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# AN APPROXIMATE DESIGN TECHNIQUE FOR MICROSTRIP PARALLEL-COUPLED BAND-PASS MICROWAVE FILTER

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## ABSTRACT

An approximate design technique is presented for parallel coupled bandpass filter in microstrip form. Both computational and graphical forms together with simulation software are used to optimize the design. Due to the use of several graphs and approximations, an average of 3% deviation from the computed to the final simulated design was noticed.

## INTRODUCTION

Bandpass filters can be implemented using lumped components or by distributed elements. Printed circuit techniques are commonly used to implement microwave filters. This is because lumped components are very hard to come by and tends to be very expensive at these frequencies.

In microwave bandpass filter designs, a microstrip line terminated in either open or short circuit can be used as a resonator. Distributed implementations of bandpass filters come in many forms. Some of the popular ones are the edge-coupled, parallel coupled, combline, interdigital, hairpin, and others.

For an edge-coupled bandpass filter, each section is a quarter-wavelength long resulting to a half-wavelength long resonator. Spurious occurs at $2f_o$ and re-entrance at $3f_o$.

## LOWPASS TO BANDPASS TRANSFORMATION

Preliminary computations are required before we can proceed with the actual design of the proposed microstrip bandpass filter. The design procedure for the bandpass filter to be described in the next section is based on the lowpass prototype circuit values and response curves. Figure 1a. shows a typical lowpass filter response curve while Figure 1b. shows the response curve for bandpass filters. In order for us to use the lowpass filter prototypes, some form of the transformation has to take place. The transformation process is as follows:

1. fractional bandwidth

$$\delta = \frac{\omega_2 - \omega_1}{\omega_0}$$

2. frequency transformation

$$\frac{\omega'}{\omega_1'} = \frac{2}{\delta}\left(\frac{\omega_\alpha - \omega_0}{\omega_0}\right)$$

In Matthaei[1] , numerous graphs are provided for different response curves that gives the number of elements needed at a given amount of attenuation at a given frequency. Likewise tables are provided to obtain the prototype element values.

Note that some of the sources of these graphs indicate

$$\left|\frac{\omega'}{\omega_1'}\right| - 1$$

instead of

$$\left|\frac{\omega_1'}{\omega'}\right|$$

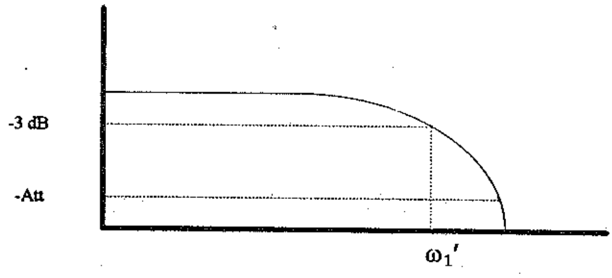


Figure 1a. Low-pass prototype response

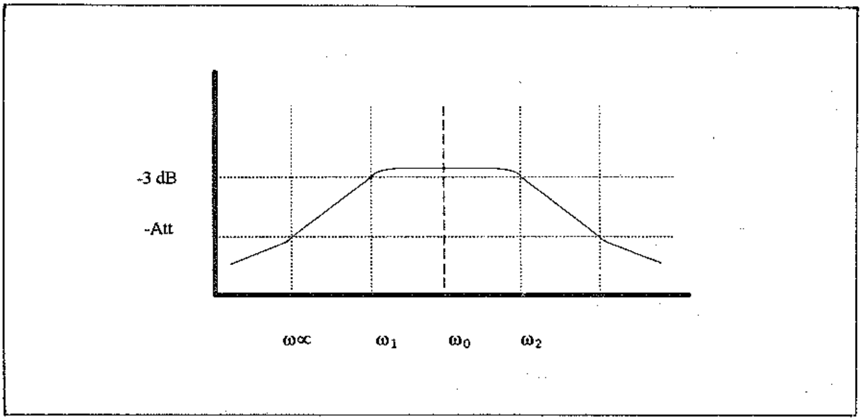


Figure 1b. Bandpass response curve

## PARALLEL-COUPLED BANDPASS FILTER

Two printed circuit lines in close proximity and parallel to each other are called coupled lines. Coupled lines are extensively used for directional couplers, matching networks and filters. For coupled lines, resonance can be achieved by making their lengths equal to or a multiple of λg/2. Maximum coupling for microstrip couplers occurs when the length of the coupled region is λg/4. Figure 2 shows the general layout of a microstrip parallel-coupled bandpass filter.

