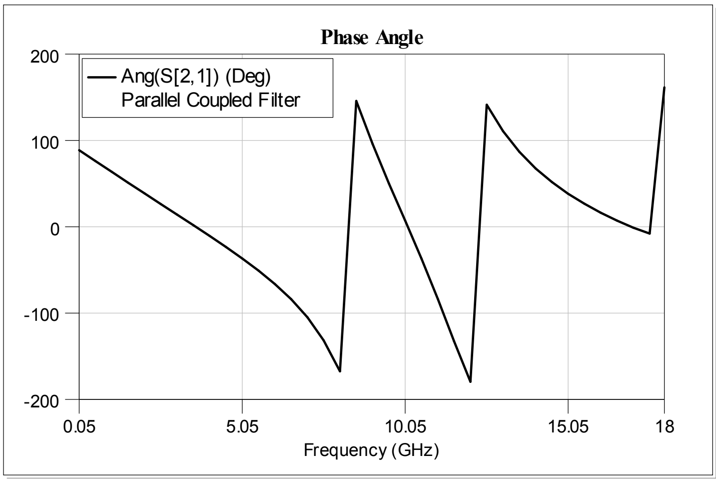

Figure (5) Phase Angle Diagram Of Parallel Coupled Filter

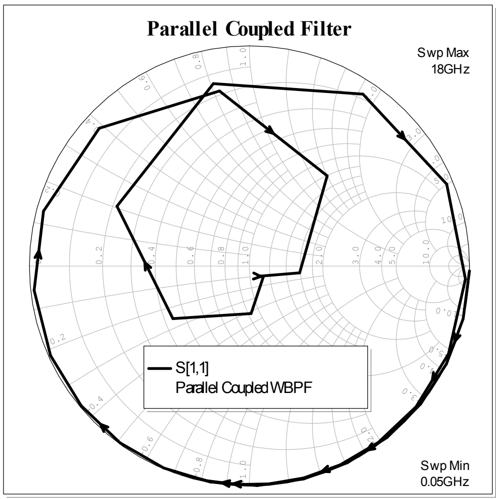

Figure (6) Scattering Parameter S_{11} With Respect To Frequency Of Parallel Coupled Filter

