Using of a New Bond Graph Technology for the Study of a High Frequency Low Pass Filter

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Abstract

Due to the frequent uses of electronic filters in radio frequency and telecommunication domains, many researchers have been interesting in its design and modeling for several years.
We will present in this study a new mathematical approach that describes the steps to conceive a high frequency low pass filter by reactive elements then by microstrip line. The scattering bond graph method is applied to determine an explicit model of filter that describes the phenomenon of energy exchange between different elements of system.

Keywords: *Low Pass Filter, Scattering Bond Graph, Reflexion and Transmission Coefficients, Modeling and Simulation.*

1. Introduction

Electronic filters are electronic circuits which execute signal processing functions, specifically to remove the unwanted frequency components from the signal, to enhance the wanted ones, or both. Filter circuits may be divided into passive and active types. They are widely used in military applications such as radars and satellites and in telecommunication domains. Depending on the characteristics and the conditions of the application, a filter can be designed by reactive elements or by micro- strip line.
In this paper we will present a complete study of high frequency low pass filter. Firstly, we will develop a mathematical approach to determine the order and the normalized elements of filter from its gain curve.
Thereafter, we will deduce the mounting of a filter that is composed by inductances and capacitances components. Then, we will determine a second mounting of filter composed by microstrip lines.
Finally, we will use a scattering bond graph method to analyze the filter.

2. Synthesis and calculation of filter order and normalized elements

The synthesis of filter will be summarized by an algorithm that is based on three main steps:

- Determination of inductance and capacitance values by Chebyshev method.
- Determination of the dimensions of the planar filter
- Modeling of filter by scattering bond graph method

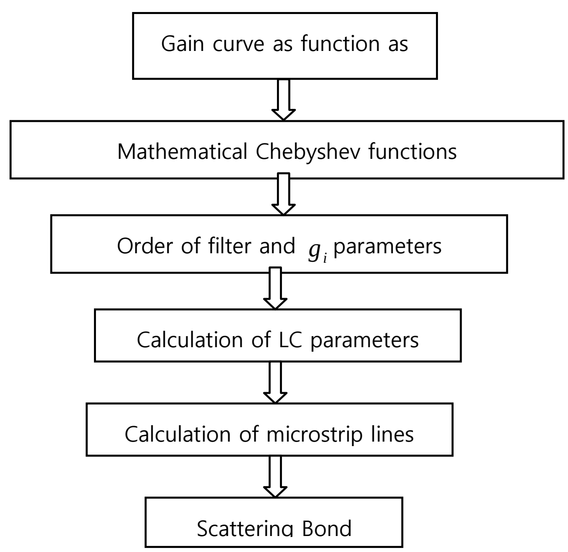

Fig.1 The synthesis algorithm of the filter

The general structure of low pass LC filter [1] is given by the following figure:

Fig.2 General Structure of low pass filter

$R_e = 50\Omega$

The gain curve as function as frequency of the filter that we will design and model is given by figure3:

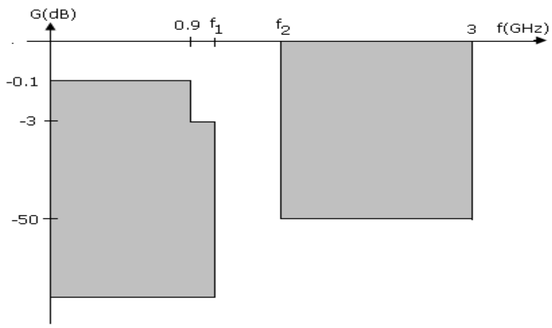

Fig.3 gain curve as function as frequency with a cut-off frequency f1=1GHz in 3 dB and an Attenuation greater than 50 dB from f2=1.5GHz to 3GHz.

From the characteristics given by the gain curve and according to the Chebyshev method, we deduce the order n of filter.

$$n \geq \frac{Argch\sqrt{\dfrac{10^{\frac{A\min}{10}}-1}{10^{\frac{A\max}{10}}-1}}}{Argch(w_s)} \quad \text{with}$$

$$\begin{cases} w_s = \dfrac{f_2}{f_1} \\ A_{\min} = 50dB \\ A_{\max} = 0.1dB \end{cases} \qquad (1)$$

We obtain n=9, so the filter is constituted of 9 elements.