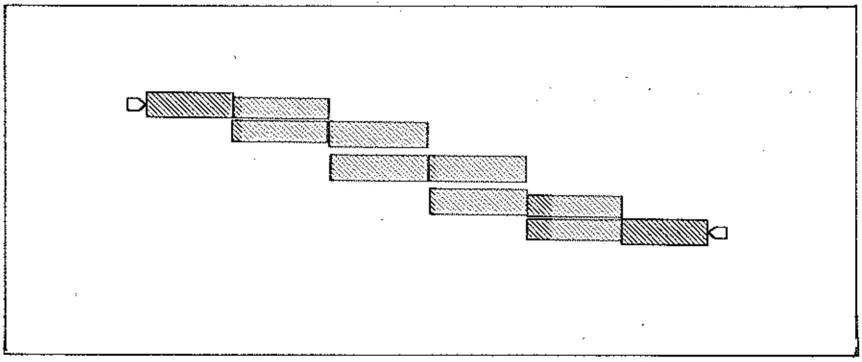


Figure 2. Parallel-coupled microstrip filter

### Design Procedures

1. Formulate the specifications
2. Using the low-pass to band-pass transformation, obtain the number of elements and its

prototype values.

3. Calculate the inventer admittance (J) using the formulas below

For the first coupling structure

$$\frac{J_{01}}{Y_0} = \left(\frac{\pi\delta}{2g_0g_1}\right)^{1/2}$$

For the intermediate coupling structures

$$\frac{J_{i,i+1}}{Y_0}\bigg|_{i=1\,\mathrm{to}\,n-1} = \frac{\pi\delta}{2\omega'_c\left(g_ig_{i+1}\right)^{1/2}}$$

For the final coupling structure

$$\frac{J_{n,n+1}}{Y_0}\bigg| = \left(\frac{\pi\delta}{2g_ng_{n+1}}\right)^{1/2}$$

4. Compute for the even and odd coupled-line impedance $Z_{oo}$ and $Z_{oe}$

$$\left(Z_{0_o}\right)_{i,i+1} = Z_0\left(1 - J_{i,,i+1}Z_0 + J_{i,i+1}{}^2Z_0{}^2\right)$$

$$\left(Z_{0_e}\right)_{i,i+1} = Z_0\left(1 - J_{i,,i+1}Z_0 + J_{i,i+1}{}^2Z_0{}^2\right)$$

where Zo is the system characteristic impedance

5. Using approximate synthesis technique by Akhtarzad et al.,[3]

a. Determine the shape ratios for the equivalent single microstrip lines

$$Z_{0so} = Z_{0so}/2$$
$$Z_{0so} = Z_{0e}/2$$

a. $Z_0 > \left(44 - 2\varepsilon_\tau\right)\Omega$

$$X = \frac{Z_0\left[2\left(\varepsilon_\tau + 1\right)\right]^{1/2}}{119.9} = \frac{1}{2}\left(\frac{\varepsilon_\tau - 1}{\varepsilon_\tau + 1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_\tau}\ln\frac{4}{\pi}\right)$$

$$\frac{w}{h} = \left(\frac{\exp X}{8} - \frac{1}{4\exp X}\right)^{-1}$$

b. $Z_0 > (44 - 2\varepsilon_r)\Omega$

$$X = \frac{59.95\pi^2}{Z_0\varepsilon_r^{1/2}}$$

$$\frac{w}{h} = \frac{2}{\pi}[(x-1) - \ln(2x-1)] + \frac{\varepsilon_r - 1}{\pi\varepsilon_r}\left[\ln(x-1) + .293 - \frac{.517}{\varepsilon_r}\right]$$

The w/h and s/h can now be obtained from the graph provided by Akhtarzad *et al.*[3]

6. Coupled-region length

From the discussions earlier, maximum coupling occurs if the coupled region is a quarter of the midband wavelength.

Using Bryant and Weiss' curves, we can now obtain the air spaced characteristic impedance $Z_{oAe}$ and $Z_{oAo}$.

