Fast Design and Optimization of Bandpass Tapped-Line Interdigital Filters Using GENESYS

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Abstract In this paper, a tapped-line interdigital filter with 10% bandwidth is proposed by using a novel method which combines interdigital filter design theory and GENESYS simulation. By using this methodology, the optimization time can be significantly reduced for fast design. The optimization of the filter, which takes only two iterations with 18 minutes, is substantially faster than the direct optimization, which requires four or more iterations with several hours. Furthermore, it has been proven that our simulation results demonstrate good agreement with previous work published.
Key words Bandpass filter, Tapped-line, Interdigital filter, Genesys.

1. Introduction

Tapped-line interdigital filters have advantages over conventional filter types (e.g. edge-coupled filters) because of the compact filter configurations. Two authors, Dishal[1] and Cristal[2], have described the realization methods of tapped-line interdigital filters. In a later paper, a method was developed using explicit design equations to design tapped-line interdigital filters, based on the theory of Cristal, Caspi and Adelman[3]. The schematic of this filter is depicted in Fig.1.
Design and optimization of tapped-line interdigital filters using electromagnetic (EM) field solvers have been greatly developed during the last decade. Nevertheless, simply designing and optimizing a tapped-line interdigital filter using an EM simulator costs a large amount of calculation time.
In this paper, we combine Caspi and Adelman's design theory and EM simulation to outline a very general, efficient, and accurate methodology for tapped-line interdigital filter design. In Section 2, we present the calculation formulae for tapped-line interdigital filters. Then, we use a Method of Moments (MoM) simulator GENESYS to optimize and simulate the filter configuration. In Section 3, we present a design example to check the feasibility of this methodology, and good results are achieved compared to the data given by Swanson[4]. Section 4 is the results and discussions of this methodology. Section 5 is the summary.

2. Design methodology

A. Design formulae

A bandpass filter specification generally includes the desired center frequency, fractional bandwidth, maximum insertion loss in the passband, and several required rejection levels in the stopbands.

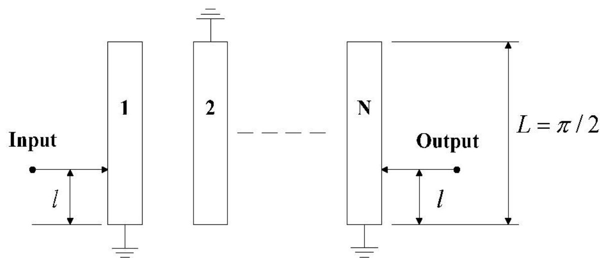

Fig. 1 Tapped-line interdigital filter

There will also be a specification on the minimum return loss in the passband. A return loss of 26.4 dB corresponds to a prototype ripple level of 0.01 dB and a return loss of 20.8 dB corresponds to a prototype ripple level of 0.036 dB[4].
For a Chebyshev prototype filter, once the prototype ripple has been determined, the filter order N can be estimated based on the graphs and equations in[5]. With both the ripple level and order N determined, we can get the normalized lowpass prototype g values in the corresponding tables. Table 1 lists the normalized g values for a Chebyshev lowpass prototype filter with 0.036 dB ripple level.

Table 1 Chebyshev lowpass prototype with 0.036 dB ripple level

N	g_0	g_1	g_2	g_3	g_4	g_5	g_6
2	1.000	0.632	0.526	1.199			
3	1.000	0.818	1.089	0.818	1.000		
4	1.000	0.898	1.284	1.541	0.749	1.119	
5	1.000	0.939	1.367	1.769	1.367	0.939	1.000

Once the ripple level and order N are known, we can use Caspi and Adelman's design equations to set the initial

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values of the filter configuration.

$$\theta_1 = (\pi / 2)(1 - FBW / 2) \quad (1)$$

$$h = 1 / (Z_S \tan\theta_1) \quad (2)$$

Where θ_1 is the electrical length of the resonator at the low edge of the frequency passband, FBW is the fractional bandwidth of the filter, and Z_S is the single-resonator line impedance (same for all resonators).

$$J_{j,j+1}|_{j=1,N-1} = h / (g_i g_{i+1})^{1/2} \quad (3)$$

$$Y_{j,j+1}|_{j=1,N-1} = J_{j,j+1} \sin(\theta_1) \quad (4)$$

$$\Phi = \sin^{-1}\left\{\left[Z_i h \sin^2\theta_1 / g_0 g_1\right]^{1/2}\right\} / (1 - FBW / 2) \quad (5)$$

Where Φ is the tapped input and output electrical length, and Z_i is the source and load impedance.

In the following steps, we will use equations to calculate the odd-mode impedance and even-mode impedance for the resonators.

