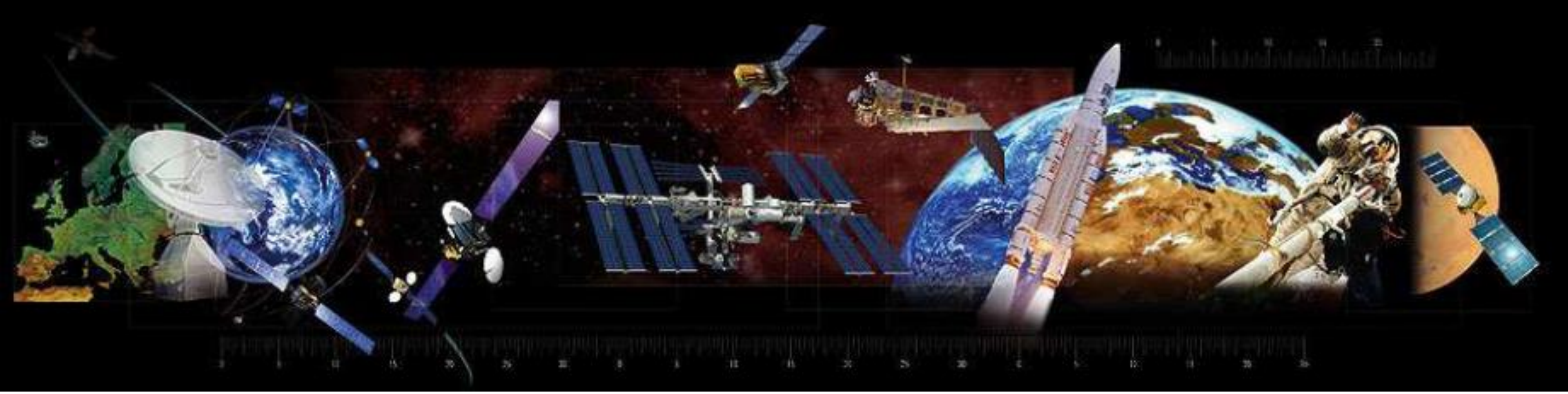

Parallel Coupled Bandpass Filters

(Stripline and Microstrip)

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Presentation Content

Parallel Coupled Bandpass Filters

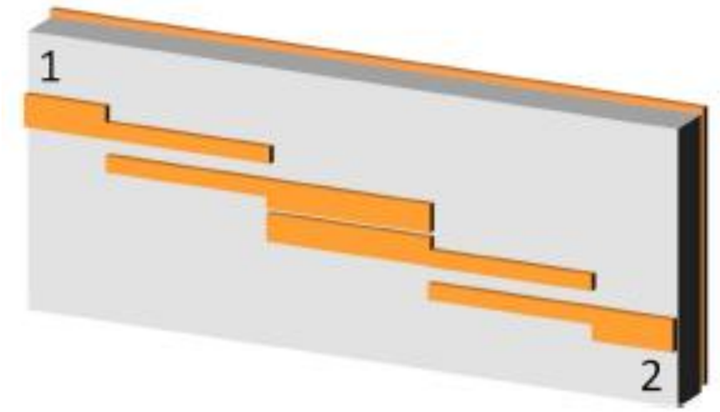

Illustration of a Parallel Coupled Bandpass Filter

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Technical Articles

Parallel Coupled Bandpass Filters

For Readers who wish to explore a more technical treatment of Parallel Coupled Bandpass Filters and their physical realization in microstrip and in stripline:

Technical articles on Parallel Coupled Bandpass Filters in *Microstrip*:

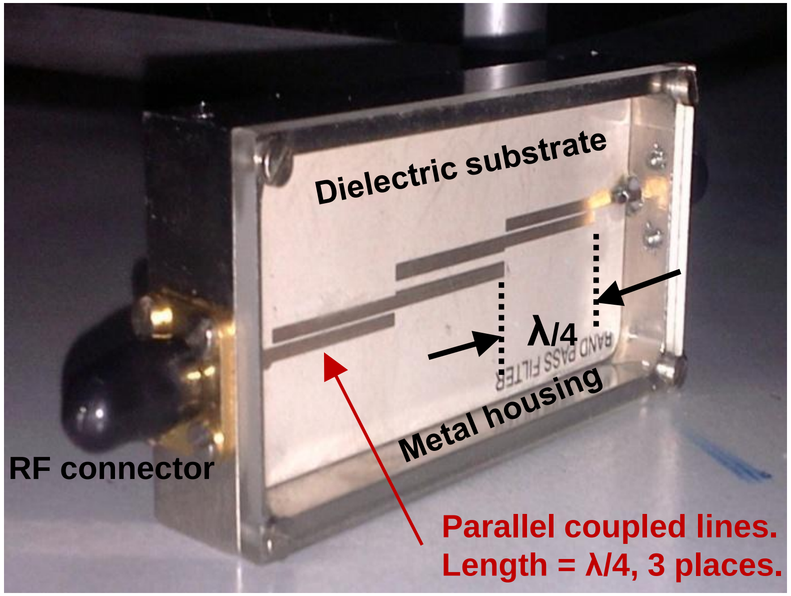
1. *Design Techniques for Bandpass Filters Using Edge-Coupled Microstrip Lines on Fused Silica*, W.H. Childs, IEEE MTT Symposium, July 1976.
2. *Broadbanding Microstrip Filters Using Capacitive Compensation*, I. J. Bahl, Applied Microwave, Aug/Sept 1989 (2 designs).
3. *Microstrip Filters for RF/Microwave Applications*, J. Hong and M.J. Lancaster, John Wiley & Sons, 2001, Page 127.
4. *RF and Microwave Coupled-Line Circuits*, R.K. Mongia, I.J. Bahl, P. Bhartia and J. Hong, Artech House, Page 285, 2007.
5. *Design & Optimization of Microstrip Parallel Coupled Bandpass Filter at 20 GHz*, P. Rani, S. Gupta and P.K. Prasad, IJARCET, Page 1808, May 2014.
6. And dozens & dozens more. . . . . .

Technical articles on Parallel Coupled Bandpass Filters in *Stripline*:

1. *Parallel-Coupled Transmission-Line Resonator Filters*, S.B. Cohn, IRE, MTT-6, April 1958.
2. *Parallel-Coupled Filter with Improved Rejection*, Master's Thesis, S. Zhongsheng, National University of Singapore, Page 25, 2008.
3. *Design and Simulation of Edge-coupled Stripline Band Pass Filter for Ka-band Application*, H. Y. Wai, et al, ICTEEP, Page 97, 2012.
4. *Design Edge-Coupled Stripline Bandpass Filter at 39GHz*, IJETAE, P. Shakdwippe & K. Vyas, May 2013.
5. *Design and Simulation of Edge-Coupled Stripline Band Pass Filter for U-band*, P. Shakdwippe, ISSR-Journals, IJIAS, Aug 2013.
6. *Compact Design of V-band Edge-Coupled Stripline Bandpass Filter*, J. Upadhyay, IJETR, July 2014.

Description of the Filter

Parallel Coupled Bandpass Filter



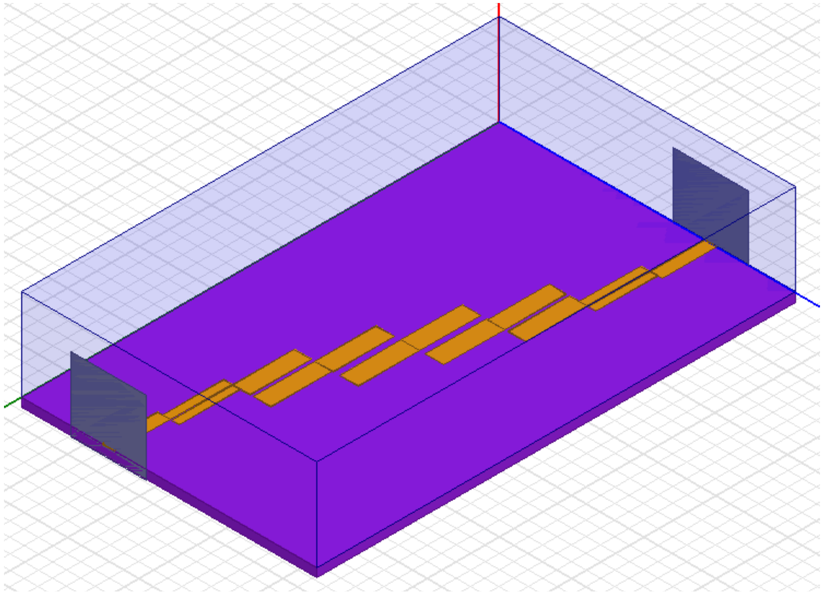
A typical planar parallel coupled band-pass filter consists of a cascade of pairs of parallel-coupled resonator lines that are open-circuited at both ends. The center conductor's coupled transmission lines are positioned parallel to each other, so that adjacent resonators are coupled along a length equal to the quarter-wavelength: $\lambda_0/4$ at the center frequency of the filter: f_0. There are *N* + 1 coupled-line sections in an *Nth-degree* parallel coupled bandpass filter.

1. The physical length of each coupled-line center conductor (or resonator) determines the center frequency: f_0 of the bandpass filter.
2. The line width: W of each center conductor, and gap spacing: S between each coupled-line center conductors, predominantly effects the filter's VSWR and operating bandwidth: BW = $(f_h - f_L)/f_0$.
3. For microstrip parallel coupled bandpass filters, the location of the metal top cover above the dielectric substrate effects the RF performance of the filter.

Advantages/Benefits

Parallel Coupled Bandpass Filter

The advantages of Parallel Coupled Bandpass Filters in RF/microwave circuits are:



1. Small physical size, whether constructed in microstrip or stripline.
2. Easy to fabricate RF circuit traces using conventional photo etching techniques.
3. Absence of short circuits (to ground plane) in its transmission line's center conductors/resonators.
4. Readily packaged with other RF circuit structures in a compact mechanical housing.
5. Produces acceptable passband insertion loss for the application.
6. Produces acceptable out-of-band attenuation for the application.

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Disadvantages/Cautions

Parallel Coupled Bandpass Filter

The disadvantages of Parallel Coupled Bandpass Filters are:

1. Parasitic passband at 2 times the filter's center frequency: 2 x f_0.
2. Difficulty to obtain a narrow passband with low insertion loss.
3. Radiation loss from open end-effect at each resonator: Microstrip.
4. As the filter's bandwidth increases, the gap spacing: S becomes small (< 0.002") in the quarterwave coupled end-sections (Input & output coupled lines), which increases manufacturing difficulties and worsens etching tolerance effects. This narrow-gap problem often becomes unmanageable for bandwidths above 10% to 15%.
5. Material property tolerances in the dielectric constant (Er or D_k) of the actual substrate material has a noticeable adverse effect on the filter's RF performance: It often shifts the filter's center frequency: f_0, especially in filters with narrow fractional bandwidths: $(f_h - f_L)/f_0$.