Using,

$$\lambda_{ge} \cong \frac{300Z_{oe}}{FZ_{oAe}} \text{ mm}$$

$$\lambda_{go} \cong \frac{300Z_{oo}}{FZ_{oAo}} \text{ mm}$$

where F = Ghz

Taking the mean value of the even and odd wavelengths,

$$\lambda = \frac{\lambda_{ge} + \lambda_{go}}{2} \quad \text{and} \quad \frac{\lambda}{4} = \frac{\lambda_m}{4}$$

7. Simulation software is used to optimize the design.

## WORKED OUT EXAMPLE

1. Specifications

fo = 1.7 Ghz
f1 = 1.65 Ghz
f2 = 1.75 Ghz
fα = 1.425 Ghz
- Chebyshev response with 0.01db ripple and 24db min attenuation at fα

2. Fractional bandwidth

$$= \frac{1.75 - 1.65}{1.7} = 0.0588$$

3. Lowpass prototype

$$\frac{2}{0.0588}\left(\frac{1.425 - 1.7}{1.7}\right) = -5.5$$

$$|-5.5| - 1 = 4.5$$

Based on the graph,

n = 3, Att = 30dB

$g_o = 1$
$g_1 = 0.6291$
$g_2 = 0.9702$
$g_3 = 1.6291$
$g_4 = 1$

4. J computations

For the first coupling structure,

$$\frac{J_{01}}{Y_0} = 0.3832$$

Intermediate structures,

$$\frac{J_{12}}{Y_0} = 0.1182$$

$$\frac{J_{23}}{Y_0} = 0.1182$$

Final coupling structure,

$$\frac{J_{34}}{Y_0} = 0.3832$$

5. Odd and Even mode impedance at 50 Ω Input/output feed

Even mode,
$Z_{oe\ 01} = 76.5021$
$Z_{oe\ 12} = 56.6086$
$Z_{oe\ 23} = 56.6086$
$Z_{oe\ 34} = 76.5021$

Odd mode,

$Z_{Oo\ 01} = 38.1821$
$Z_{Oo\ 12} = 44.7886$
$Z_{Oo\ 23} = 44.7886$
$Z_{Oo\ 34} = 38.1821$

6. Using Duroid RT /6010

$\varepsilon_r = 10.2$
$h = 25$ mil
$t = 1.4$ mil

7. Using Akhtarzad et.al.[3]

$J=0;$

$Z_{ose} = 38.2510; \; Z_{oso} = 19.0910$

$$\frac{w}{h}_{se} = 1.55$$

$$\frac{w}{h}_{so} = 4.42$$

$J=1;$

$Z_{ose} = 28.3043; \; Z_{oso} = 22.3943$

$$\frac{w}{h}_{se} = 2.52$$

$$\frac{w}{h}_{so} = 3.53$$

$J=2;$

$Z_{ose} = 28.3043; \; Z_{oso} = 22.3943$

$$\frac{w}{h}_{se} = 2.52$$

$$\frac{w}{h}_{so} = 3.53$$

$J=3;$

$Z_{ose} = 38.2510; \; Z_{oso} = 19.0910$

$$\frac{w}{h}_{se} = 1.55$$

$$\frac{w}{h}_{so} = 4.42$$

Using the graph provided by Akhtarzad et.al.

0;

$$\frac{w}{h} = 0.625 \; ; \; \frac{s}{h} = 0.1875$$

$w = 15.625$ mil ; $s = 4.6875$ mil

1;

$$\frac{w}{h} = 0.875 \; ; \; \frac{s}{h} = 1$$

$w = 21.875$ mil ; $s = 25$

2;

* same as 1

3;

