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PRACTICAL BROADBAND MICROSTRIP FILTER DESIGN AND IMPLEMENTATION METHOD

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ABSTRACT

Broadband microstrip filter operating within 1.5GHz bandwidth at UHF range for RF communication systems has been designed, simulated, and implemented using a practical network parameter method. The design has been performed using the network parameter method with ABCD parameters, which simplified the analysis significantly. The analytical, simulated and measured results have been compared and excellent agreement is observed. It has been shown that the network parameter method such as the one presented in this paper can be used to design and implement broadband microstrip filters with high accuracy.

Keywords: *Microstrip, filter, ABCD, network parameters, S Parameters, Sonnet.*

1. INTRODUCTION

RF and microwave circuit designers have been using CAD tools to design better performing circuits and integrated systems. Electronic design automation (EDA) and electromagnetic (EM) analysis software are some of tools that are commonly used to design and optimize RF sub-component and systems.

Modern RF and microwave communication systems, specifically mobile and satellite communications require high-performance narrow-band filters with low insertion loss and high selectivity together with linear phase. In wireless systems, indispensable requirements are the realization of robust filters for frequency selection circuits in power amplifiers, mixers, and low noise amplifiers. Filters have important implications for impedance matching and frequency selectivity, which greatly impact RF receiver performance such as noise, power consumption, and gain [1-2]. As technology matures, new filter designs are developed and more robust filter models are used for the analysis and design of microstrip filters [3-4] to meet these requirements.

In this paper, a practical analytical method using ABCD network parameters to design a broadband microstrip filter is presented. Microstrip filter is designed using 5th order Chebyshev filter topology to meet with the specifications, and simulated with planar electromagnetic simulator, Sonnet V12.56. Comparison between analytical, simulated, and measured results has been made and agreement is observed on all the values.

2. DESIGN TECHNIQUES

The design specifications for a microstrip low pass filter (LPF) on Alumina substrate is given in [5] and illustrated in Table I. In the following sub-section, practical analytical method will be presented using ABCD network parameters.

TABLE I. DESIGN SPECIFICATIONS

Frequency (GHz)	Design Criteria
0.5-2	S21>-3dB
3	S21=-20dB
3.1-3.5	S21>-20dB

2.1 ABCD Network Parameters in Filter Design

In general, RF/Microwave filters and filter components can be represented using a two-port network shown in Fig. 1. Two-port network is described by a set of four independent parameters, which can be related to voltage and current at any ports of the network. As a result two-port network can be treated as a black box modeled by the relationships between the four variables. There exist six different ways to describe the relationships between these

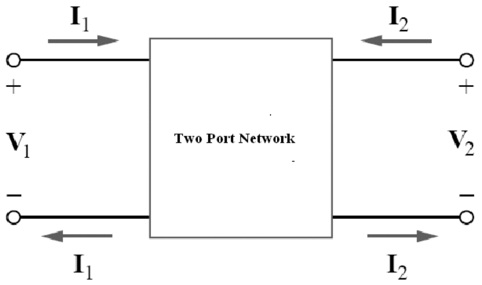


Fig. 1 Two-port network representation

variables, depending on which two of the four variables are given, while the other two can always be derived. All voltages and currents are complex variables and represented by phasors containing both magnitude and phase.

Two-port networks are characterized by using two port network parameters such as Z-impedance, Y-admittance, h-hybrid, and ABCD. They are usually expressed in matrix notation and they establish relations between the following parameters: Input voltage V_1, output voltage V_2, input current I_1, and output current I_2. ABCD parameters are preferred over others when the network contains cascaded elements as shown in Fig. 2. When this condition exists, the overall ABCD parameter of the network is found by simply multiplication of individual ABCD parameter of each cascaded component. ABCD parameter of individual network in Fig. 2 can be found by using the relation given in (1).

$$\begin{Bmatrix} v_1 \\ i_1 \end{Bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{Bmatrix} v_2 \\ -i_2 \end{Bmatrix} \tag{1}$$

The overall ABCD parameters for the cascaded network is then found using

$$\begin{Bmatrix} v_1 \\ i_1 \end{Bmatrix} = \left(\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdots\cdots\cdots\cdots \begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \right) \begin{Bmatrix} v_2 \\ -i_2 \end{Bmatrix} \tag{2}$$

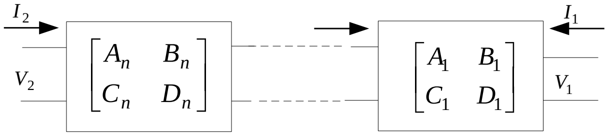


Figure 1. Cascaded network representation with ABCD parameters.