The normalized parameters g_i are calculated by the equations given bellow.

$$g_1 = \frac{2}{\eta}\sin\left(\frac{\pi}{2n}\right) \qquad (2)$$

$$g_k * g_{k+1} = \frac{4 * \sin\left(\dfrac{2k-1}{2n}\pi\right) * \sin\left(\dfrac{2k+1}{2n}\pi\right)}{\eta^2 + \sin^2\left(\dfrac{k}{n}\pi\right)} \qquad (3)$$

With: $\eta = sh\left(\dfrac{Argch(1/\varepsilon)}{n}\right)$

and

$$\varepsilon = \sqrt{10^{\frac{A\max}{10}} - 1} \qquad (4)$$

The values of normalized parameters g_i are given in table 1.

Table1: g_i parameters

g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9
1.19	1.45	2.15	1.6	2.22	1.6	2.15	1.44	1.19

3. Design of filter by LC elements

From the normalization parameters g_i, we deduce the values of inductances L_i and capacitance C_i by using the equations bellow:

$$L_i = \frac{g_i Z_0}{f_1} \qquad (5)$$

$$C_i = \frac{g_i}{Z_0 f_1} \qquad (6)$$

Table 2: Denormalized elements (L_i, C_i) of filter

g_i elements	Inductance L_i (nH)	Capacitance C_i (pF)
1.19	9.4745	
1.45		4.6178
2.15	17.11783	
1.6		5.09554
2.22	17.675	
1.6		5.09557
2.15	17.11783	
1.44		4.5859
1.19	9.4745	

We get the mounting of the filter given by Figure3

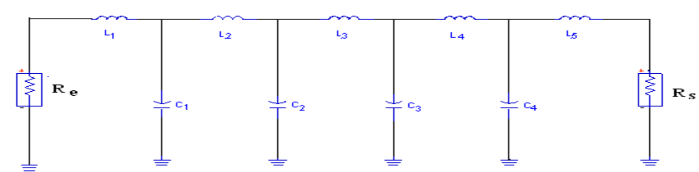

Fig. 4 LC low pass filter

The simulation of the above circuit by ADS software, gave us the characteristic of transmission and reflection coefficients as function as frequency below.

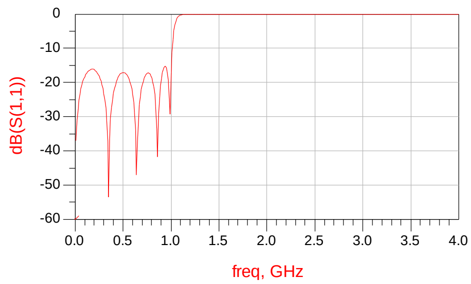

Fig. 5 Reflection coefficient S11 seen at entry.

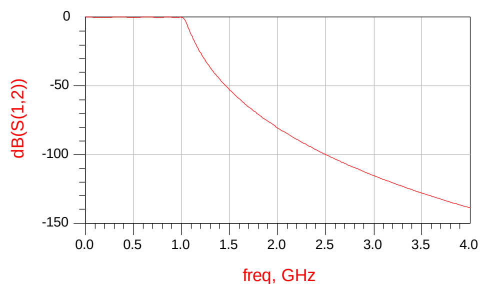

Fig. 6 Transmission coefficient S12 seen from exit to entry.

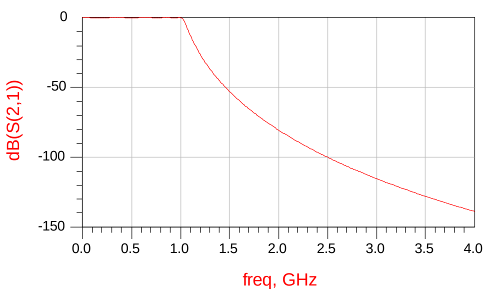

Fig. 7 Transmission coefficient S21 seen from entry to exit.

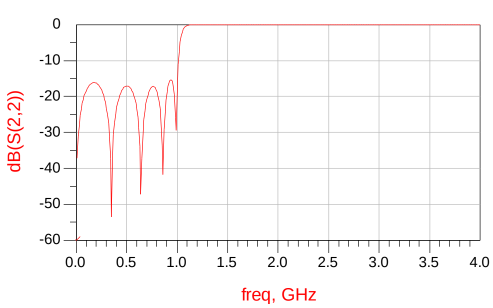

Fig. 8 Reflection coefficient S22 seen at exit.

The obtained results are in agreement with the ideal curve given by Figure2.

4. Design of filter by microstrip line

A microstrip line is a type of electrical transmission line [2]. It is used to convey microwave-frequency signals. We can design a high frequency filter by using cascaded microstrip lines with a number corresponding to the filter order [3].
In our study, the order of filter is 9; therefore, we need to 9 microstrip lines to conceive the filter.