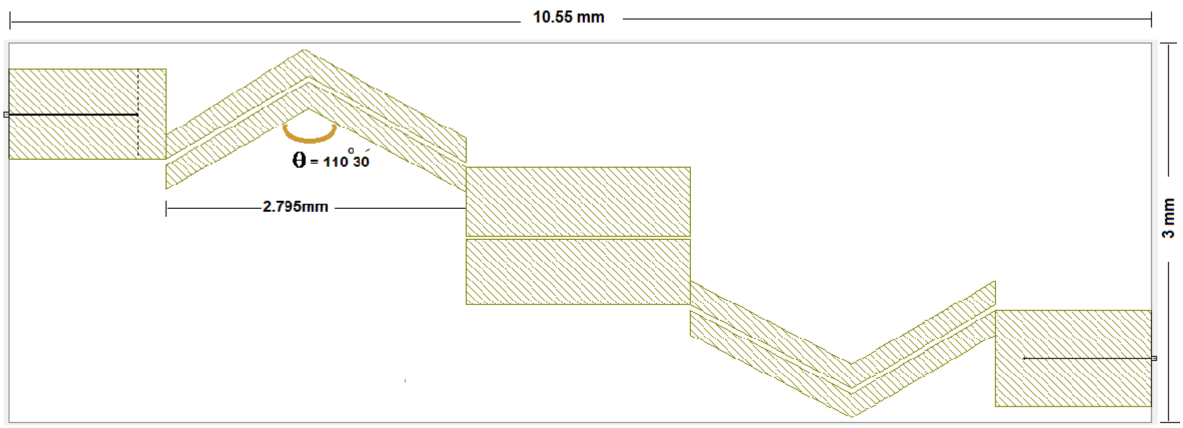

Figure (7) Bending Angle Broadband Parallel Coupled Filter Design

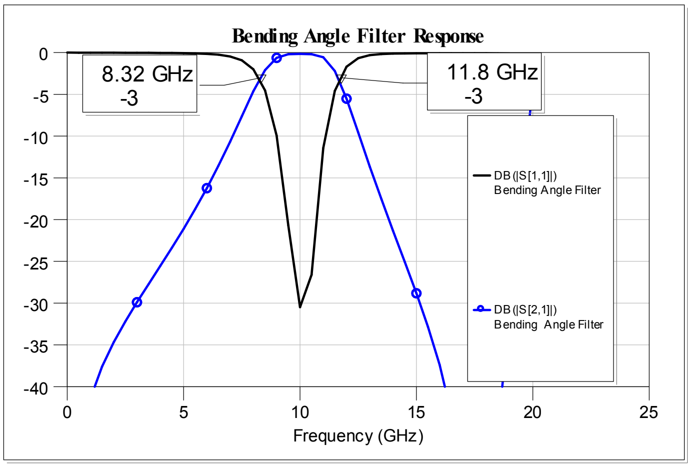

Figure (8) Filter Response Of Bending Angle Parallel Coupled Filter

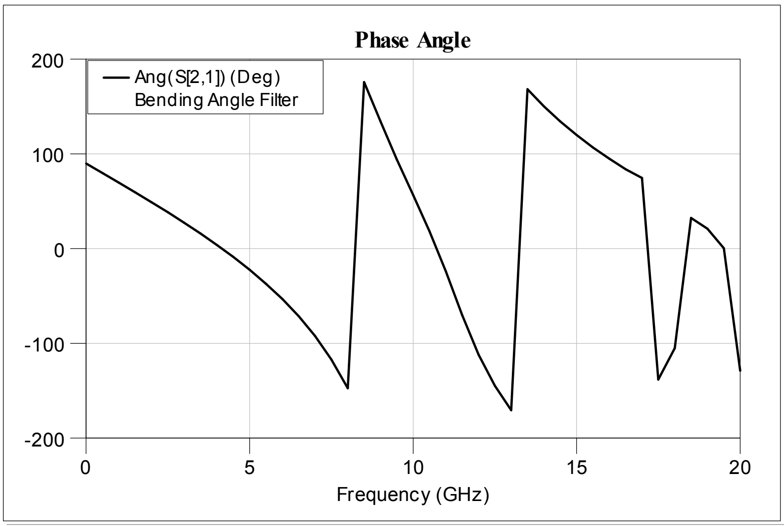

Figure (9) Phase Angle Diagram Of Bending Angle Parallel Coupled Filter

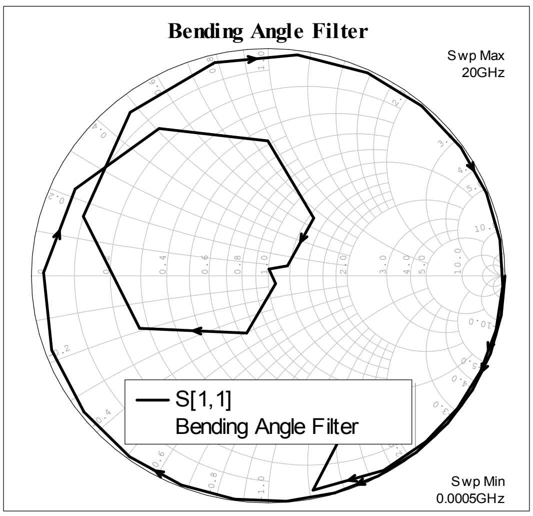

Figure (10) Scattering Parameter S_{11} With Respect To Frequency Of Bending Angle Parallel Coupled Filter

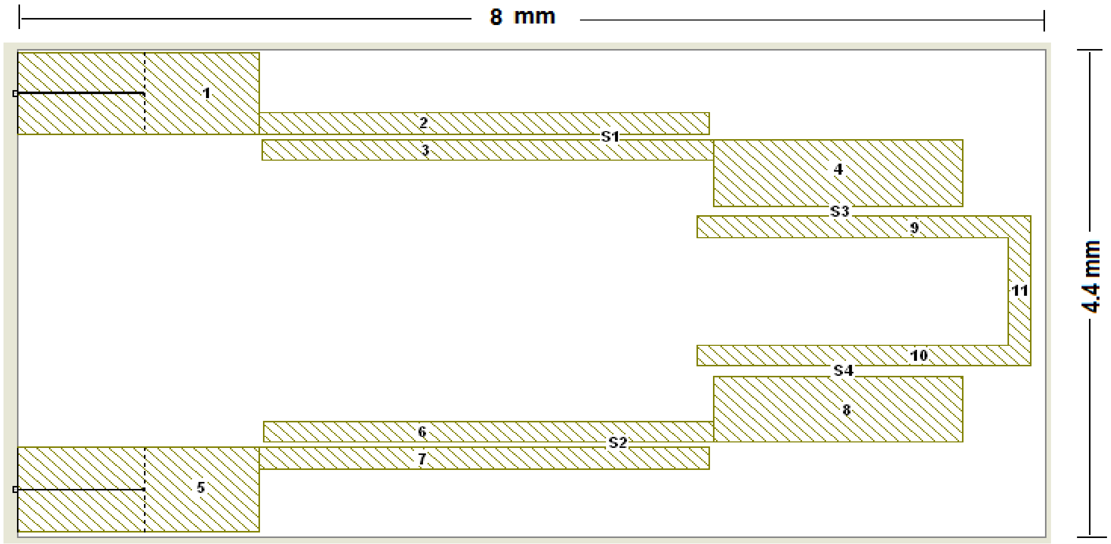

Figure (11) Modified Design (U-Shape) Of Broadband Parallel-Coupled Filter Design