Conventional filter design begins with identification of the low pass prototype circuit according to the specifications in the passband and stopband. The low pass prototype circuit is obtained and illustrated in Fig. 3 based on the filter specifications given in Table I using 5^{th} order, 0.2dB ripple, Chebyshev filter topology to provide the attenuation needed within the specified frequency range.

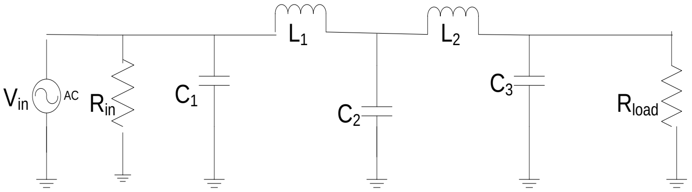


Figure 2. Low pass prototype for 5th order, 0.2dB ripple, Chebyshev filter.

TABLE II. LOW PASS PROTOTYPE VALUES

Lumped Element	Value
C_1	1.339 pF
L_1	1.337 nH
C_2	2.166 pF
L_2	1.337 nH
C_3	1.339 pF

Lumped element based filter can be converted to microstrip type filter by using distributed elements. Distributed element values can be obtained from the lumped element values using different methods. It is a common method to apply Richard's transformation with the application of Kuroda's identities as described in [6] to convert lumped element values to distributed element values. Conversion formulas are also available to obtain distributed values for thick film microstrip filter applications for specific substrates. The distributed element values for the filter presented in this paper are found for Alumina substrate using Akello's relations [7] as follows

$$L' = 7.82x10^{-3} xZ_0 + 0.03[nH/mm], if\, 20 \le Z_0 \le 110\Omega \qquad (3)$$

$$C' = 88.9x10^{-3} x\, w/h + 0.08[pF/mm],\ for\ 0.5 \le w/h \le 6 \qquad (4)$$

After the application of the conversion relations in (3) and (4), the width and the length of each stub of the filter is obtained and given in Table III.

TABLE III. DISTRIBUTED ELEMENT VALUES

Element	Width	Length
C1	2.90mm	4.9mm
L2	0.20mm	8.8mm
C3	2.9mm	7.4mm
L4	0.20mm	8.8mm
C5	2.90mm	4.9mm

The layout of the filter, which is constructed using the calculated width, and the length of the stubs, are shown in Fig. 4. In this layout, there are five cascaded filter components.

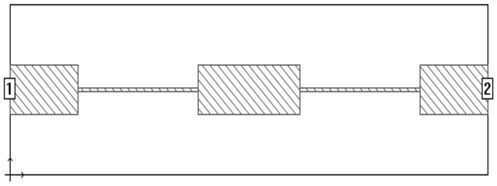


Figure 3. Layout of the filter

Filter response is obtained with the knowledge of insertion and return losses because insertion loss illustrates the passband characteristics whereas return loss shows the stopband characteristics of the filter. The proposed design method obtains insertion and return losses of the filter using the ABCD parameters of overall network. This is accomplished by calculating ABCD parameter of each component using (1) and then obtaining ABCD parameters of overall network with the application of equation (2). The ABCD network parameters for each stub is found as

$$\begin{bmatrix} \cos(\beta\ell) & jZ_O \sin(\beta\ell) \\ \dfrac{j\sin(\beta\ell)}{Z_O} & \cos(\beta\ell) \end{bmatrix} \qquad (5)$$

where β is the phase constant, ℓ is the length of section, Z_o is the characteristic impedance. The phase constant is computed as

$$\beta = 2\pi f / v_p \qquad (6)$$

f is the frequency of the signal and v_p is the phase velocity. The phase velocity can be computed using

$$v_p = \frac{2.98x10^8}{\sqrt{\varepsilon_{eff}}} \qquad (7)$$

where ε_{eff} is the effective permittivity and is computed using relations which depend on the width (W) to board thickness (d) ratio

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[\left(1+12\frac{d}{W}\right)^{-\frac{1}{2}}+0.04\left(1-\frac{W}{d}\right)^2\right] \quad \text{for W/d} \le 1 \quad (8)$$