For $j = 1$,

$$Z_{oe1} = 1 / (1 / Z_S - Y_{1,2}) \quad (6)$$

$$Z_{oo1} = 1 / (1 / Z_S + Y_{1,2}) \quad (7)$$

For $j = N - 1$,

$$Z_{oeN-1} = 1 / (1 / Z_S - Y_{N-1,N}) \quad (8)$$

$$Z_{ooN-1} = 1 / (1 / Z_S + Y_{N-1,N}) \quad (9)$$

For $j = 2$ to ($N - 2$),

$$Z_{oej} = 1 / (2 / Z_S - 1 / Z_{oej-1} - Y_{j-1,j} - Y_{j,j+1}) \quad (10)$$

$$Z_{ooj} = 1 / (2Y_{j,j+1} + 1 / Z_{oej}) \quad (11)$$

Where Z_{oej} and Z_{ooj}, respectively, are even-mode impedance and odd-mode impedance for the j th coupled resonators. Thus, the complete set of design formulae for the tapped-line interdigital filter is given by equations (1)-(11).

B. Design and optimization method using GENESYS

GENESYS is a powerful software of Agilent corporation which can provide efficient and accurate simulation and optimization for RF and Microwave application. Its distinguishing feature can allow a much faster design and optimization of microwave filters than other commercial simulators (e.g. ADS).

After obtaining the even and odd mode impedances values, we can get the initial values for resonator spacing (s) and width (w) by using TLine synthesis of GENESYS.

Then, we will optimize the filter. In order to save simulation time, we will use sweep evaluation in GENESYS to reduce the optimization range.

Finally, the filter layout will be simulated using Momentum GX of GENESYS, only two to three iterations are needed to obtain our desired results. In the last iteration, we will calculate microstrip with loss and set a finer grid to get more accurate results.

3. Tapped-line interdigital filter design

We choose a microstrip interdigital filter with the filter order $N = 5$, center frequency at 2.44 GHz, and a 10% fractional bandwidth for this example. The Chebyshev prototype filter ripple level is 0.036 dB.

In this design, a 25 mil thick alumina substrate with ε_r = 9.8, 1.18 mil thick of the microstrip and 13 mil via hole at one end of the resonator are used.

We choose single-resonator line impedance to be 50Ω .The source and load impedance is also 50Ω and g values can be obtained in Table 1. Then, we will calculate the even and odd mode impedances by using MATLAB software. The results are listed in Table 2.

Table 2 Even and odd mode impedances

Microstrip	Z_{oe}	Z_{oo}
1 and 2	53.72	46.76
2 and 3	52.66	47.60
3 and 4	52.66	47.60
4 and 5	53.72	46.76

With the even and odd mode impedances known, we can use TLine synthesis[6] to obtain s and w. We can also use LineCalc program[7] to get these values. The length (L) of the resonator is calculated as 12.10 mm. The tapped input and output electrical length (Φ) is calculated as 2.37 mm. The other results are listed in Table 3.

Table 3 Results of width and space of resonators

Microstrip	Z_{oe}	Z_{oo}	w (mm)	s (mm)
1 and 2	53.72	46.76	0.56	1.25
2 and 3	52.66	47.60	0.56	1.58
3 and 4	52.66	47.60	0.56	1.58
4 and 5	53.72	46.76	0.56	1.25

Then, we build a schematic for this tapped-line interdigital filter in GENESYS.

Because the tapping process reflects inductance into the end resonators, an extension in length of the first and last resonators is needed in order to compensate for the tapping process [8].

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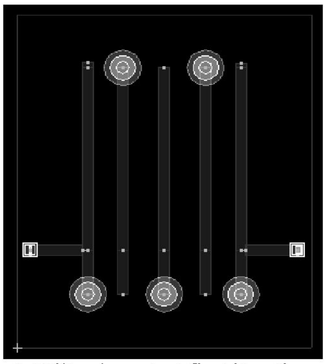
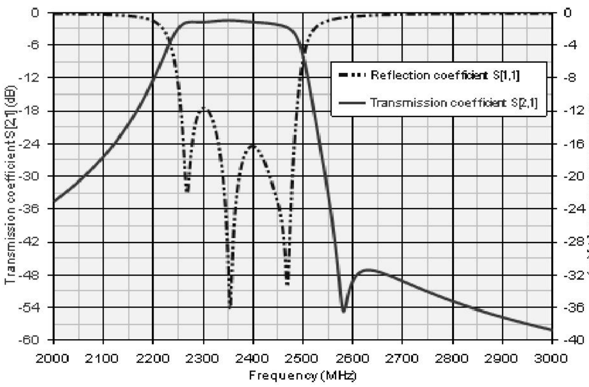
Thus, we add two pieces of microstrip, respectively, to the open-end of the first and last resonators.



(a)Filter layout at first iteration



(b) Simulated results for S_{11} and S_{21}

Fig. 1 The filter layout and performance simulation.