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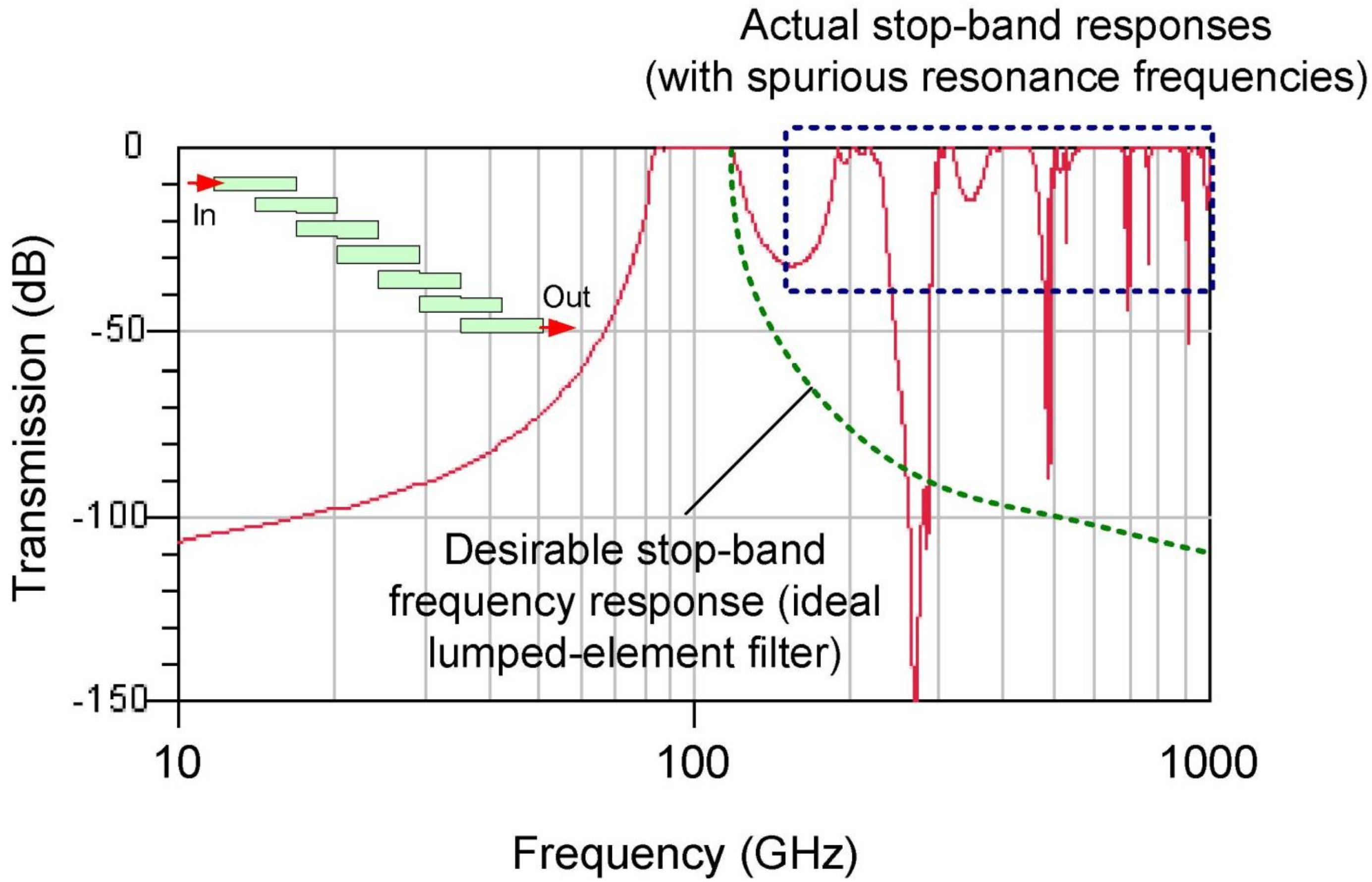
Parasitic Passband. . . .Spurious Response

Parallel Coupled Bandpass Filter



Frequency response of a conventional half-wave parallel coupled line bandpass filter (red solid line) at 100 GHz is compared to its idealized lumped-element band-pass counterpart (green dashed line). The high frequency parallel coupled line filter's deviation from the ideal lumped element response in the parallel coupled line filter can arise from inadequate control over resonances in the individual filter sections.

Broader Operating Bandwidth

Parallel Coupled Bandpass Filter

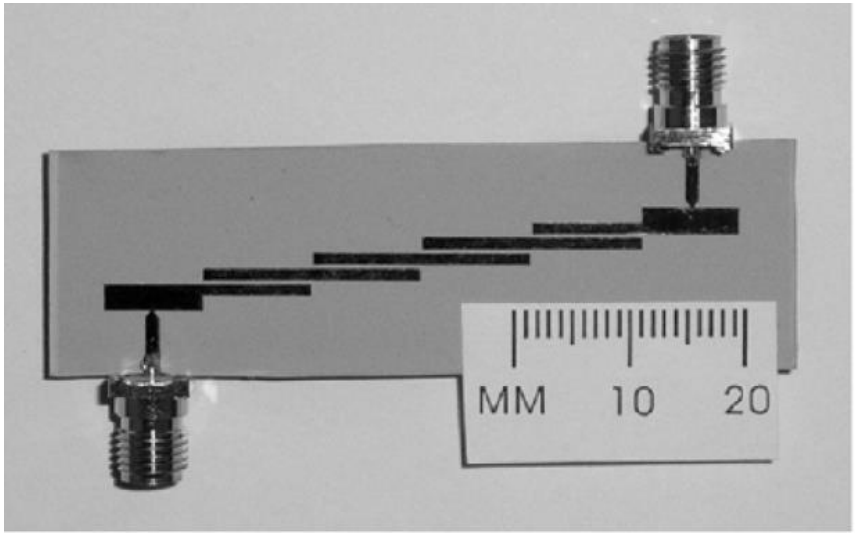
As the filter’s operating bandwidth (= passband) increases above 10% to 15%, the gap spacing: S becomes small (< 0.002”) in the quarter-wave coupled end-sections (Input & output coupled lines), which increases manufacturing difficulties and worsens etching tolerance effects.

Three methods are often used to circumvent this difficulty:

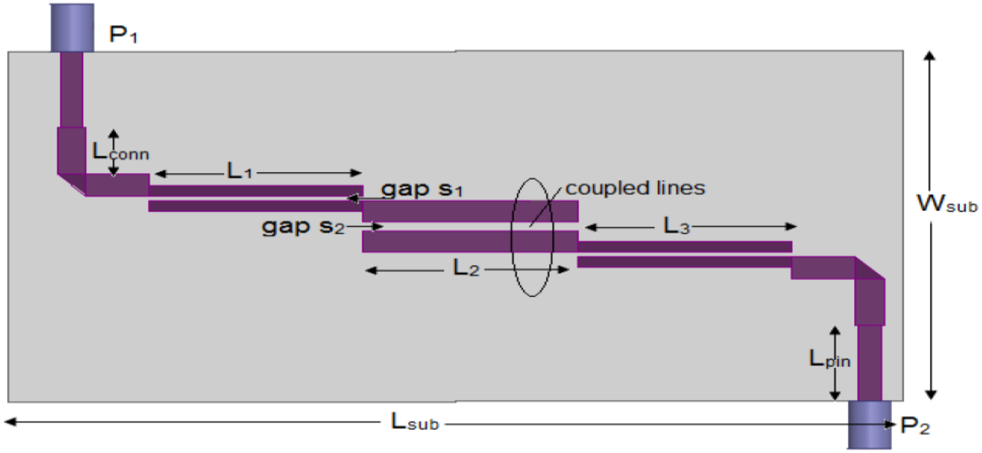
1. The impedance of the resonators may be increased, which increases the required spacings.
2. The first resonator may be externally coupled by inductive tapping, instead of using a coupler section. Because the tightest spacings generally occur in the external coupling sections: input & output, this approach significantly extends the useful operating bandwidth.
3. Raising the termination resistance presented to the filter by using quarter-wave impedance transformer sections for the input and output sections.

Broader Operating Bandwidth

Parallel Coupled Bandpass Filter



5th-order Microstrip Parallel Coupled Bandpass Filter with tapped RF input section and tapped RF output section.



Microstrip Parallel Coupled Bandpass Filter with single-section impedance transformers at RF input and output sections.

Description of Design Process

Parallel Coupled Bandpass Filters

The design process for a parallel coupled bandpass filter starts with the electrical parameters desired for the filter (which you select), then proceeds to calculate the electrical circuit parameters and physical/dimensional parameters so the filter can be manufactured:

Electrical parameters desired for the filter, based on its intended application in the RF circuit or RF assembly:

1. Center frequency: f_0, most often defined in Mega-Hertz: MHz.
2. Operating bandwidth: BW = $f_h - f_L$, also called: Filter's passband.
3. VSWR desired across filter's operating bandwidth, often expressed as the amplitude ripple: L_{ar}, dB.
4. Attenuation desired at frequencies below the filter's passband or at frequencies above the filter's passband; often called: Out-of-band attenuation.
5. A dielectric substrate is selected to fabricate the parallel coupled bandpass filter.

Description of Design Process

Parallel Coupled Bandpass Filters: Select Dielectric Substrate

6. A dielectric substrate is selected based on its compatibility with other RF circuit structures within the assembly, and is based on the filter’s frequency response, both across its passband (for low insertion loss) and at its out-of-band attenuation/rejection:
   a. The dielectric constant: E_r and thickness of the dielectric substrate often determine the frequency when higher-order modes and surface waves could launch, and these higher-order modes/waves could adversely effect the out-of-band attenuation produced by the filter, mostly at frequencies above the filter’s passband.
   b. The thickness of the center conductor can effect the design of the filter, since a thick center conductor allows stronger coupling than a thin center conductor. As such, a thicker center conductor enables larger gap spacings between parallel coupled resonators. Most planar filters fabricated on flexible dielectric substrates (i.e.: not ceramic or quartz) are available with copper center conductors whose metal is 0.0007” thick (1/2-ounce), 0.0014” thick (1-ounce) and 0.0028” thick (2-ounce).

Description of Design Process

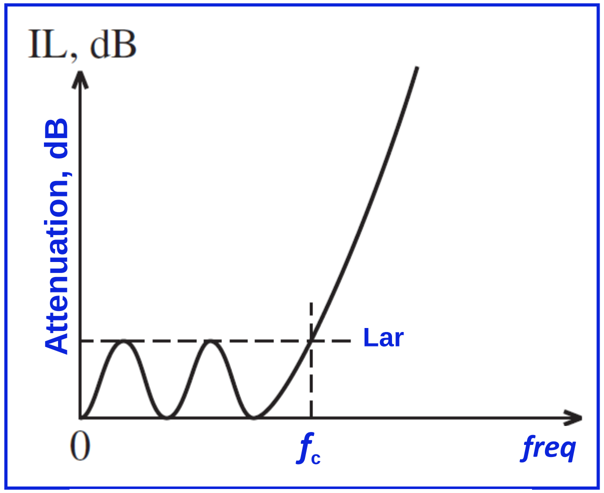
Parallel Coupled Bandpass Filters: Number of Sections

With the required/desired electrical parameters defined, and a dielectric substrate & conductor thickness are selected, the electrical synthesis of the parallel coupled bandpass filter can proceed:

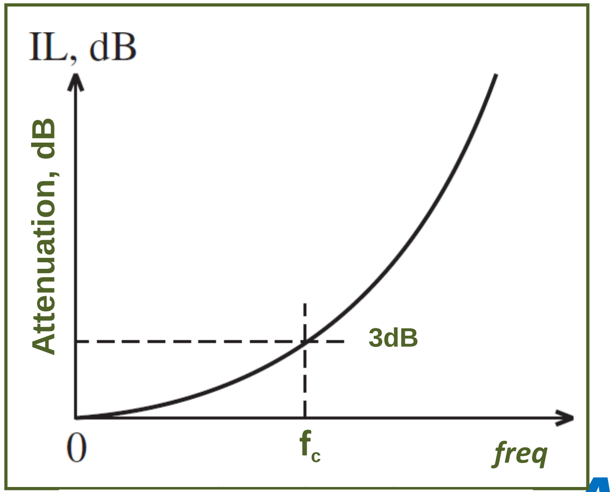
1. Determine the number of resonant sections: N, needed in the filter based on its desired passband response: Chebyschev or Butterworth, and its desired out-of-band attenuation: *A* at an out-of-band frequency: w_1.

$$N > \frac{\cosh^{-1}\sqrt{(10^{A/10}-1)/(10^{Lar/10}-1)}}{\cosh^{-1}\left(\frac{\omega_1}{\omega_c}\right)}$$

$$N > \frac{\log_{10}\left(10^{A/10}-1\right)}{2\log_{10}\left(\omega_1/\omega_c\right)}$$



Chebyshev Filter Response (Equi-Ripple passband)



Butterworth Filter Response (Maximally-flat passband)

Description of Design Process

Parallel Coupled Bandpass Filters: Lowpass Element Values

2. Calculate the lowpass prototype filter element values: $g_o, g_1, g_2. \ . \ . \ . \ g_{n+1}$ for the N-section bandpass filter that produces the desired passband response: Chebyschev or Butterworth, and the desired out-of-band rejection.