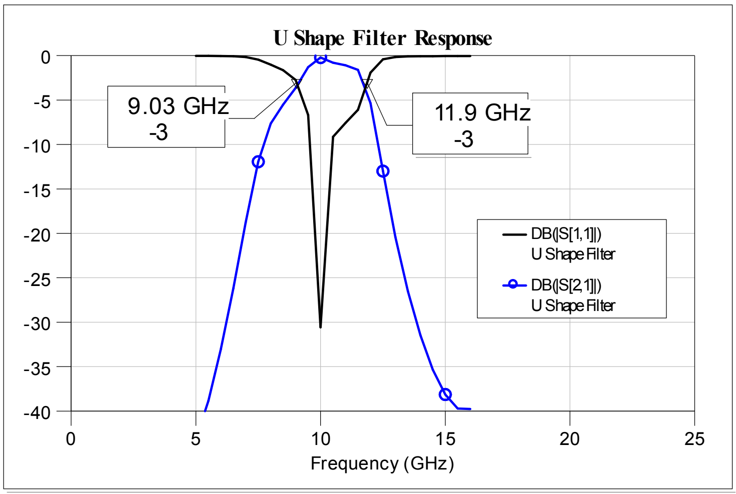

Figure (12) Filter Response Of U-Shape Parallel Coupled Filter

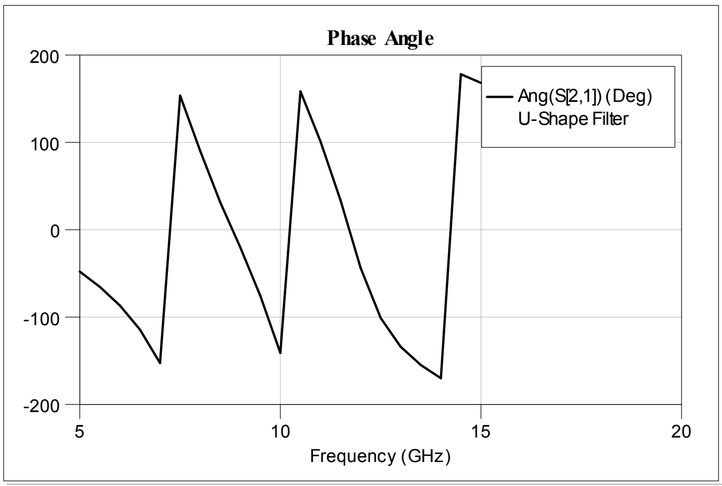

Figure (13) Phase Angle Diagram Of U-Shape Parallel Coupled Filter

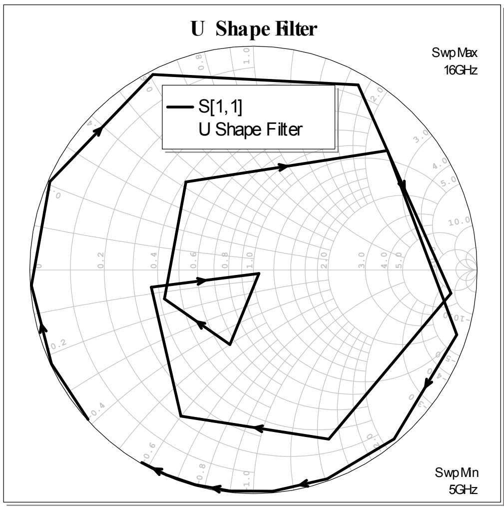

Figure (14) Scattering Parameter S_{11} With Respect To Frequency Of U-Shapeparallel Coupled Filter