* same as 0

8. Using Bryant and Weiss curves ($\varepsilon_r = 1$),

0,

$Z_{OAo} = 73$

$Z_{OAe} = 220$

$\lambda_m = (64.29 + 81.18)/2 = 72.73$

$\lambda/4 = 18.18$ mm $= 715$ mil

1,

$Z_{OAo} = 95$

$Z_{OAe} = 170$

$\lambda m = (64.45 + 71.85)/2 = 68.15$

$\lambda/4 = 17.04$ mm $= 670$ mil

2,

* same as 1

3,

* same as 0

9. Using simulation software, the final filter is shown in Figure 3

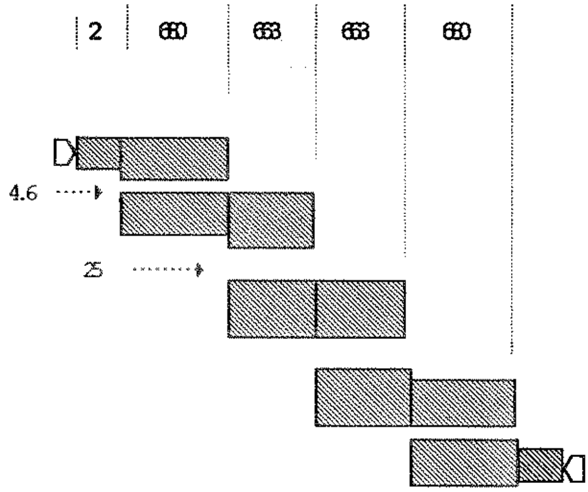
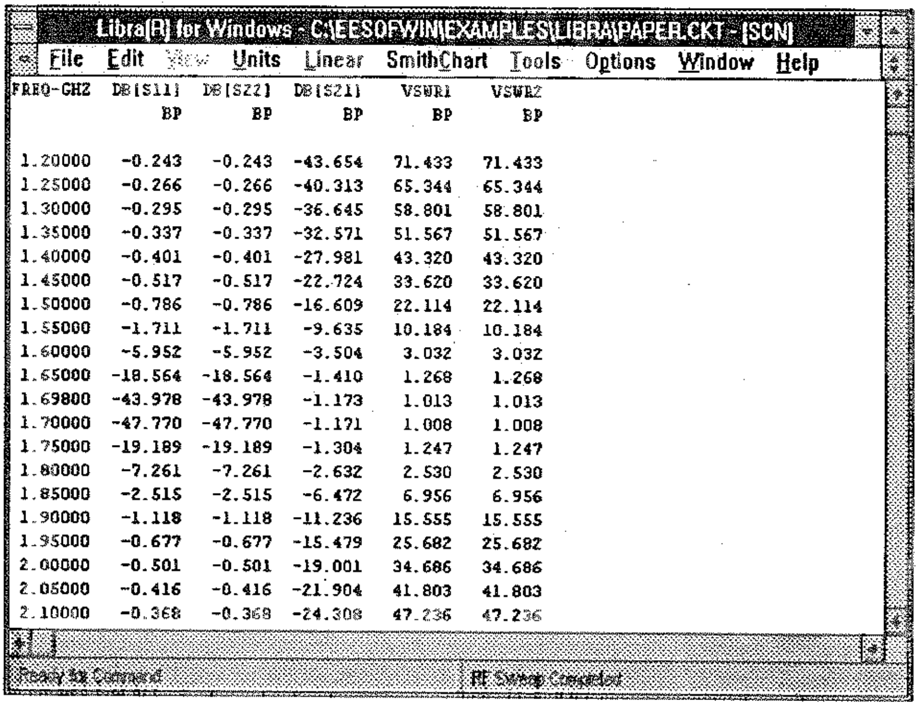


Figure 3. B.P. Filter realization

Eesof simulation results of the example filter as shown in Figures 4,5, and 6.



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FREQ-GHZ  DB[S11]  DB[S22]  DB[S21]    VSWR1    VSWR2
               BP       BP       BP       BP       BP