Butterworth lowpass prototype filter circuit element values:

$$g_0 = g_{n+1} = 1 \begin{cases} \text{Series } R_s = R_L = Z_o \\ \text{Shunt } G_s = G_L = 1/Z_o \end{cases}$$

$$g_i = 2 \sin\left[\frac{(2i-1)\pi}{2n}\right]$$, ***i*** = 1,2,3….n

Chebyshev lowpass prototype filter circuit element values:

$$g_0 = 1 \,;\, g_1 = \frac{2a_1}{\gamma} \,;\, g_k = \frac{4a_{i-1}a_i}{b_{i-1}g_{i-1}}$$

$$g_{n+1} = \begin{cases} 1 & \text{for } n \text{ odd} \\ \coth^2\left(\frac{\beta}{4}\right) & \text{for } n \text{ even} \end{cases}$$

where: $\beta = \ln(\coth\frac{L_{ar}}{17.34}) \quad ; \quad \gamma = \sinh(\frac{\beta}{2n})$

$$a_i = \sin\left[\frac{(2i-1)\pi}{2N}\right] \quad ; \quad i = 1,2,....N$$

$$b_i = \gamma^2 + \sin^2\left[\frac{i\pi}{N}\right] \quad ; \quad i = 1,2,...,N$$

N : Order of the filter.

L_{ar} : Maximum passband ripple, dB.

A Note about Passband Amplitude Ripple

Filters synthesized using the Insertion Loss Method produce a passband VSWR that is related to the passband's amplitude ripple: L_{ar}.

1. The passband's amplitude ripple is directly related to the filter's input/output VSWR as:

$$\Gamma = \sqrt{1+10^{Lar/10}}$$

$$VSWR = \frac{1+\Gamma}{1-\Gamma}$$

As such, a higher passband amplitude ripple produces a higher passband VSWR, as shown in the table. Often, higher passband VSWR can adversely effect the performance in communication systems and, therefore, it seems 'silly' to publish any filter's design whose ripple exceeds L_{ar} > 0.5dB passband ripple = 9.64dB Return Loss.

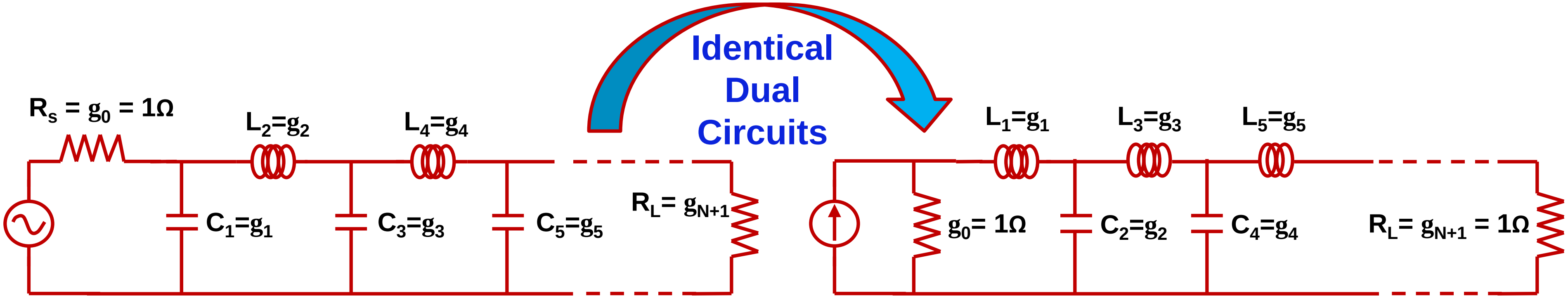
Passband Ripple, Lar, dB	Reflection Coefficient Γ	Return Loss, dB	VSWR
0.001	0.0151734	36.38	1.03
0.005	0.0339209	29.39	1.07
0.010	0.0479576	26.38	1.10
0.020	0.0677834	23.38	1.15
0.030	0.0829696	21.62	1.18
0.040	0.0957500	20.38	1.21
0.050	0.1069902	19.41	1.24
0.060	0.1171346	18.63	1.27
0.070	0.1264472	17.96	1.29
0.080	0.1351002	17.39	1.31
0.090	0.1432132	16.88	1.33
0.100	0.1508734	16.43	1.36
0.250	0.2365145	12.52	1.62
0.500	0.3297712	9.64	1.98
0.750	0.3982523	8.00	2.32
1.000	0.4535105	6.87	2.66
2.000	0.6074888	4.33	4.10
3.000	0.7062668	3.02	5.81

Butterworth →

Description of Design Process

Parallel Coupled Bandpass Filters: Synthesize Electrical Circuit

Based on calculations from lowpass prototype filter element values: g_o, g_1, g_2. . . . g_{n+1} , form the prototype filter electrical circuit as:



(a) Prototype Lowpass Filter with series inductor input: L_1.

(b) Prototype Lowpass Filter with shunt capacitor input: C_1.

where:

N = Order of the filter = Number of reactive elements in the filter.

g_0 = Generator's source resistance or generator 's source conductance.

g_i = Inductance for series inductors or capacitance for shunt capacitors.

g_{N+1} = Load resistance, if g_N is a shunt capacitor or
Load conductance, if g_N is a series inductor.

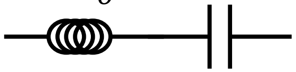
Description of Design Process

Parallel Coupled Bandpass Filters: Frequency & Impedance Scaling

Frequency scale the prototype element values to the filter’s desired operating frequency using your center frequency: f_0 and fractional bandwidth: $(f_h - f_L)/f_0$. Impedance scale the prototype element values to the filter’s desired impedance level, often: 50 ohms.

1. The series inductor: $g_k = L_k$ is transformed into a series *LC* circuit with element values:

$$L_k' = \frac{Z_0 g_k}{\Delta\omega_0} \qquad C_k' = \frac{\Delta}{\omega_0 Z_0 g_k}$$



Fractional bandwidth:

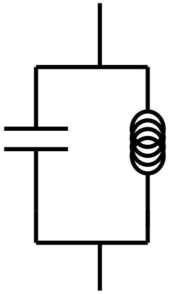
$$\boxed{\Delta = \frac{\omega_2 - \omega_1}{\omega_o}}$$

Center frequency:

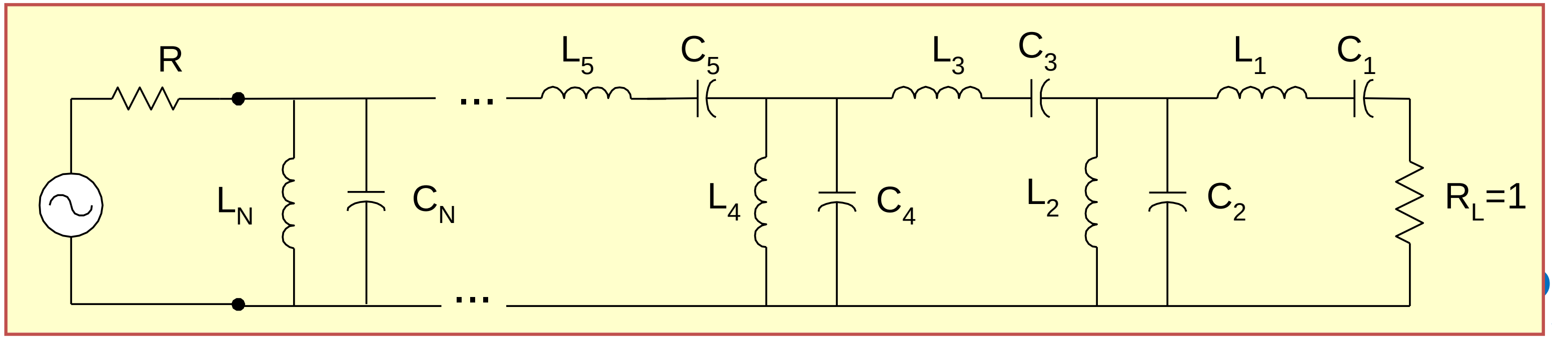
$$\boxed{\omega_o = \frac{\omega_1 + \omega_2}{2} \text{ or } \sqrt{\omega_1 \omega_2}}$$

2. The shunt capacitor: $g_k = C_k$ is transformed into a shunt *LC* circuit with element values:

$$C_k' = \frac{g_k}{\Delta Z_0 \omega_0} \qquad L_k' = \frac{\Delta Z_0}{\omega_0 g_k}$$