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\frac{d}{W}\right)^{-\frac{1}{2}} \quad \text{for W/d} > 1 \qquad (9)$$

ε_r is the relative permittivity of the board material and assumed to be equal to 9. Conductor, which is used as trace in the filter, is assumed to have a zero thickness in our calculation. This will cause negligible error depending on the operational frequency. Any realizable conductor will have a finite thickness (t) causing fringing. The effect of non-zero conductor thickness can be approximated as an increase in the effective width (W) of the conductor as follows

$$W_{eff}=W+\frac{t}{\pi}\left(1+\ln\frac{2x}{t}\right) \qquad (10)$$

where x can take on two different values :

$$x=d \qquad \text{for} \quad \text{W>d/(2π)>2t} \qquad (11)$$

or

$$x=2\pi W \qquad \text{for} \quad \text{h/(2π)>W>2t} \qquad (12)$$

Characteristic impedance is found using

$$Z_0=\frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(\frac{8d}{W}+\frac{W}{4d}\right) \quad \text{for W/d} \leqslant 1 \qquad (13)$$

$$Z_O=\frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[W/d+1.393+\frac{2}{3}\ln(W/d+1.444)\right]} \quad \text{for W/d} > 1 \quad (14)$$

Characteristic impedance defined for each stub is based on trace length, width, and dielectric thickness. The insertion and return losses are analytically found utilizing the relation between ABCD and S-parameters of the network with the following relations.

$$S_{11}=\frac{A+B/Z_o-CZ_o-D}{A+B/Z_o+CZ_o+D} \qquad (15)$$

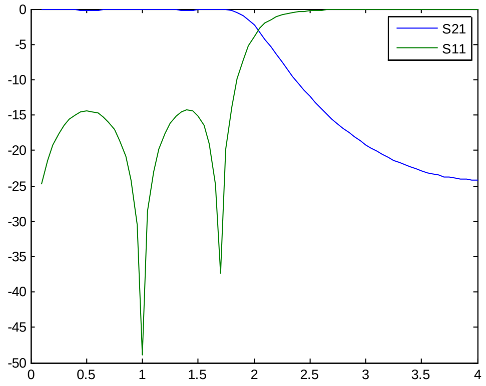
$$S_{12}=\frac{2(AD-BC)}{A+B/Z_o+CZ_o+D} \qquad (16)$$

$$S_{21}=\frac{2}{A+B/Z_o+CZ_o+D} \qquad (17)$$

$$S_{22}=\frac{-A+B/Z_o-CZ_o+D}{A+B/Z_o+CZ_o+D} \qquad (18)$$

MATLAB is used to compute the insertion and return losses and obtain filter response using the formulations given (1)-(18). The calculated insertion and return losses for the filter shown in Fig. 4 using the proposed network method are plotted and illustrated in Fig. 5.

Figure 4. Frequency response of 5th order chebyshev filter with ABCD parameters



To determine how well the analysis agrees with the specifications in Table I, areas of interest are zoomed in and shown in Fig. (6-7) below. Fig. 6 shows the response at 2 GHz whereas Fig. 7 shows the response between 3.1–3.5 GHz.

