Modeling of a Microstrip Low-Pass Filter by the Scattering-Bond Graph Formalism

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Abstract

Low pass filters play an important role in wireless systems. At the reception and the transmission, the signal has to be filtered at a certain frequency with a specific bandwidth. In this paper we present a design of microstrip low-pass filter. The bond graph and the scattering formalism are used jointly to give an explicit model of filter. The representations of transmission and reflection coefficients of filter are derived from the obtained model.

Keywords: Low Pass Microstrip Filter, Bond Graph Model, Scattering Formalism, Transmission and Reflection Characteristics.

1. Introduction

Electronics filters are required in all radio-frequency communication techniques. They are used to execute signal processing functions specifically to enhance the wanted frequency component, to remove the unwanted one [1]. There are four filter types: Low Pass Filters, High Pass Filters, Band Pass Filters and Band Stop Filters [2,3]. Depending on the characteristics and the conditions of application, the electronic filter can be designed by distributed or lumped elements [4].

In order to describe the physical behavior of a low pass microstrip filter, we will use a procedure which links the bond graph formalism to the scattering formalism. Firstly, we will develop a bond graph model of microstrip filter. Secondly, we will derive the scattering matrix from the reduced bond graph model. Finally, we will use the scattering parameters to extract the transmission and reflection characteristics by maple program.

2. Bond Graph Model

The Bond graphs are a kind of graphical language and systematic representation. They were applied in physical multidiscipline domains, such as mechanics, electronics and hydraulics... They include elements and constitutive relations which can used to express the common energy transfer or transform behavior underlying the several physical domains. The characteristics of bond graphs include:

• being able to obtain important qualitative information as a conceptual model.
• being able to reveal the relationships among system, subsystems, and elements.
• not only being able to represent the topology of subsystems or elements of different physical domains, but also being able to represent the relationships of their products among them.

The concepts of bond graphs include port and bond, elements, variables, constitutive relations and causality. Fig.1 shows the concept of the basic bond graph component.

![Fig. 1 Bond and ports of bond graph.](image)

Between two elements, there is always a bond. Every bond has two power variables, one is effort (e), and the other is flow (f) associated with it. Energy will flow through the bond in either direction.
Bond graphs consist of nine types of elements, they are source of effort (Se), source of flow (Sf), inductor (I), capacitor (C), resistor (R), transformer (TF), gyrator (GY), 0-junction and 1-junction.

3. Proposed Structure and Bond Graph Model

The chosen structure, given by Fig 2, is a low pass microstrip filter formed by an alternating of high and low impedance transmission lines which are linked in cascade.

The large line with low impedance present a better approximation of lumped-element capacitor connected in parallel.

$$C = \frac{I_{Ci}}{Z_{0c}b_p^2}$$

(2)

Where

$$\nu_{pi} = \frac{\omega}{\beta i}$$

(3)

And

$$\beta i = \frac{2\pi}{\lambda_{gi}}$$

(4)

The guided wavelength

Thus the equivalent circuit constituted by lumped elements is given by Fig. 5.

Applying the above formulas in our structure, we obtain:

$$L = \frac{Z_{0L} I_{Li}}{\nu_{pi}}$$

(1)

$$C = \frac{Z_{0C} I_{Ci}}{\nu_{pi}^2}$$

(2)
The values of inductances: \( L_1 = L_2 = 7.7316 \, nH \)
The values of capacitances: \( C_1 = C_2 = 2.816 \, pF \)

So we can easily deduce the bond graph model of the filter. This model describes clearly the exchange of physical energy between the filter elements.

So we have:
\[
\begin{align*}
\mathcal{Z}_{eq1} &= r_1 + \tau_{L1} \cdot s \\
\mathcal{Y}_{eq1} &= \tau_{C1} \cdot s \\
\mathcal{Z}_{eq2} &= \tau_{L2} \cdot s \\
\mathcal{Y}_{eq2} &= \tau_{C2} \cdot s + r_2 \\
\end{align*}
\]

s: The Laplace operator.

\[
\begin{align*}
r_1 &= \frac{R_{source}}{R_0} \\
r_2 &= \frac{R_{load}}{R_0} \\
\tau_{Ci} &= C_i \cdot R_0 \\
\tau_{Li} &= \frac{L_i}{R_0} \\
R_0 &= 50 \, \Omega \\
\end{align*}
\]

The reduced bond graph model is easier to study by dividing it into two sub models.
\( B_1 = - \frac{1}{z_{eq1} \cdot y_{\text{eq1}}} \) (11): Loop gain of the algebraic loop given by the first sub-model.