 1.20000   -0.243   -0.243  -43.654   71.433   71.433
 1.25000   -0.266   -0.266  -40.313   65.344   65.344
 1.30000   -0.295   -0.295  -36.645   58.801   58.801
 1.35000   -0.337   -0.337  -32.571   51.567   51.567
 1.40000   -0.401   -0.401  -27.981   43.320   43.320
 1.45000   -0.517   -0.517  -22.724   33.620   33.620
 1.50000   -0.786   -0.786  -16.609   22.114   22.114
 1.55000   -1.711   -1.711   -9.635   10.184   10.184
 1.60000   -5.952   -5.952   -3.504    3.032    3.032
 1.65000  -18.564  -18.564   -1.410    1.268    1.268
 1.69800  -43.978  -43.978   -1.173    1.013    1.013
 1.70000  -47.770  -47.770   -1.171    1.008    1.008
 1.75000  -19.189  -19.189   -1.304    1.247    1.247
 1.80000   -7.261   -7.261   -2.632    2.530    2.530
 1.85000   -2.515   -2.515   -6.472    6.956    6.956
 1.90000   -1.118   -1.118  -11.236   15.555   15.555
 1.95000   -0.677   -0.677  -15.479   25.682   25.682
 2.00000   -0.501   -0.501  -19.001   34.686   34.686
 2.05000   -0.416   -0.416  -21.904   41.803   41.803
 2.10000   -0.368   -0.369  -24.308   47.236   47.236
```

Ready for Command

RF Sweep Completed

Figure 4. Screen Output Response

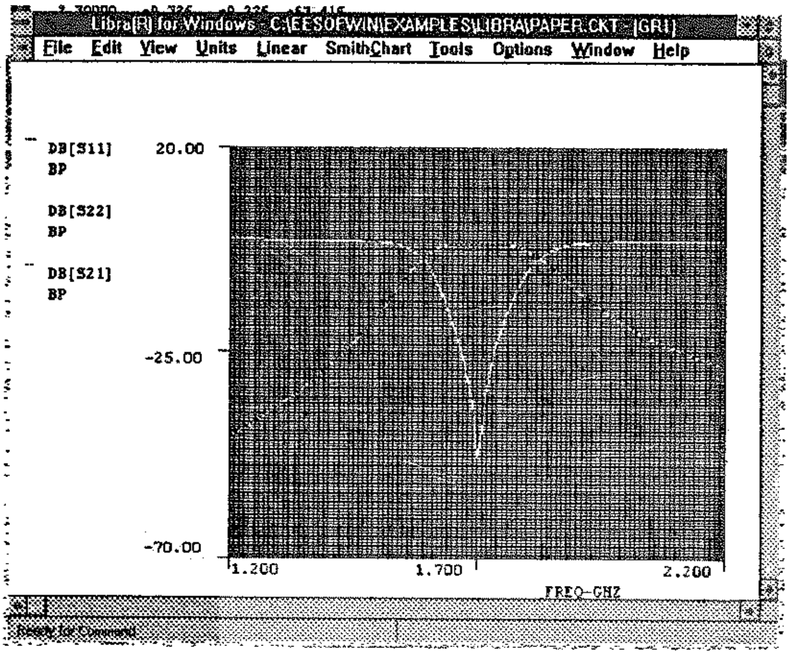

Figure 5. Bandpass Filter Response Curve

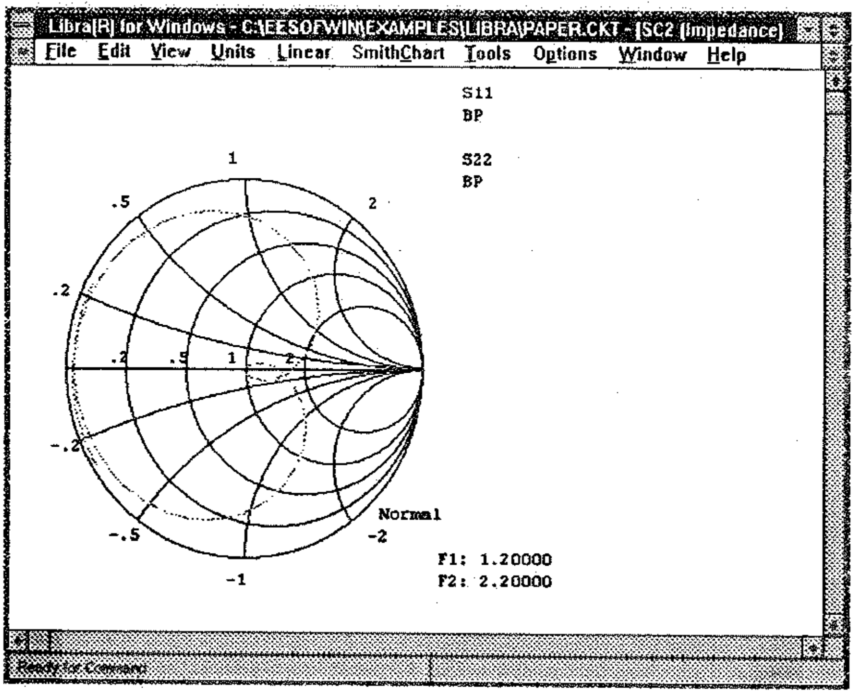

Figure 6. Input/Output Impedance Smith Chart

## CONCLUSION

The technique presented for the design of parallel-coupled microstrip bandpass filter were found to yield filter dimensions with an average of 3% error on the microstrip length from the simulated results. This error may be due to the approximations used on the equations and on the graphs. This paper merely suggests a fast and approximate technique to help the designer come up with an initial design. Simulation software is necessary to optimize the filter dimensions and response.

## REFERENCES

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