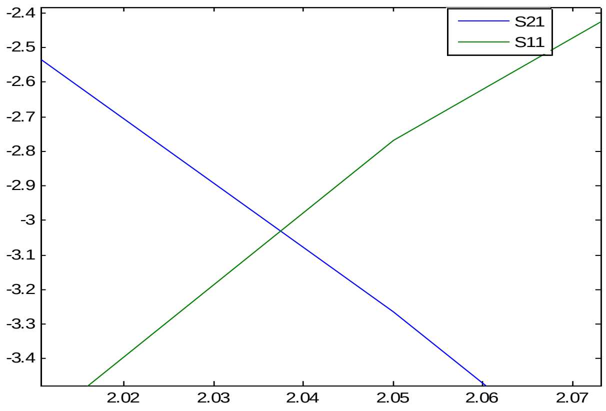


Figure 5. Frequency response at 2 GHz

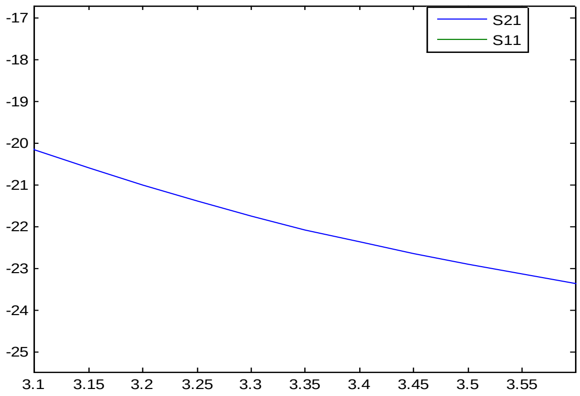


Figure 6. Frequency response between between 3.1 – 3.5 GHz

It is shown that analytical results meet with the desired filter specifications. Hence, filter now can be simulated with the planar electromagnetic simulator Sonnet for verification of the results, which are obtained using the proposed method.

2.2 Simulation of Microstrip Filter

The filter is simulated using Sonnet EM (Electro magnetic) simulator and the results are compared with the analytical results obtained in Section 2.1. The cell size was set to 0.05 mm spacing to optimize the processing time and obtain accurate results with Sonnet V12.56. The simulation results, which are shown in Fig. 8 match closely with the results obtained using ABCD network parameters as illustrated in Figures 5-8. The analytical and simulation results obtained in this paper also check with the results presented in [5].

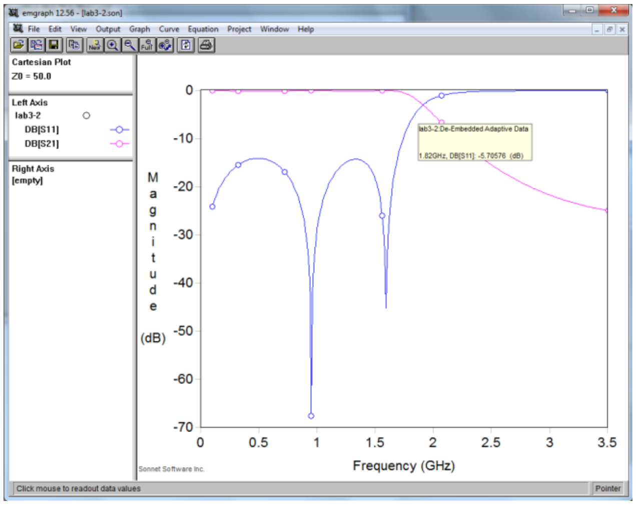


Fig. 8 Frequency response of 5^{th} order chebyshev filter with Sonnet

3. CONCLUSION

In this paper, a practical analytical method to design broadband microstrip filters at the UHF range for RF communication systems is presented. The method is based on the network parameter technique using ABCD parameters. The method significantly facilitates the design process and gives accurate results. Microstrip filter operating within 1.5GHz bandwidth using 5^{th} order Chebyshev filter topology is designed with the proposed method and simulated using the planar electromagnetic simulator, Sonnet and then implemented. It has been shown that the analytical and simulation results agree in all the frequency regions of interest. The method presented in this paper can be used to design low cost, broadband microstrip filters with high accuracy.

4. REFERENCES

[1] A. Nieuwoudt, J. Kawa, and Y. Massoud, “Robust reconfigurable filter design using analytic variability quantification techniques,” in Proc. IEEE International Conference on Computer-Aided Design (ICCAD), Nov. 2008, pp. 765–770.

[2] L. Vanbeylen, and J. Schoukens, “Comparison of filter design methods to generate analytic signals” in Proc. IEEE Instrumentation and Measurement Technology Conference (IMTC), April 2006, pp. 24–27.

[3] W. H. Tu, H. Li, K. A. Michalski, and K. Chang, “Microstrip Open-Loop Ring Bandpass Filter Using Open Stubs for Harmonic Suppression,” in IEEE Microwave Symposium Digest, 2006, pp. 357-360.

[4] M. H. Hsu, and J. F. Huang, “Novel resonators with a applying binomial coefficients admittance values to design multifrequency bands of microstrip filters,” in IEEE Joint Conference of the 10th Asia-Pacific, 2004, pp. 568-572.

[5] V. Crnojevic-Bengin, and D. Budimir, “Design of thick film microstrip lowpass filters,” in IEEE International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service, TELSIKS 2003, pp. 360-362.

[6] G. Matthaei, E.M.T. Jones, and L. Young, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, Artech House Publishers, Norwood. MA, 1980.

[7] M. Haskard, and K. Pitt, Thick-Film Technology and Applications, Electrochemical Publications Ltd, UK, 1997.