\( B_2 = - \frac{1}{z_{eq2} \cdot y_{\text{eq2}}} \) (12): Loop gain of the algebraic loop given by the second sub-model.

\[ \Delta_1 = 1 + \frac{1}{z_{eq1} \cdot y_{\text{eq1}}} \] (13): Determinant of causal bond graph of the first sub-model.

\[ \Delta_2 = 1 + \frac{1}{z_{eq2} \cdot y_{\text{eq2}}} \] (14): Determinant of causal bond graph of the second sub-model.

The all integro-differentials operators of the first sub model are:

\[
\begin{align*}
H_{11}[1] &= \frac{y_{\text{eq1}}}{z_{eq1} \cdot y_{\text{eq1}} + 1} \\
H_{12}[1] &= \frac{1}{z_{eq1} \cdot y_{\text{eq1}} + 1} \\
H_{21}[1] &= \frac{1}{z_{eq1} \cdot y_{\text{eq1}} + 1} \\
H_{22}[1] &= -\frac{z_{\text{eq1}}}{z_{eq1} \cdot y_{\text{eq1}} + 1} \\
\Delta(s)[1] &= -\frac{1}{z_{eq1} \cdot y_{\text{eq1}} + 1}
\end{align*}
\] (15)

The all integro-differentials operators of the second sub model are:

\[
\begin{align*}
H_{11}[2] &= \frac{y_{\text{eq2}}}{z_{eq2} \cdot y_{\text{eq2}} + 1} \\
H_{12}[2] &= \frac{1}{z_{eq2} \cdot y_{\text{eq2}} + 1} \\
H_{21}[2] &= \frac{1}{z_{eq2} \cdot y_{\text{eq2}} + 1} \\
H_{22}[2] &= -\frac{z_{\text{eq2}}}{z_{eq2} \cdot y_{\text{eq2}} + 1} \\
\Delta(s)[2] &= -\frac{1}{z_{eq2} \cdot y_{\text{eq2}} + 1}
\end{align*}
\] (16)

From these operators, we can deduce directly the wave matrix of the first and the second sub-model [11, 12, 13].

\[
W[1] = \begin{bmatrix} W_{11}[1] & W_{12}[1] \\ W_{21}[1] & W_{22}[1] \end{bmatrix}
\] (17)

\[
W[2] = \begin{bmatrix} W_{11}[2] & W_{12}[2] \\ W_{21}[2] & W_{22}[2] \end{bmatrix}
\] (18)

Such as:

\[
W_{11}[i] = \frac{1 - H_{11}[i] + H_{22}[i] - \Delta H[i]}{2H_{21}[i]} 
\] (19)

\[
W_{12}[i] = \frac{1 - H_{11}[i] - H_{22}[i] + \Delta H[i]}{2H_{21}[i]} 
\] (20)

\[
W_{21}[i] = \frac{1 + H_{11}[i] + H_{22}[i] + \Delta H[i]}{2H_{21}[i]} 
\] (21)

\[
W_{22}[i] = \frac{1 + H_{11}[i] - H_{22}[i] - \Delta H[i]}{2H_{21}[i]} 
\] (22)
\[ \Delta H[i] = H_{11}[i]H_{22}[i] - H_{12}[i]H_{21}[i] \]  

(23)

The global Wave matrix \( W_g \) is given by the product of \( W[1] \) and \( W[2] \) [14,15,16]:

\[ W_g = W[1] \ast W[2] = \begin{bmatrix} W_g[11] & W_g[12] \\ W_g[21] & W_g[22] \end{bmatrix} \]  

(24)

Then we can determine the \( S \) matrix[17]:

\[ S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \]  

(25)

\[ S_{11} = -\frac{W_g[12]}{W_g[22]} \]  

(26)

\[ S_{12} = \frac{1}{W_g[22]} \]  

(27)

\[ S_{21} = \frac{W_g[22]W_g[11] - W_g[12]W_g[21]}{W_g[22]} \]  

(28)

\[ S_{22} = \frac{W_g[21]}{W_g[22]} \]  

(29)

A simple programming and simulation of the above scattering parameters equations, gives the Figures 11-14 which represent respectively the reflection and transmission coefficients of the studied filter.

Fig. 11 Reflection coefficient S11

Fig. 12 Transmission coefficient S12
The obtained results are in accordance with the characteristics of the filter, which proves the validity of the scattering bond graph formalism to analyze the linear systems.

5. Conclusions

In this article, we have used a procedure which links the bond graph formalism to the scattering formalism to analyze a low pass microstrip filter. Firstly, we have explained the method to find the bond graph model from the filter. Then, we showed the steps to obtain the S matrix. Afterwards, we have developed a maple program from the scattering parameters which has allowed us to represent the transmission and reflection characteristics.

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References


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