The microstrip line that we will use is characterized by:

- A substrate thickness: h= 1.52mm
- A permittivity: $\varepsilon_r = 4.32$
- A Copper Thickness: T = 0.035mm
- A resistivity: $\rho = 0.71$
- $Tang\Phi = 0.018$
- input impedance: $Z_0 = 50\Omega$

We consider:

- The characteristic impedance of the capacitive line section: $Z_{0C} = 10\Omega$
- The characteristic impedance of the inductive line section: $Z_{0L} = 100\Omega$

By using the line calc of ADS software we calculated the width values of lines, we obtained $W_C = 4mm$, the width of capacitances and $W_L = 0.8mm$, the width of inductances.
The length values of lines l_{C_i} and l_{L_i} can be easily calculated from the values of the reactive elements and the characteristic impedances as follows:

$$l_{C_i} = C_i.Z_{0C}.\vartheta \quad (7)$$

$$l_{L_i} = \frac{L_i.\vartheta}{Z_{0L}} \quad (8)$$

With ϑ : wave propagation velocity

The mounting of microstrip filter is given by Figure 9.

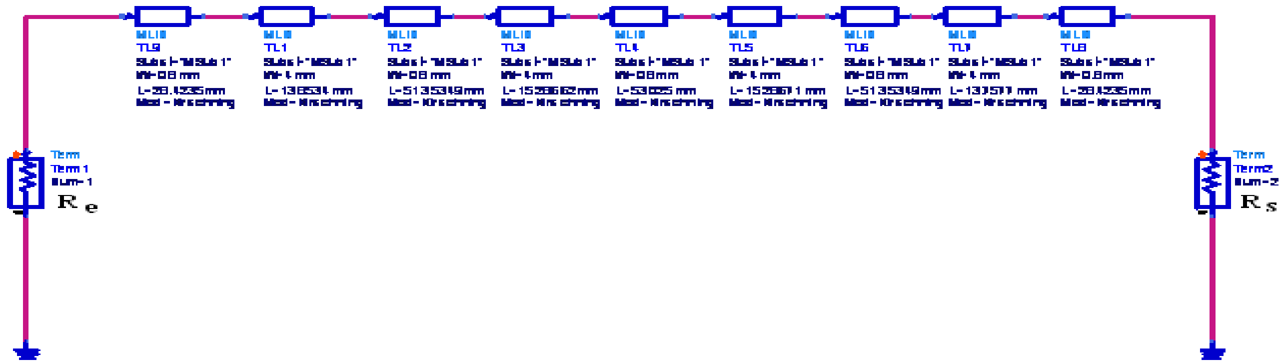

Fig. 9 The microstrip low pass filter

We obtained easily the layout of filter by ADS software.

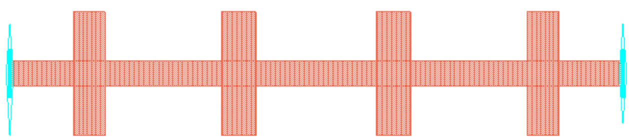

Fig.10 Layout of low pass filter

The simulation of the microstrip filter gave us the following results:

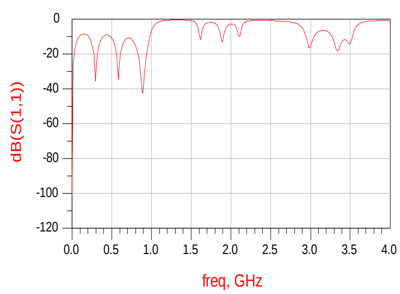

Fig.11 Reflection coefficient S11 seen at entry

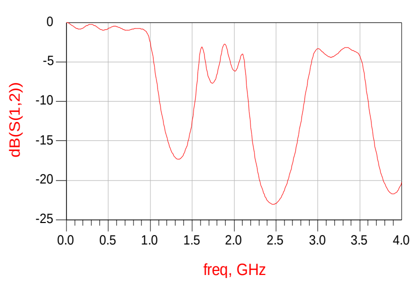

Fig.12 Transmission coefficient S12 seen from exit to entry

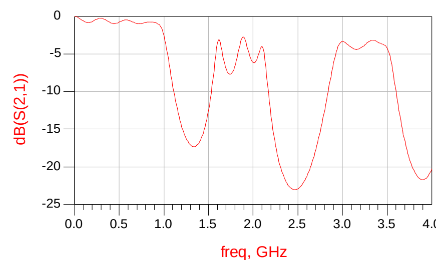

Fig. 13 Transmission coefficient S21 seen from entry to exit

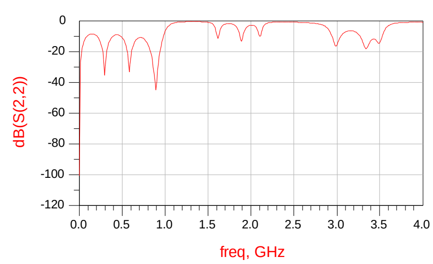

Fig. 14 Reflection coefficient S22 seen at exit

The microstrip filter presents the same cut-off frequency (1 GHz) than LC filter. However it presents parasitic responses that we can remove by changing the used uniform transmission lines by non-uniform Transmission Lines.