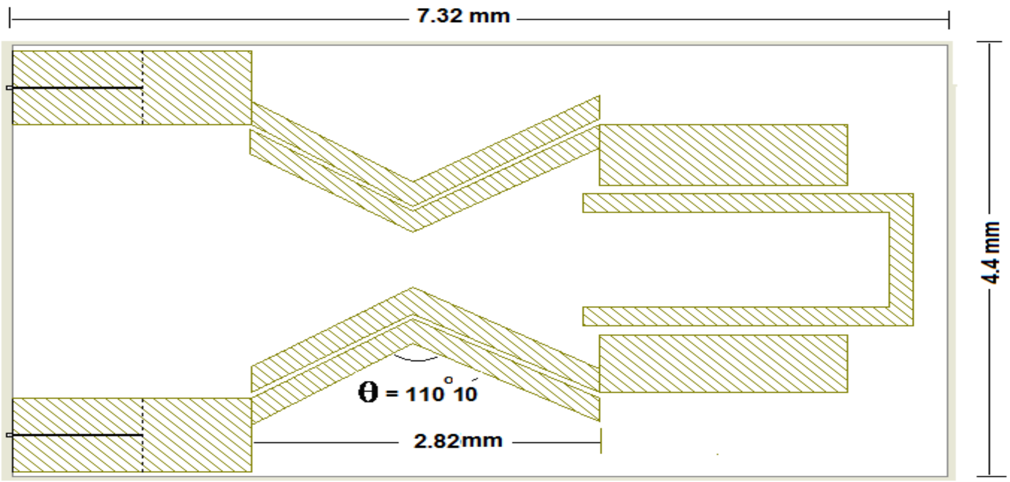

Figure (15) Bending Angle U-Shape Parallel Coupled Filter Design

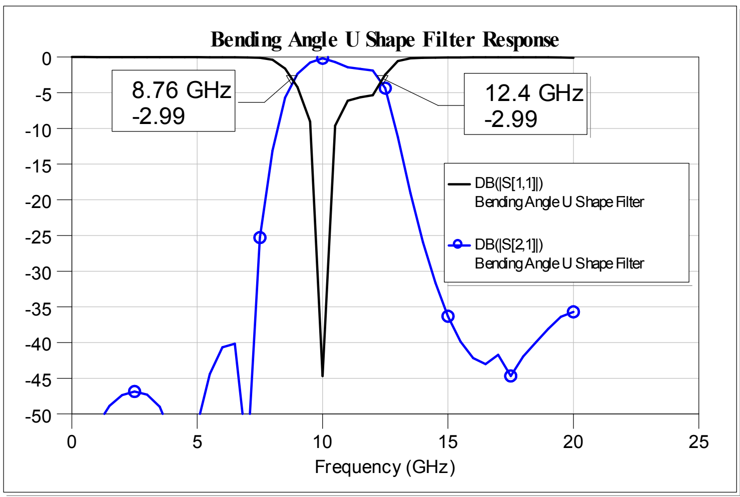

Figure (16) Filter Response Of Bending Angle U-Shape PCF

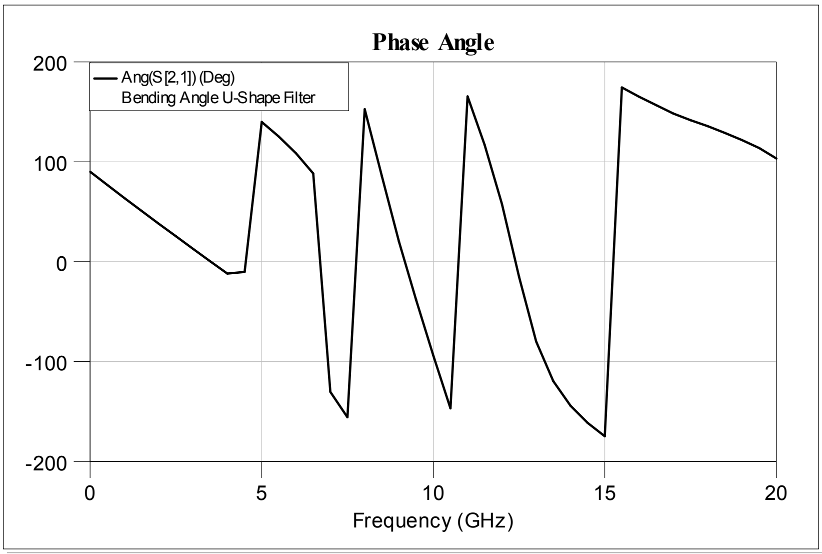

Figure (17) Phase Angle Diagram Of Bending Angle U-Shape PCF

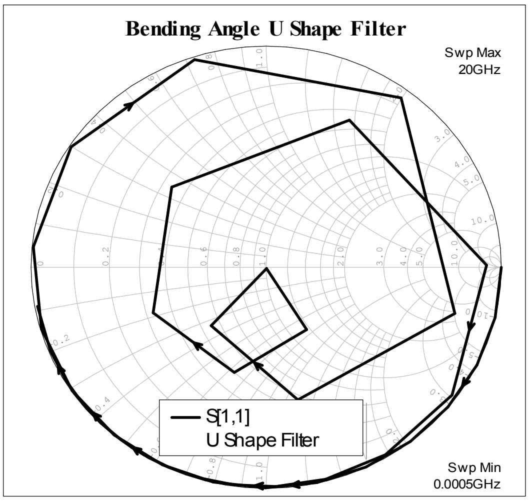

Figure (18) Scattering Parameter S_{11} ***Of Bending Angle U-Shape PCF***

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