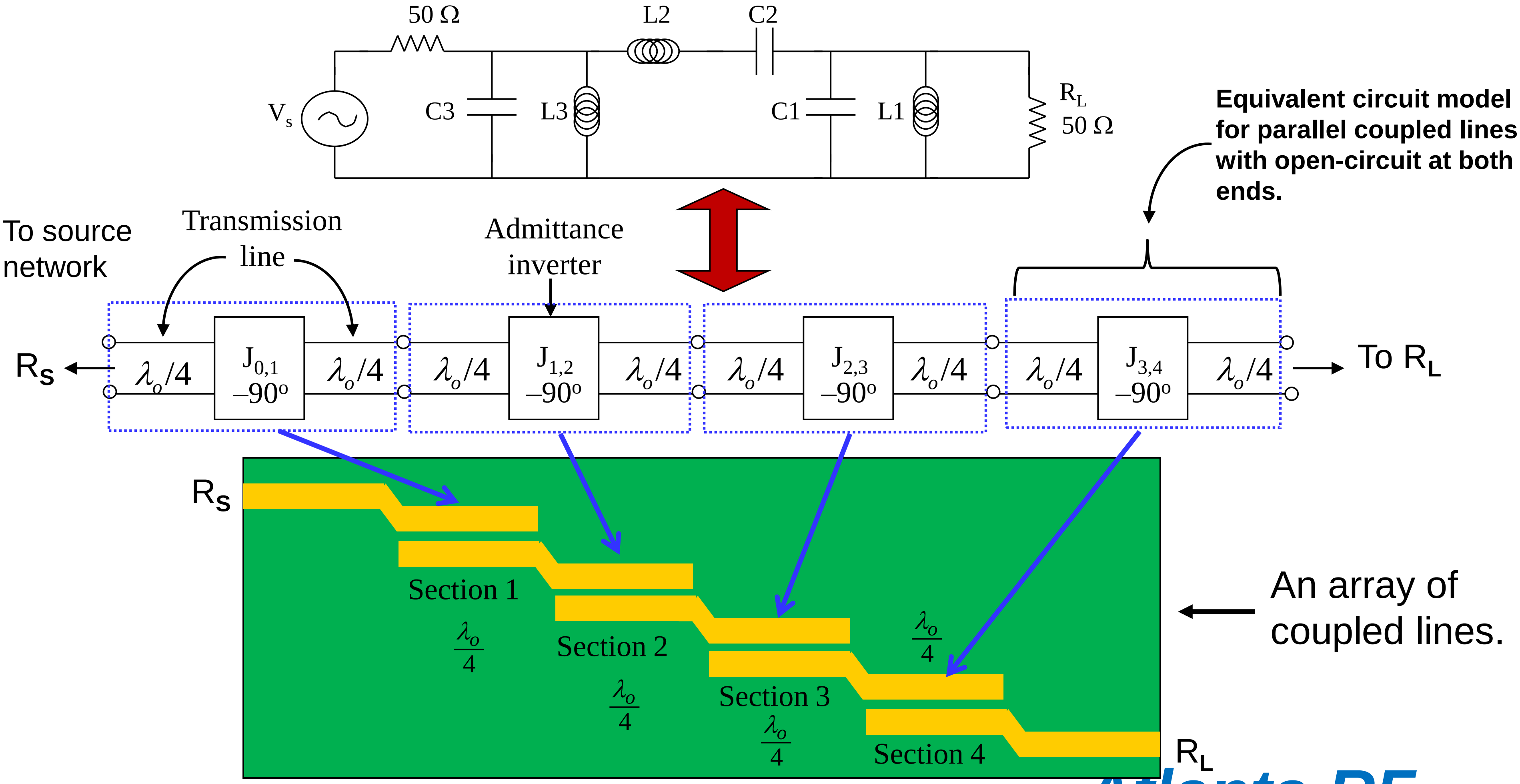
Bandpass filter derived from the prototype lowpass filter:



Description of Design Process

Parallel Coupled Bandpass Filter: Realize Physical RF Circuit

Apply distributed RF circuits to scaled bandpass filter using Richard's Transformations and Kuroda's Identities. Example: 3-pole bandpass filter.



Equivalent circuit model for parallel coupled lines with open-circuit at both ends.

An array of coupled lines.

λ_o = wavelength at ω_o

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Description of Design Process

Parallel Coupled Bandpass Filters: Impedance/Admittance Inverters

The Admittance Inverters: $J_{i,i+1}$ or Impedance Inverters: $K_{i,i+1}$ in each coupled-line section of the filter are calculated from the lowpass prototype element values: g_i and the fractional bandwidth: FBW = $(f_h - f_L)/f_0$ as:

For the first coupled-line structure:

$$Z_0 J_{0,1} = \frac{Z_0}{K_{0,1}} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_0 g_1}}$$

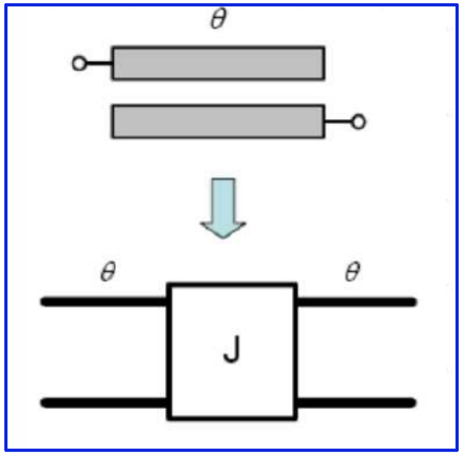
For the intermediate/middle coupled-line structures:

$$Z_0 J_{i,i+1} = \frac{Z_0}{K_{i,i+1}} = \frac{\pi\, FBW}{2\sqrt{g_i g_{i+1}}}, i = 1 \text{ to n -1}$$

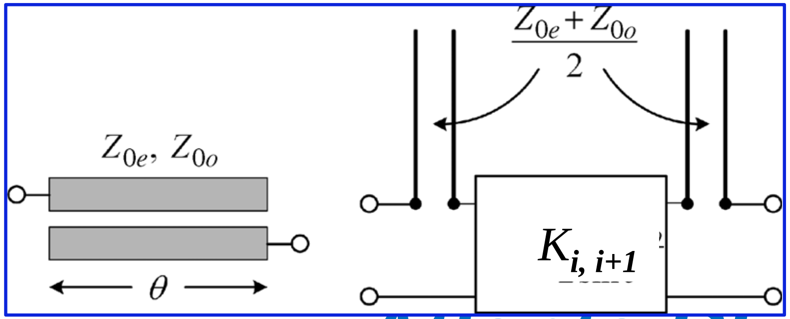
For the last coupled-line structure:

$$Z_0 J_{n,n+1} = \frac{Z_0}{K_{n,n+1}} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_n g_{n+1}}}$$

From these Admittance or Impedance Inverters, the Even and Odd-Mode Impedances can be calculated.



Admittance Inverter: J



Impedance Inverter: K

Description of Design Process

Parallel Coupled Bandpass Filters: Even & Odd-Mode Impedances

Even and Odd-Mode Impedances: Z_{oe} and Z_{oo} for each coupled-line section in the bandpass filter are calculated from the filter's Admittance Inverters: $J_{i,i+1}$, or Impedance Inverters: $K_{i,i+1}$, and the characteristic impedance of the filter: Z_0 as:

$$Z_{0e}\Big|_{i,i+1} = Z_0\left[1 + Z_0 J_{i,i+1} + (Z_0 J_{i,i+1})^2\right] = Z_0\left[1 + \frac{Z_0}{K_{i,i+1}} + \left(\frac{Z_0}{K_{i,i+1}}\right)^2\right]$$

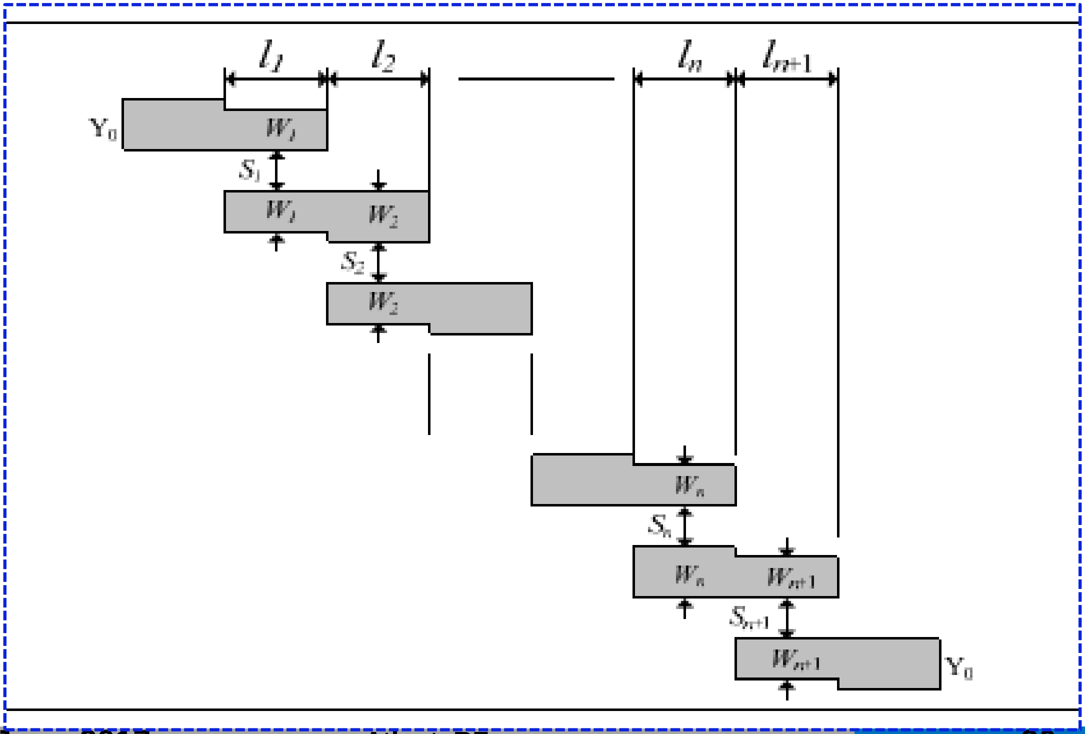
$$Z_{0o}\Big|_{i,i+1} = Z_0\left[1 - Z_0 J_{i,i+1} + (Z_0 J_{i,i+1})^2\right] = Z_0\left[1 - \frac{Z_0}{K_{i,i+1}} + \left(\frac{Z_0}{K_{i,i+1}}\right)^2\right]$$

From these Even and Odd-Mode impedances, the physical dimensions needed to realize the parallel coupled bandpass filter can be calculated: Strip Width (W) and gap spacing between strips (S), based on the substrate's dielectric constant, height and strip thickness, and the method to construct: Microstrip or Stripline.

Description of Design Process

Parallel Coupled Bandpass Filter: Physical Dimensions

From the Even and Odd-Mode impedances: Z_{oe} and Z_{oo}, the physical dimensions needed to realize the parallel coupled bandpass filter can be calculated: Strip Width: $W_{i,i+1}$ and gap spacing between strips: $S_{i,i+1}$, based on the substrate's dielectric constant: E_r, substrate's height and strip thickness of the center conductor: T, and the method to construct: Microstrip or Stripline.



Top view: General structure of parallel-coupled bandpass filter that use quarter-wavelength line resonators: N + 1 sections.

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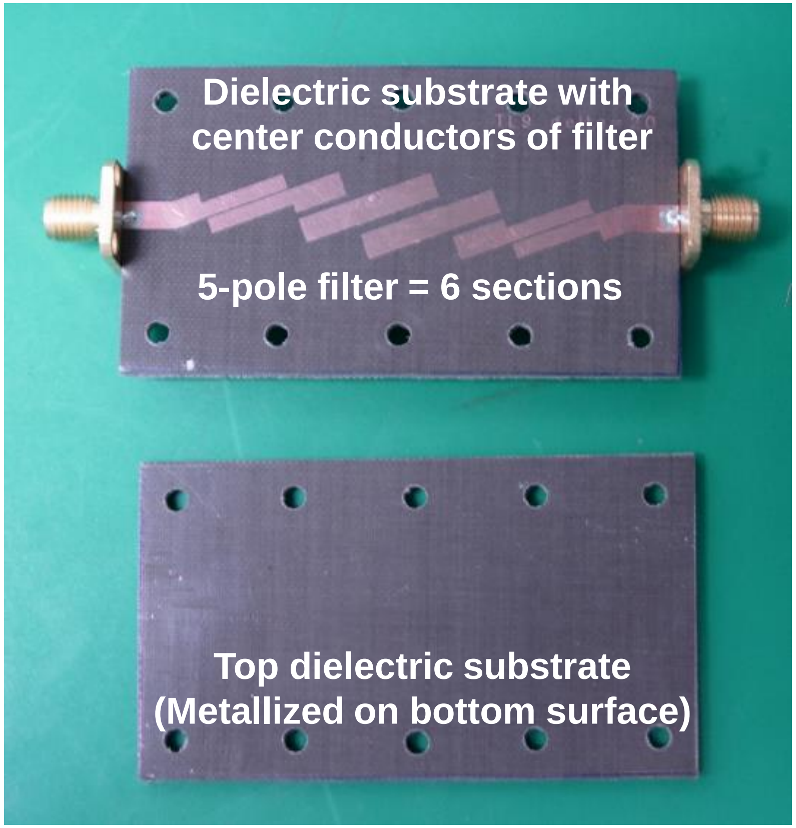
Description of Design Process

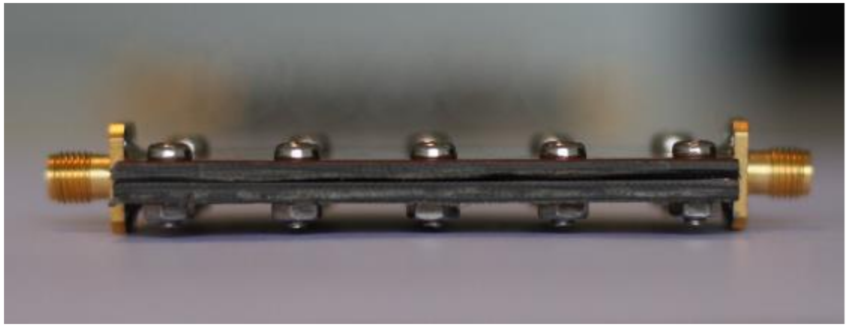
Parallel Coupled Bandpass Filter: Stripline Construction

Photograph of a typical 5-pole Parallel Coupled Bandpass Filter constructed in balanced stripline:

1. Metal/copper center conductor is sandwiched between two dielectric materials which has metallization on its bottom surface.
2. Metallization on top surface of dielectric substrate is chemically etched to produce line widths: $W_{i,i+1}$ and gap spacing between strips: $S_{i,i+1}$.