5. Scattering bond graph model of filter

Bond graph is a graphical representation of physical systems. This technique is based on exchange of energy and can give concise description of complex systems. By this approach, a physical system can be represented by symbols and lines, identifying the power flow paths. This method is widely used to model low frequency systems.

A new approach of analyzing high frequency system is developed by Mr Abdelkader Mami and Mr Hichem Taghouti in [4][5]. This new method combines the bond graph approach with the scattering formalism that used for several years to describe high frequency systems. This new technique is called scattering bond

graph method described clearly in [6][7]. It is used to give a concise model of filter and describes clearly the distribution of energy between different elements of filter.
The bond graph model of the studied filter is given in Figure 15.

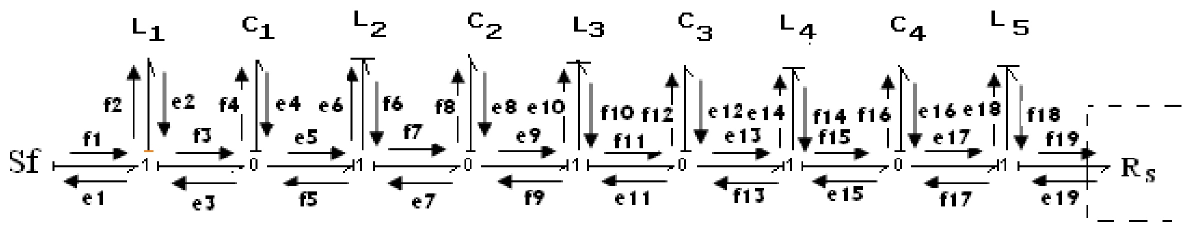

Fig. 15 Bond graph model of filter

e: effort
f: flow

To extract the scattering parameters from the bond graph representation and by using the new method which is described in[4][5][6][7], we must transform the bond graph model given by figure15 into a causal bond graph model often named reduced bond graph given by Figure16.

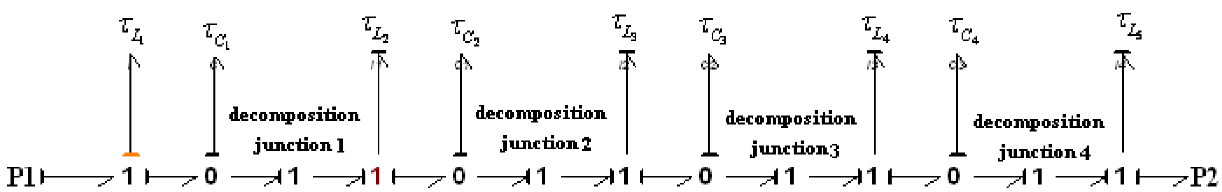

Fig. 16 The reduced bond graph method

$$\tau_{L_i} = \frac{L_i}{R_0} \quad (9)$$

$$\tau_{C_i} = C_i.R_0' \quad (10)$$

By decomposition the reduced bond graph given by figure 16, we will have the following bond graph representation:

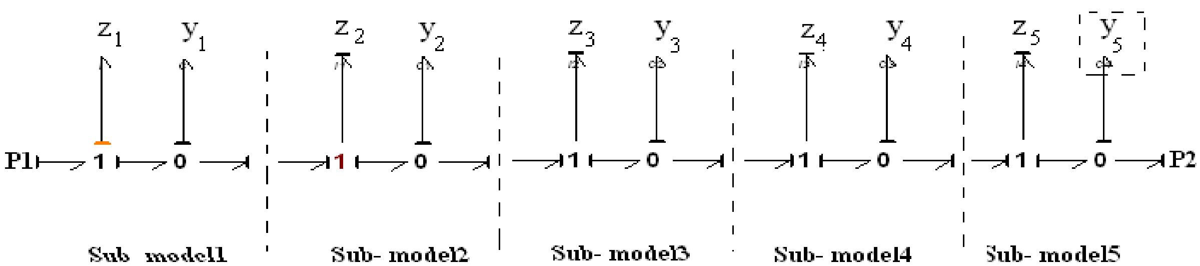

Fig. 17 Five bond graph sub model

$$z_i = \tau_{L_i}.s \quad (11)$$

$$y_i = \tau_{C_i}.s \quad (12)$$

We have the integro differentials operators by taking into account to the equations from the reduced bond graph model with effort-flow causality [7]:

$$B_i = -\frac{1}{z_i.y_i} \quad (13)$$

Loop gain of sub- model i

$$\Delta_i = 1 + \frac{1}{z_i.y_i} \quad (14)$$

Determinant of causal bond graph of the sub- model i

$$\begin{cases} H_{11} = \frac{z_i}{z_i.y_i + 1} \\ H_{12} = \frac{1}{z_i y_i + 1} \\ H_{21} = \frac{1}{z_i.y_i + 1} \\ H_{22} = -\frac{y_i}{z_i.y_i + 1} \\ \Delta(s) = -\frac{1}{z_i.y_i + 1} \end{cases} \quad (15)$$

The all integro- differentials operators of the sub model i
From these operators, we can deduce directly the wave matrix of each sub model.

$$W^{(i)} = \frac{1}{2}\begin{bmatrix} z_i y_i - z_i - y_i + 2 & -z_i y_i + z_i + y_i \\ -z_i y_i - z_i + y_i & z_i y_i + z_i + y_i \end{bmatrix} \quad (16)$$

We deduced the wave matrix of the total model.

$$W^{(T)} = W^{(1)} * W^{(2)} * W^{(3)} * W^{(4)} * W^{(5)} = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \quad (17)$$

From the total wave matrix, we deduced the scattering bond graph matrix S [5].

$$S = \begin{bmatrix} W_{22}^{-1} W_{12} & W_{11} - W_{21} W_{12} W_{22}^{-1} \\ W_{22}^{-1} & -W_{21} W_{22}^{-1} \end{bmatrix} \quad (18)$$

$$S_{11} = W_{22}^{-1}.W_{12} \quad (19)$$

$$S_{12} = W_{11} - W_{21}.W_{12}.W_{22}^{-1} \quad (20)$$

$$S_{21} = W_{22}^{-1} \quad (21)$$

$$S_{22} = -W_{21}.W_{22}^{-1} \quad (22)$$

From the determined equations of scattering parameters, we developed a maple program. Its simulation gave us the following results.

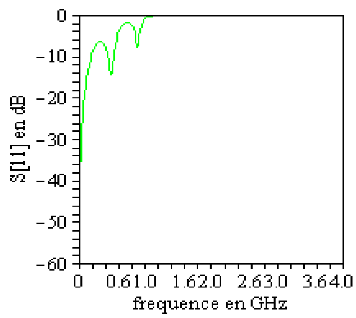

Fig. 18 Reflection coefficient S11 seen at entry

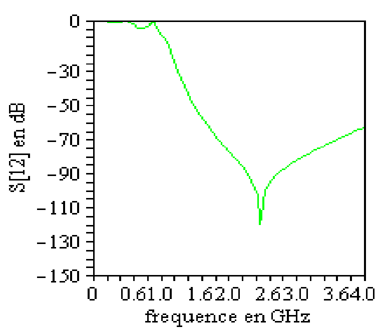

Fig. 19 Transmission coefficient S12 seen from exit to entry

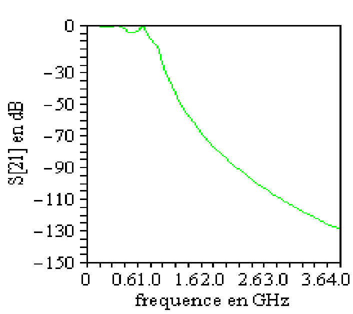

Fig. 20 Transmission coefficient S21 seen from entry to exit

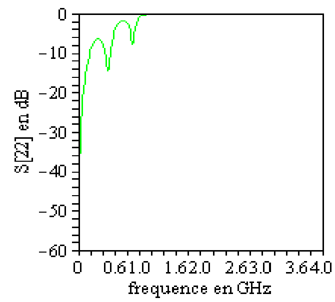

Fig. 21 Reflection coefficient S22 seen at exit

From the above results, we notice that the scattering bond graph method gives the same results of microstrip and RLC filter. So we confirm that the new method is useful to model high frequency systems.

6. Conclusion

In this paper, we presented a general study of high frequency filter. We developed the equations to conceive a high frequency low pass filter by reactive elements and by microstrip lines. And we used the scattering bond graph approach to give an explicit model of filter that describes the distribution of energy between its components.

We confirmed that the scattering bond graph method is appropriate to analyze and model high frequency systems.

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