After using Momentum GX[9] simulator in GENESYS, the filter layout for simulation and the corresponding curves are presented in Fig. 2. From Fig. 2 it can be seen that the center frequency is shifted about 100MHz towards the lower part of the frequency passband. Thus, we will adjust the tapped length in order to fix the center frequency at 2.44 GHz.

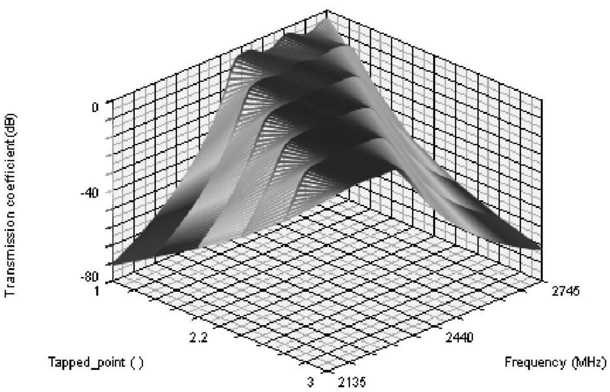


Fig. 2 Sweep evaluation results

Using sweep evaluation in GENESYS, we can predict the desired optimization range, which significantly reduces calculation time. We sweep the variable of tapped length from 1 mm to 3 mm. Fig. 3 shows the sweep evaluation results. Observing Fig. 3, we find the center frequency shifts from lower part to higher part of the passband as the tapped length reduces. Therefore, optimization range for tapped length is fixed from 1.5 mm to 2.37 mm.

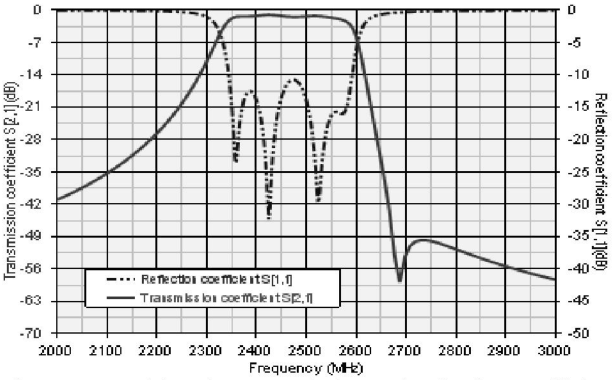


Fig. 3 Second iteration transmission and reflection coefficient curves.

After the second iteration optimization, the values of all the design variables are listed in Table 4.

Table 4 Second iteration optimization results. Units are mm.

Tapped length	w	s_1	s_2	L	L_a	L_b
1.99	0.56	1.28	1.62	11.64	0.28	0.25

The second iteration transmission and reflection coefficient curves are presented in Fig. 4.

4. Results and discussions

In the case of this tapped-line interdigital filter, good agreement is achieved in comparison to previously published results, especially the data reported by Swanson[4]. For the equal ripple bandwidth, 251 MHz bandwidth is obtained with 2.87% deviation as compared to 253 MHz bandwidth with 3.70% deviation. The insertion loss at 2.44 GHz is 1.11 dB as compared to 1.21 dB. Furthermore, we obtain a steeper upper stopband with insertion loss 58.8 dB at 2.68 GHz.

5. Conclusion

This paper combines Caspi and Adelman's design theory and GENESYS optimization to generate a fast and accurate methodology for tapped-line interdigital filter design. Caspi and Adelman's explicit equations are used to obtain good starting values for EM simulation. GENESYS simulation provides us an efficient tool which takes only 18 minutes for two iterations optimization, substantially faster than several hours' simulation for four iterations. By comparison with

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previously published results, good agreement is achieved and design validity is verified. Obviously, it shortens design cycle.

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References

[1] M. Dishal, A simple design procedure for small percentage bandwidth round-rod interdigital filters. IEEE Trans MTT, 1965, 13(5): 696-698.

[2] E. G.. Cristal, Tapped-line coupled transmission lines with applications to interdigital and combline filter. IEEE Trans MTT, 1975, 23(12): 1007-1012.

[3] S. Caspi, J. Adelman, Design of combline and interdigital filters with tapped-line input. IEEE Trans MTT, 1988, 36(4): 759-763.

[4] G.. Daniel Swanson, Jr, Narrow-band microwave filter design. Microwave J, 2007, 8(5): 105-114.

[5] G.. L. Matthaei, L.Young, and E.M.T Jones, Microwave filters, Impedance-Matching Networks and Coupling Structures. New York: McGraw-Hill, 1964, 85-95.

[6] Agilent Corporation, TLine synthesis, GENESYS version 2008.01 SP1.

[7] Agilent Corporation, LineCalc program, Advanced Design System version 2006A.

[8] R. Rhea, HF filter design and computer simulation. Atlanta, GA: Noble Publishing, 1994

[9] Agilent Corporation, Momentum GX, GENESYS version 2008.01 SP1.

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