Center conductor of 5-pole Parallel Coupled stripline Bandpass filter.



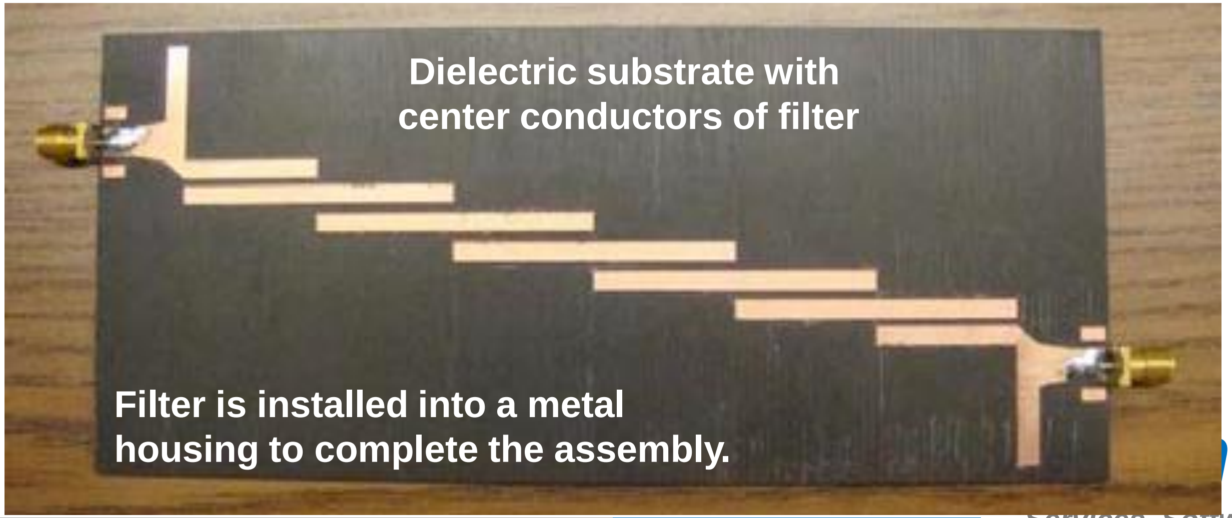
Side view of stripline filter after assembly.

Description of Design Process

Parallel Coupled Bandpass Filter: Microstrip Construction

Photograph of a typical 5-pole Parallel Coupled Bandpass Filter constructed in microstrip:

1. In microstrip construction, metal center conductor is exposed to environment, which makes the small gap spacing between strips susceptible to short circuit by stray pieces of metal: FOD (Foreign Object Debris).
2. Metallization on top surface of single dielectric substrate is chemically etched to produce line widths: $W_{i,i+1}$, and gap spacing between strips: $S_{i,i+1}$.
3. Stand-alone dielectric substrate has metallization on its bottom surface.
4. Caution: Don’t forget effects of metal top cover on RF performance of filter.



Dielectric substrate with center conductors of filter

Filter is installed into a metal housing to complete the assembly.

PCfilter: Computer Software

Parallel Coupled Bandpass Filter

Atlanta RF (www.AtlantaRF.com) offers RF/microwave CAE software product: *PCfilter* to aid in the design of multi-section Parallel Edge Coupled Bandpass Filters constructed in microstrip or in stripline:

1. *Synthesis* of the filter's electrical circuit:
   a. Lowpass prototype elements values: Chebyschev or Butterworth.
   b. Even and Odd-Mode Impedances: Z_{oe} and Z_{oo} of each section.
   c. Admittance Inverters: $J_{i,i+1}$ for each section in the filter.
2. *Synthesis* of distributed circuit in microstrip or balanced stripline:
   a. Synthesis of line widths: $W_{i,i+1}$ and gap spacing between strips: $S_{i,i+1}$.
   b. Synthesis of physical length of each resonator section
3. *Frequency Analysis* response profile of parallel coupled bandpass filter based on physical dimensions:
   a. VSWR/Return Loss, thru-path Insertion Loss and phase
   b. Frequency when higher-order modes may launch.

Software product: *PCfilter* provides the User with full design capability, from Synthesis to Frequency Analysis of Parallel Edge-Coupled Bandpass Filters and their Distributed form: Microstrip or Stripline.

PCfilter: Synthesis of Electrical Circuit

Parallel Coupled Bandpass Filter

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        RF/Microwave Computer-Aided Engineering Software.
           Program: PCfilter (v. 1.3)       Date:  6/24/2017

This program performs Electrical SYNTHESIS, Dimensional
SYNTHESIS and Frequency ANALYSIS of multi-section Parallel
Coupled Line Bandpass Filters exhibiting a Tchebyscheff or
Butterworth response across its passband, with construction in
Microstrip or Stripline.

 Please enter the following Design Data:
    -Filter`s Center Frequency,  MHz = 1200.
    -Filter`s Passband Bandwidth,MHz = 120.
    -Desired Bandwidth for Filter    = 10.00 %
    -Select RESPONSE profile for your Filter:
       *1: Tchebyscheff (Equi-ripple) Passband Response (Default).
        2: Butterworth (Maximally Flat) Passband Response.
          RESPONSE profile selected = 1

    -Enter Passband RIPPLE Level in dB:
         - Enter 0.01 for VSWR = 1.10; R.L. = 26.4 dB.
         -*Enter 0.05 for VSWR = 1.24; R.L. = 19.5 dB (Default).
         - Enter 0.10 for VSWR = 1.35; R.L. = 16.5 dB.
         - Enter 0.20 for VSWR = 1.54; R.L. = 13.5 dB.
         - Enter 0.50 for VSWR = 2.00; R.L. =  9.6 dB.
         - Or a value of your choice.
         Enter Passband RIPPLE in dB = 0.00986
    -Select METHOD for entering Number of Filter Sections:
      *1: User enters Number of Filter Sections: N (Default).
       2: User enters Attenuation at out-of-band Skirt Frequency.
                METHOD selected = 1
    -Number of Resonate Poles: N < 12= 6
    -Impedance of the System: Zo,Ohms= 50.
```

Example: Data entry for synthesis of electrical circuit for User's Parallel Coupled Bandpass Filter:

User enters filter's center frequency and operating bandwidth.

User enters passband ripple and selects number of sections: N.

PCfilter: Electrical Circuit after Synthesis

Parallel Coupled Bandpass Filter

```
        PCfilter (v. 1.3)                    Date: 6/24/2017 at 20: 2: 4Hours
        Copyright 2012-2017 Atlanta RF Software (www.AtlantaRF.com)
          RF/Microwave Computer-Aided Engineering Design Data For
           Multi-Section Parallel Coupled Line Bandpass Filters.

       SYNTHESIS of the Distributed Electrical Circuit for your Parallel
       Coupled Line Bandpass Filter results in the following Prototype
       Lowpass Element Values and Even-Mode & Odd-Mode Impedances:

           Flow    =  1140.000 MHz     Response    = Tchebyscheff
           Fo       =  1200.000 MHz     # of Poles    =  6
           Fhigh   =  1260.000 MHz     Ripple (Am) = 0.0099 dB
           BW      =   120.000 MHz     Zo of System=  50.00 Ohms
           BW3dB=   144.023 MHz

     Prototype  Coupled  Even & Odd Mode               Normalized
     Low-Pass   Section   Impedances   Coupling Coeff  J Inverter
   I  Elements   (K,K+1)    Zoe     Zoo   Numeric   dB    J(K,K+1)/Yo
  ---------------------------------------------------------------------------------
   0   1.00000      0  1     82.51  37.63                         0.44884
   1   0.77970      1  2     58.79  43.53  0.09680 -20.28   0.15258
   2   1.35922      2  3     55.72  45.35  0.06591 -23.62   0.10370
   3   1.68802      3  4     55.35  45.59  0.06204 -24.15   0.09760
   4   1.53455      4  5     55.72  45.35  0.06591 -23.62   0.10370
   5   1.49516      5  6     58.79  43.53  0.09680 -20.28   0.15258
   6   0.70881      6  7     82.51  37.63                         0.44884
   7   1.10001    Source and Load Impedance =  50.00 Ohms
  ---------------------------------------------------------------------------------
  End Section`s External Q: Qe(1) =  7.78 and Qe( 7) =  7.78.
```

Example: Synthesis data of electrical circuit for User's Parallel Coupled Bandpass Filter:

Summary: Baseline electrical design parameters for User's bandpass filter.

Electrical circuit synthesized from filter's baseline electrical parameters.

PCfilter: Synthesis of Physical Circuit

Parallel Coupled Bandpass Filter

```
      PCfilter (v. 1.3)               Date: 6/24/2017 at 20: 2: 4Hours
      Copyright 2012-2017 Atlanta RF Software (www.AtlantaRF.com)
       RF/Microwave Computer-Aided Engineering Design Data For
        Multi-Section Parallel Coupled Line Bandpass Filters.

     SYNTHESIS of Physical Dimensions for your Parallel Coupled
     Line Bandpass Filter results in the following design data:

        Flow =  1140.000 MHz     Response    = Tchebyscheff
        Fo    =  1200.000 MHz     # of Poles    =  6
        Fhigh=  1260.000 MHz     Ripple (Am) = 0.010 dB
        BW    =   120.000 MHz    Zo of System=  50.00 Ohms
        Er     =     2.550             Construction= Stripline
        B      =     0.500 inches        Strip Thick = 0.0017 inches

                                                    Resonator  Open-End
Section Line Width:W  Section Gap Spacing:S   Length   Capacitance
  (K)      Inches    MM  (K,K+1) Inches    MM      Inches     pico-farads
-----------------------------------------------------------------------------------
   1       0.2323  5.901    0  1   0.0244  0.6210    1.5397       0.1468
   2       0.3408  8.656    1  2   0.1127  2.8633    1.5397       0.2027
   3       0.3532  8.970    2  3   0.1636  4.1544    1.5397       0.2090
   4       0.3544  9.001    3  4   0.1722  4.3747    1.5397       0.2097
   5       0.3532  8.970    4  5   0.1636  4.1544    1.5397       0.2090
   6       0.3408  8.656    5  6   0.1127  2.8633    1.5397       0.2027
   7       0.2323  5.901    6  7   0.0244  0.6210    1.5397       0.1468
     Total Length of your Bandpass Filter =  10.7782 inches.

For Zo =  50.00 Ohms, Line Width = 0.3636 inches in Er =  2.550.
For Fo =  1200.00 MHz, Quarter Wavelength =  1.5397 inches.
Maximum usable operating frequency =   4.890 GHz before possible
launch of higher-order modes.
-----------------------------------------------------------------------------------
```

Example: Synthesis data of distributed circuit for User's Parallel Coupled Bandpass Filter constructed in stripline.

Summary: Electrical and physical design data on User's parallel coupled filter.

Synthesis of distributed RF circuit for User's Parallel Coupled Bandpass Filter in stripline.

PCfilter: Frequency Analysis

Parallel Coupled Bandpass Filter

```
     PCfilter (v. 1.3)                Date: 6/24/2017 at 20: 2: 4Hours
     Copyright 2012-2017 Atlanta RF Software (www.AtlantaRF.com)
      RF/Microwave Computer-Aided Engineering Design Data For
       Multi-Section Parallel Coupled Line Bandpass Filters.

     Frequency Analysis of your Parallel Coupled Line Bandpass Filter
     results in the following response profile:

       Flow =  1140.000 MHz     Response     = Tchebyscheff
       Fo      =  1200.000 MHz     # of Poles     =  6
       Fhigh=  1260.000 MHz     Ripple (Am) = 0.00986 dB
       BW    =   120.000 MHz    Zo of System=  50.00 Ohms
       SR     =      5.000 u"             Resistivity = 1.700 u-Ohm-cm
                                    Loss Tangent = 0.00100

  Frequency     Input Port: S11     Input Impedance   Thru Loss: S21
    MHz       VSWR   RL,dB   Phase   Real     Imag       dB       Phase
  -------------------------------------------------------------------------------
    1050.00  99.990    -0.12  145.5     0.37     15.50  -49.861 -126.85
    1075.00  99.990    -0.17  125.6     0.61     25.65  -39.466 -147.35
    1100.00  57.960    -0.30    94.2     1.60     46.42  -26.052 -179.89
    1125.00    8.844    -1.97    18.6 146.55  204.10    -7.460  101.78
    1150.00    1.091  -27.22    32.3   53.75       2.50    -0.785   -59.35
    1175.00    1.065  -30.08  108.4   48.93       2.91    -0.647 -169.32
    1200.00    1.093  -27.02 -177.2   45.73    -0.19    -0.629     93.44
    1225.00    1.057  -31.17 -104.1   49.25    -2.64    -0.663      -3.45
    1250.00    1.086  -27.68   -26.6   53.79    -1.99    -0.816  -111.76
    1275.00    6.499    -2.69     -8.3 266.33-123.15    -6.171     89.61
    1300.00  48.326    -0.36   -91.0     2.03  -49.03  -24.953       3.73
    1325.00  86.026    -0.20 -123.9     0.74  -26.62  -38.650    -30.30
    1350.00  99.990    -0.15 -144.3     0.46  -16.08  -49.208    -51.38
 Source Impedance: Zs =  50.000 Ohms.
 Load   Impedance: ZL =  50.000 Ohms.
 ---------------------------------------------------------------------------------
```

Example: Frequency analysis data of distributed circuit for User’s Parallel Coupled Bandpass Filter: Stripline.

Summary: Electrical design parameters for User’s parallel coupled stripline filter.

2-port scattering parameters for User’s Parallel Coupled Bandpass Filter based on filter’s physical dimensions: Stripline.

Example: 6-pole Stripline Bandpass Filter

Parallel Coupled Bandpass Filter: Synthesis of Dimensional Data

Parallel-Coupled Transmission-Line Resonator Filters, S.B. Cohn, IRE, MTT-6, April 1958.

PCfilter (v. 1.3) Date: 5/28/2017 at 18:33: 3Hours
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RF/Microwave Computer-Aided Engineering Design Data For
Multi-Section Parallel Coupled Line Bandpass Filters.

SYNTHESIS of Physical Dimensions for your Parallel Coupled
Line Bandpass Filter results in the following design data:

Flow = 1140.000 MHz Response = Tchebyscheff
Fo = 1200.000 MHz # of Poles = 6
Fhigh = 1260.000 MHz Ripple (Am) = 0.010 dB
BW = 120.000 MHz Zo of System= 50.00 Ohms
Er = 2.550 Construction = Stripline
B = 0.500 inches Strip Thick = 0.0017 inches

				Resonator	Cohn's	Cohn's	Cohn's	Error: Cohn - PCfilter, inches		
Section	Width: W	Section	Spacing: S	Length,	Width: W	Gap: S	Length: L	Width: W	Gap: S	Length: L
(K)	Inches	(K,K+1)	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
--------	------	--------	-------	--------						
1	**0.2323**	0 1	**0.0244**	**1.5397**	**0.236**	**0.021**	**1.467**	**0.0037**	**-0.0034**	**-0.0727**
2	**0.3408**	1 2	**0.1127**	**1.5397**	**0.346**	**0.110**	**1.456**	**0.0052**	**-0.0027**	**-0.0837**
3	**0.3532**	2 3	**0.1636**	**1.5397**	**0.360**	**0.158**	**1.455**	**0.0068**	**-0.0056**	**-0.0847**
4	**0.3544**	3 4	**0.1722**	**1.5397**	**0.361**	**0.163**	**1.455**	**0.0066**	**-0.0092**	**-0.0847**
5	**0.3532**	4 5	**0.1636**	**1.5397**	**0.360**	**0.158**	**1.456**	**0.0068**	**-0.0056**	**-0.0837**
6	**0.3408**	5 6	**0.1127**	**1.5397**	**0.346**	**0.110**	**1.467**	**0.0052**	**-0.0027**	**-0.0727**
7	**0.2323**	6 7	**0.0244**	**1.5397**	**0.236**	**0.021**		**0.0037**	**-0.0034**	

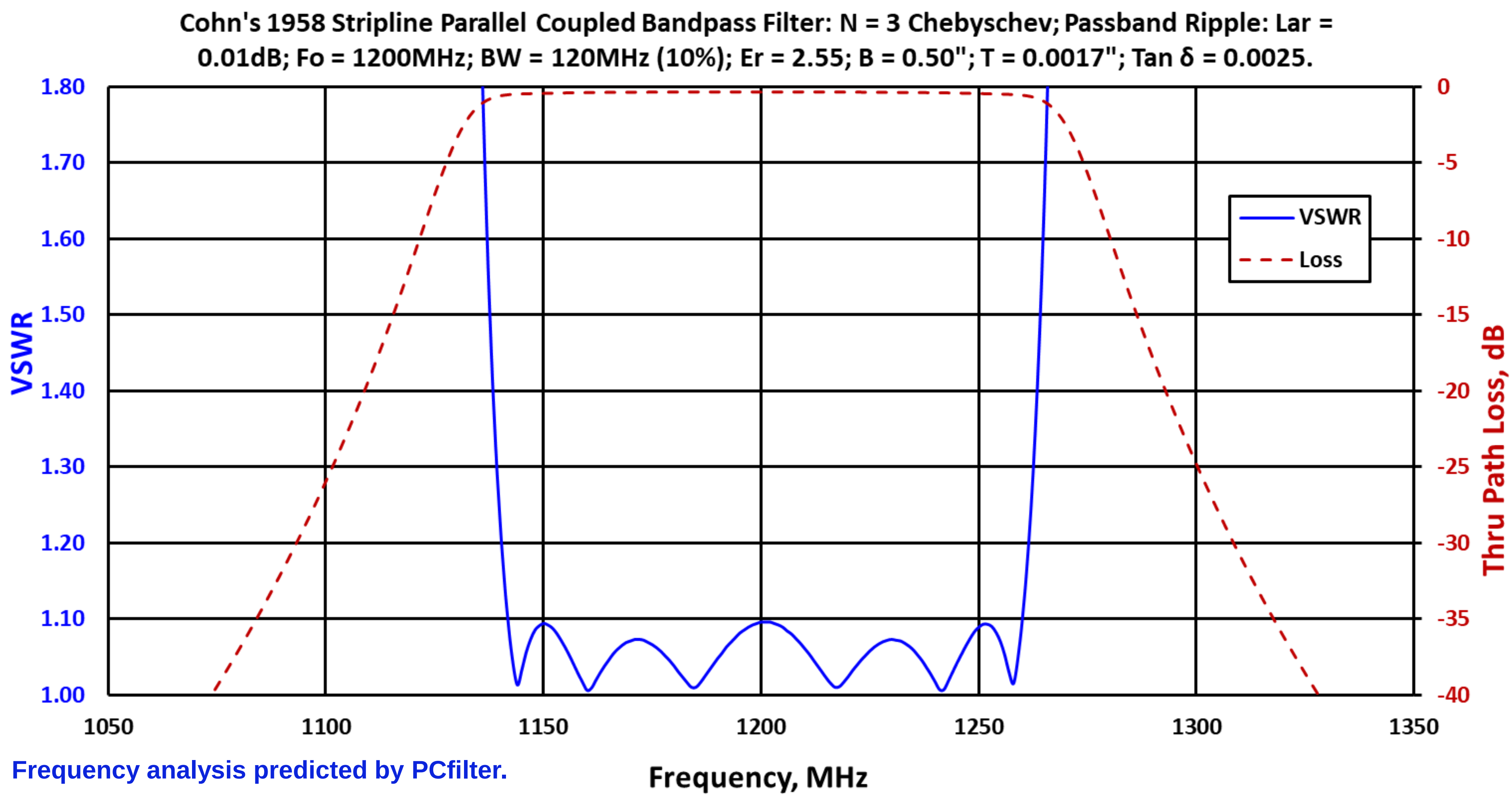
Total Length of your Bandpass Filter = 10.7782 inches.

Note: Foreshorten resonator length by: d = 0.165B = 0.165*0.5" = 0.0825"

Example: 6-pole Stripline Bandpass Filter

Parallel Coupled Bandpass Filter: Frequency Analysis Results

Parallel-Coupled Transmission-Line Resonator Filters, S.B. Cohn, IRE, MTT-6, April 1958.



Cohn's 1958 Stripline Parallel Coupled Bandpass Filter: N = 3 Chebyschev; Passband Ripple: Lar = 0.01dB; Fo = 1200MHz; BW = 120MHz (10%); Er = 2.55; B = 0.50"; T = 0.0017"; Tan δ = 0.0025.

Frequency analysis predicted by PCfilter.

Example: 3-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Synthesis of Dimensional Data

Design Techniques for Bandpass Filters Using Edge-Coupled Microstrip Lines on Fused Silica, W.H. Childs, IEEE MTT Symposium, July 1976.

PCfilter (v. 1.3) Date: 5/29/2017 at 13: 3:54Hours

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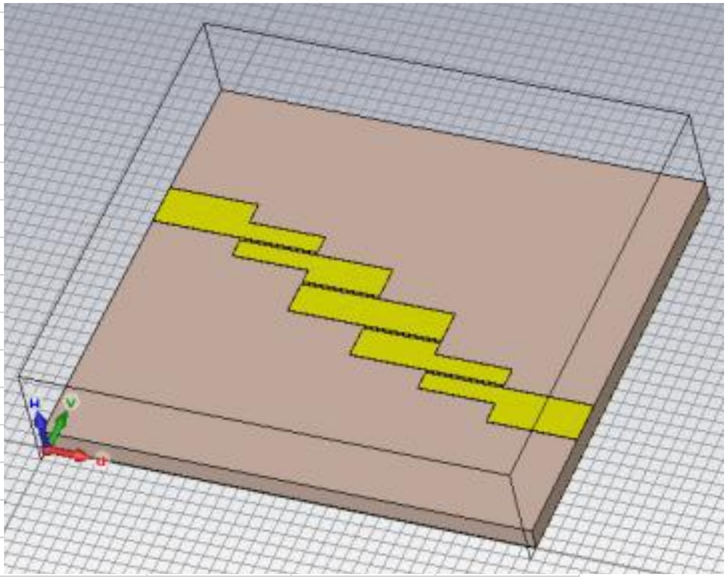
RF/Microwave Computer-Aided Engineering Design Data For
Multi-Section Parallel Coupled Line Bandpass Filters.

SYNTHESIS of Physical Dimensions for your Parallel Coupled
Line Bandpass Filter results in the following design data:

Flow = 11500.000 MHz Response = Tchebyscheff
Fo = 11950.000 MHz # of Poles = 3
Fhigh= 12400.000 MHz Ripple (Am) = 0.200 dB
BW = 900.000 MHz Zo of System = 50.00 Ohms
Er = 3.800 Construction = Microstrip
H = 0.015 inches Strip Thick = 0.0007 inches



				Resonator	Childs Dimensions, Inches			Error = Childs - PCfilter, Inch		
Section (K)	Width: W Inches	Section (K,K+1)	Spacing: S Inches	Length, Inches	Width: W	Gap: S	Length: L	Delta W	Delta S	Delta L
1	**0.0242**	0 1	**0.0040**	**0.1442**	0.0255	0.0033	0.1385	0.0013	-0.0007	-0.0057
2	**0.0298**	1 2	**0.0196**	**0.1429**	0.0315	0.0180	0.1365	0.0017	-0.0016	-0.0064
3	**0.0298**	2 3	**0.0196**	**0.1429**	0.0315	0.0180	0.1365	0.0017	-0.0016	-0.0064
4	**0.0242**	3 4	**0.0040**	**0.1442**	0.0255	0.0033	0.1385	0.0013	-0.0007	-0.0057

Total Length of your Bandpass Filter = 0.5741 inches.

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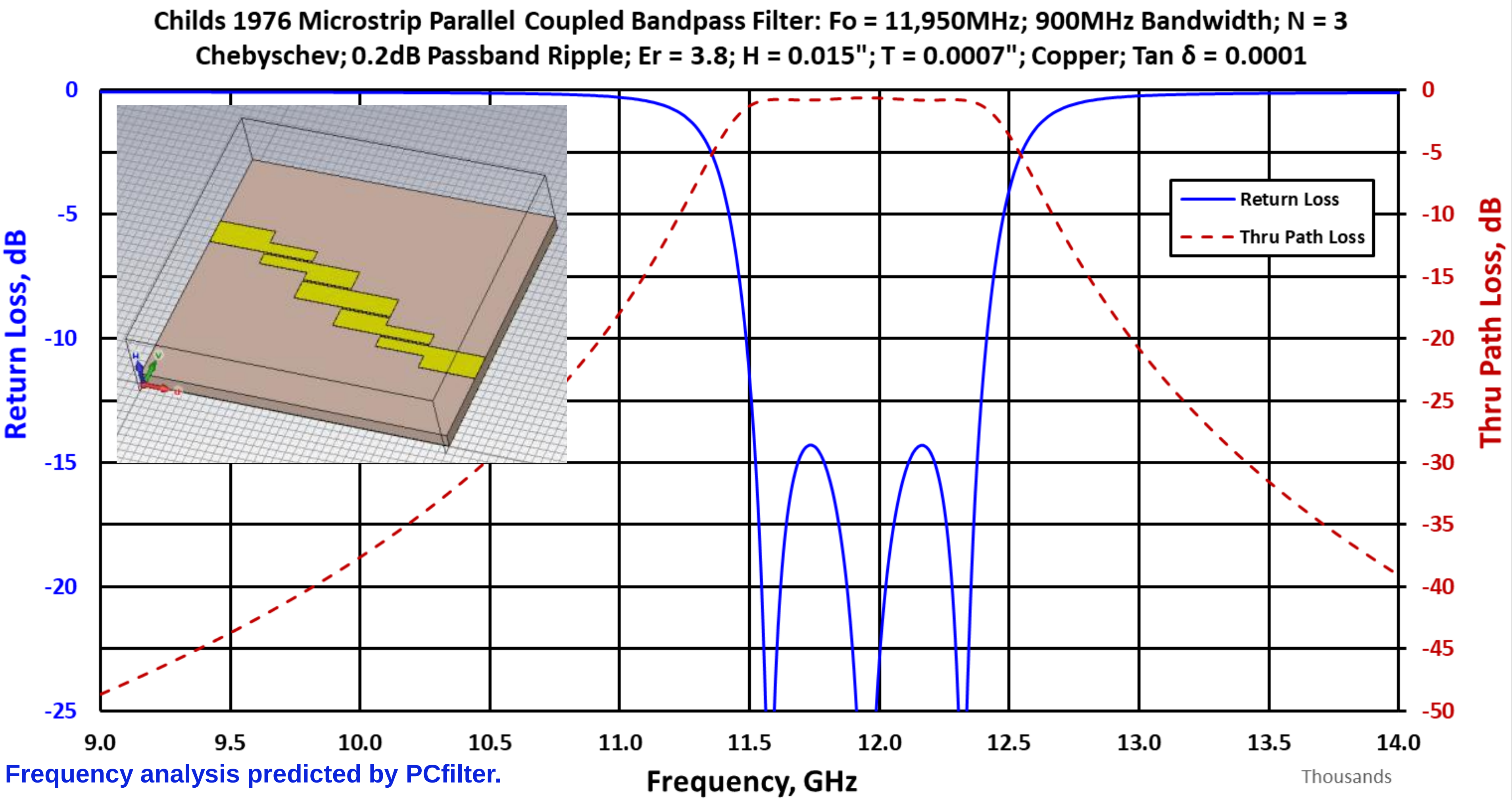
Example: 3-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Frequency Analysis Results

Design Techniques for Bandpass Filters Using Edge-Coupled Microstrip Lines on Fused Silica, W.H. Childs, IEEE MTT Symposium, July 1976.



Childs 1976 Microstrip Parallel Coupled Bandpass Filter: Fo = 11,950MHz; 900MHz Bandwidth; N = 3 Chebyschev; 0.2dB Passband Ripple; Er = 3.8; H = 0.015"; T = 0.0007"; Copper; Tan δ = 0.0001

Frequency analysis predicted by PCfilter.

Example: 5-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Synthesis of Dimensional Data

Microstrip Filters for RF/Microwave Applications, J. Hong and M.J. Lancaster, John Wiley & Sons, 2001, Page 127.

PCfilter (v. 1.3) Date: 5/29/2017 at 12:15:34Hours

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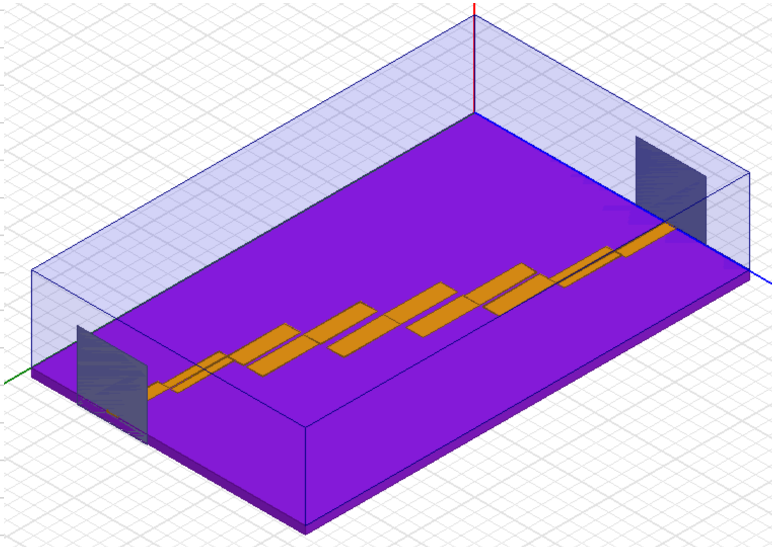
RF/Microwave Computer-Aided Engineering Design Data For
Multi-Section Parallel Coupled Line Bandpass Filters.

SYNTHESIS of Physical Dimensions for your Parallel Coupled
Line Bandpass Filter results in the following design data:

Flow = 9250.000 MHz Response = Tchebyscheff
Fo = 10000.000 MHz # of Poles = 5
Fhigh= 10750.000 MHz Ripple (Am) = 0.100 dB
BW = 1500.000 MHz Zo of System= 50.00 Ohms
Er = 10.200 Construction = Microstrip
H = 0.025 inches Strip Thick = 0.0002 inches

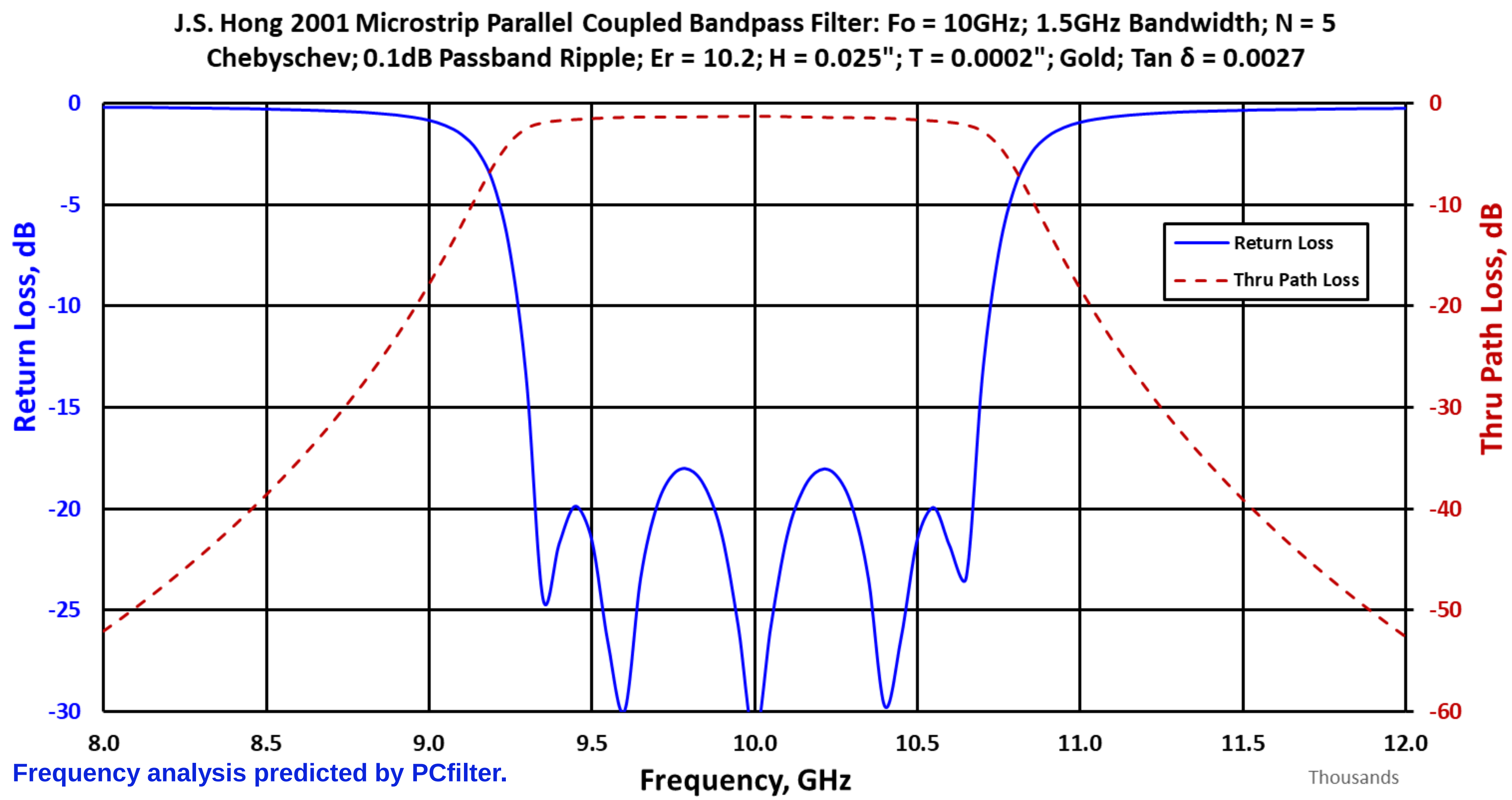


				Resonator	Hong2001 Dimensions, Inches			Error = Hong - PCfilter, Inch		
Section (K)	Width: W Inches	Section (K,K+1)	Spacing: S Inches	Length Inches	Width: W	Gap: S	Length: L	Delta W	Delta S	Delta L
--------	--------	--------	------	--------						
1	**0.0136**	0 1	**0.0059**	**0.1124**	0.0152	0.0063	0.1123	0.0016	0.0004	-0.0001
2	**0.0206**	1 2	**0.0194**	**0.1109**	0.0226	0.0213	0.1091	0.002	0.0019	-0.0018
3	**0.0214**	2 3	**0.0257**	**0.1107**	0.0234	0.0287	0.1085	0.002	0.003	-0.0022
4	**0.0214**	3 4	**0.0257**	**0.1107**	0.0234	0.0287	0.1085	0.002	0.003	-0.0022
5	**0.0206**	4 5	**0.0194**	**0.1109**	0.0226	0.0213	0.1091	0.002	0.0019	-0.0018
6	**0.0136**	5 6	**0.0059**	**0.1124**	0.0152	0.0063	0.1123	0.0016	0.0004	-0.0001

Example: 5-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Frequency Analysis Results

Microstrip Filters for RF/Microwave Applications, J. Hong and M.J. Lancaster, John Wiley & Sons, 2001, Page 127.

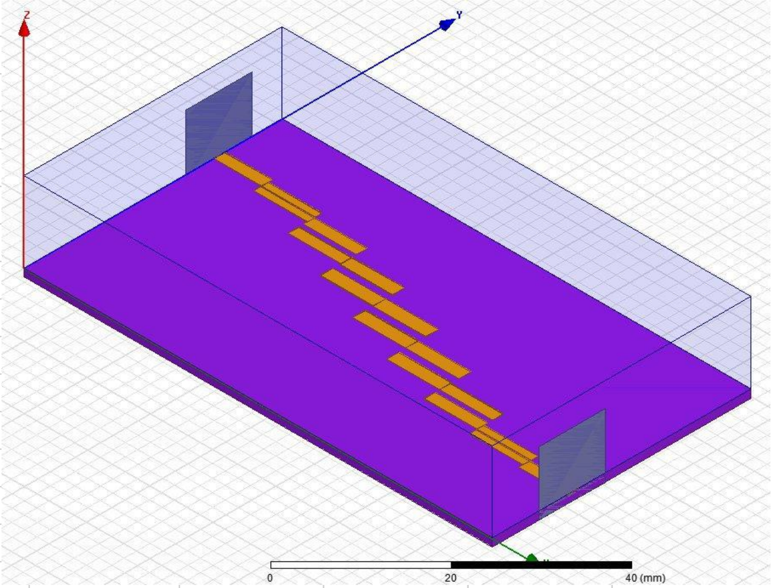


Frequency analysis predicted by PCfilter.

Example: 6-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Synthesis of Dimensional Data

Broadbanding Microstrip Filters Using Capacitive Compensation, I. J. Bahl, Applied Microwave, Aug/Sept 1989 (2 designs).



PCfilter (v. 1.3) Date: 5/29/2017 at 11:36: 9Hours

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RF/Microwave Computer-Aided Engineering Design Data For
Multi-Section Parallel Coupled Line Bandpass Filters.

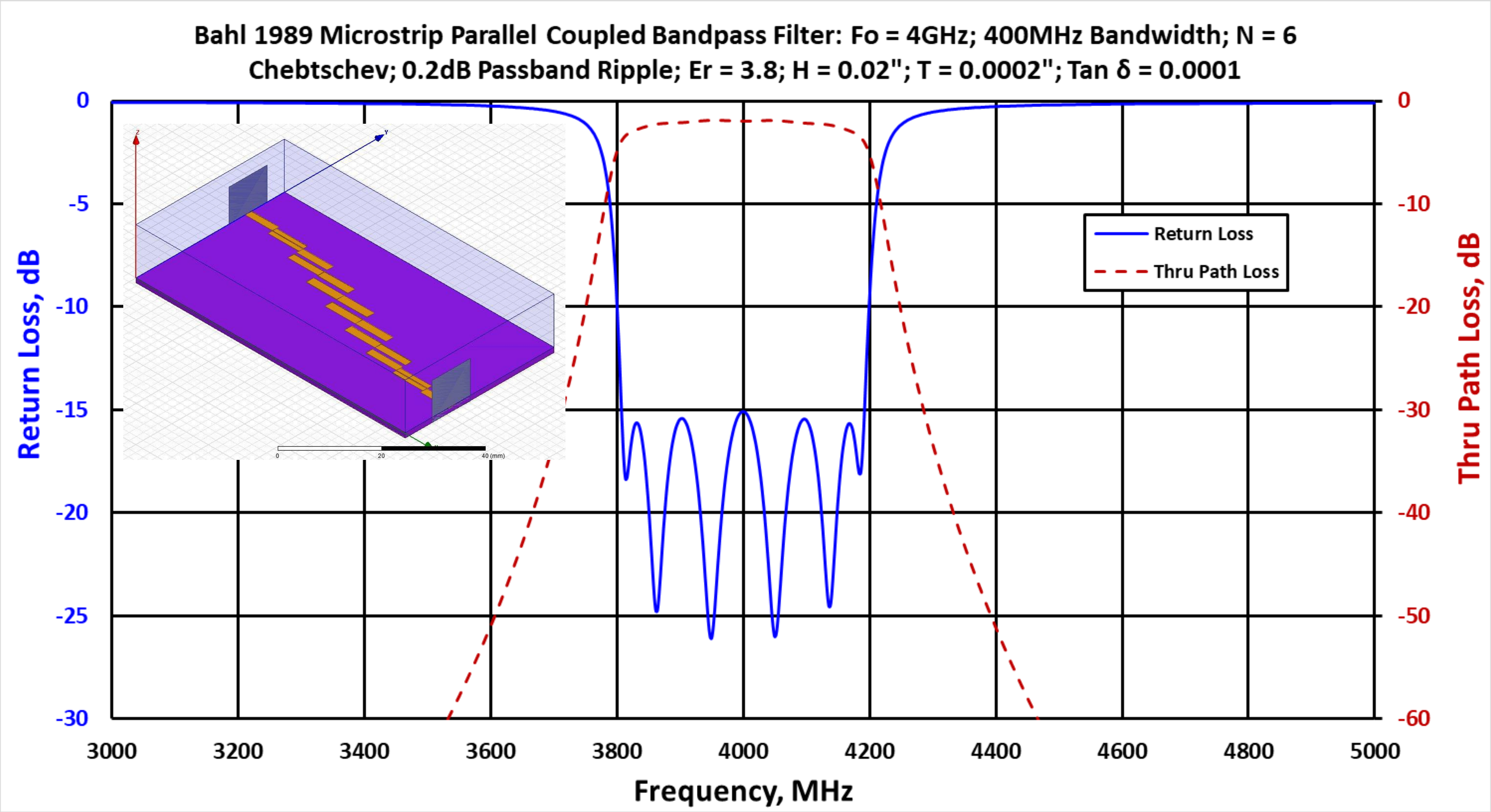
SYNTHESIS of Physical Dimensions for your Parallel Coupled
Line Bandpass Filter results in the following design data:

Flow = 3800.000 MHz Response = Tchebyscheff
Fo = 4000.000 MHz # of Poles = 6
Fhigh = 4200.000 MHz Ripple (Am) = 0.200 dB
BW = 400.000 MHz Zo of System= 50.00 Ohms
Er = 3.800 Construction = Microstrip
H = 0.020 inches Strip Thick = 0.0002 inches

Section	Width: W	Section	Spacing: S	Resonator Length	Bahl6 Dimensions, Inches			Error = Bahl6 - PCfilter, Inch		
(K)	**Inches**	(K,K+1)	**Inches**	**Inches**	**Width: W**	**Gap: S**	**Length: L**	**Delta W**	**Delta S**	**Delta L**
--------	--------	--------	------	--------						
1	**0.0316**	0 1	**0.0042**	**0.4335**	**0.0317**	**0.0043**	**0.4417**	**0.0001**	**0.0001**	**0.0082**
2	**0.0401**	1 2	**0.0216**	**0.4294**	**0.0403**	**0.0215**	**0.4327**	**0.0002**	**-0.0001**	**0.0033**
3	**0.0406**	2 3	**0.0280**	**0.4291**	**0.0407**	**0.0274**	**0.4319**	**0.0001**	**-0.0006**	**0.0028**
4	**0.0406**	3 4	**0.0289**	**0.4290**	**0.0408**	**0.0281**	**0.4319**	**0.0002**	**-0.0008**	**0.0029**
5	**0.0406**	4 5	**0.0280**	**0.4291**	**0.0407**	**0.0274**	**0.4319**	**0.0001**	**-0.0006**	**0.0028**
6	**0.0401**	5 6	**0.0216**	**0.4294**	**0.0403**	**0.0215**	**0.4327**	**0.0002**	**-0.0001**	**0.0033**
7	**0.0316**	6 7	**0.0042**	**0.4335**	**0.0317**	**0.0043**	**0.4417**	**0.0001**	**0.0001**	**0.0082**

Example: 6-pole Microstrip Bandpass Filter

Parallel Coupled Bandpass Filter: Frequency Analysis Results



Frequency analysis predicted by PCfilter.

Summary
Parallel Coupled Bandpass Filters

Parallel Coupled Bandpass Filters are effective means to allow desired RF signals to pass-thru a communications circuit, while attenuating RF signals operating at out-of-passband frequencies.

A design process has been presented for the electrical and dimensional design of Parallel Coupled Bandpass Filters constructed in microstrip or in stripline transmission lines.

Atlanta RF's software product: PCfilter is presented, which offers the User with a valuable and viable design aid for the electrical synthesis, dimensional synthesis and frequency analysis of Parallel Coupled Bandpass Filters constructed in microstrip or in stripline. As with all computer-generated RF circuit designs, the User is encouraged to confirm the physical design generated by PCfilter in an electromagnetic simulator, then adjust physical dimensions (if needed), prior to manufacturing the filter.

Atlanta RF, LLC

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