Application of the Fault Tolerance of Reduced Bond Graph Approach of Parallel Computing of a Matching Network

Shiv Kumar Gupta, Rajiv Kumar, Krishna Kumar Verma

Abstract— In this paper we present a new method for modeling high frequency systems. This method combines the scattering formalism with the bond graph model in a new technique called scattering bond graph model. This method allows describing explicitly the distribution of electromagnetic waves of any high frequency system. We applied this method to deduce the reflection and transmission coefficient as function as frequency of a parallel computing matching network of a Planar Inverted F Antenna.

Index Terms—Matching network, scattering matrix, scattering formalism, bond graph modeling, scattering bond Graph model, PIFA.

I. INTRODUCTION

The scattering formalism which results in a matrix noted S can be used to study linear or nonlinear, multi-energy representations of physical system [1]. It's an appropriate method to describe the behavior of microwave structure. This method represents the relations of transmission and reflection waves between different ports of structures. At the same, Bond graph is a graphical representation of a physical dynamic system. 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 [2].Many researchers proved the possibility of using bond graph model jointly with scattering formalism to study physical systems [3],[4]. The feasibility and efficiency of using formalism scattering jointly with bond graph approach as the representation technique of high frequency systems will be verified in our experiment with matching Network of Planar Inverted F Antenna.We will start this work by the description of the scattering method. Then we will show the relationship between the scattering formalism and the bond graph method. Finally, we will use the two methods jointly to study a matching network of Planar Inverted F Antenna. By a simple maple programme, we will extract the representation of reflection and transmission coefficient in Edges of Antenna. And to validate the found results, we will compare them by the results of simulation circuit obtained by advanced design system (ADS).

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II. SCATTERING FORMALISM

Scattering parameters or S-parameters (the elements of a scattering matrix or S-matrix) describe the electrical behavior of linear electrical networks, they may describe large and complex network. S-parameters are useful for electrical engineering, electronics engineering, and communication systems design, and especially for microwave engineering. Scattering matrix, are frequently used to characterize multiport networks, especially at high frequencies. They are used to represent microwave devices, such as amplifiers and circulators, and are easily related to concepts of gain, loss and reflection. S-parameters are readily represented in matrix form and obey the rules of matrix algebra. The S-parameter matrix for the 2-port network is probably the most commonly used and serves as the basic building block for generating the matrix of one port network or multi port networks. Consider a circuit or device inserted into a T-Line as shown in the Figure1, we can refer to this circuit or device as a two-port network.

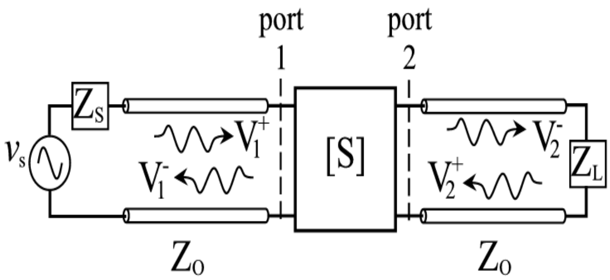

Figure1: Two port- network

The scattering matrix is written as follows:

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

The scattering parameters represent ratios of voltage waves entering and leaving the ports:

$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+ .$$

[2]

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$$V_2^- = S_{21}V_1^+ + S_{22}V_2^+ . \quad [3]$$

In matrix form this is written as:

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}, \quad [4]$$

$$[V]^- = [S][V]^+ .$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+=0} \quad [5]$$

S_{11}: is the input port voltage reflection coefficient

$$S_{12} = \left. \frac{V_1^-}{V_2^+} \right|_{V_1^+=0} \quad [6]$$

S_{12}: is the reverse voltage gain

$$S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+=0} \quad [7]$$

S_{21}: is the forward voltage gain

$$S_{22} = \left. \frac{V_2^-}{V_2^+} \right|_{V_1^+=0} \quad [8]$$

S_{22}: is the output port voltage reflection coefficient.

A network is reciprocal if it is equal to its transpose:

$$[S] = [S]^t , \quad [9]$$

In terms of scattering parameters, a network is lossless if:

$$[S]^t [S]^* = [U], \quad [11]$$

Where $[U]$ is the unitary matrix:

$$[U] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}. \quad [12]$$

For a 2-port network, the product of the transpose matrix and the complex conjugate matrix yields:

$$[S]^t [S]^* = \begin{bmatrix} \left(|S_{11}|^2 + |S_{21}|^2\right) & \left(S_{11}S_{12}^* + S_{21}S_{22}^*\right) \\ \left(S_{12}S_{11}^* + S_{22}S_{21}^*\right) & \left(|S_{12}|^2 + |S_{22}|^2\right) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

[13]

If the network is reciprocal and lossless:

$$|S_{11}|^2 + |S_{21}|^2 = 1$$

$$S_{11}S_{12}^* + S_{21}S_{22}^* = 0$$

A. *Scattering transfer parameters:*

The Scattering transfer parameters or W-parameters of a 2-port network are expressed by the W-parameter matrix and are closely related to the corresponding S-parameter matrix[5]. The W-parameter matrix is related to the incident and reflected waves at each of the ports as follows:

$$\begin{bmatrix} b_1 \\ a_1 \end{bmatrix} = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \cdot \begin{bmatrix} a_2 \\ b_2 \end{bmatrix} \quad [14]$$

However, they could be defined differently, as follows:

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \cdot \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \quad [15]$$

$$a_1 = V_1^+ \qquad a_2 = V_2^+$$

$$b_1 = V_1^- \qquad b_2 = V_2^-$$

$$W_{11} = -\frac{\det(S)}{S_{21}} \quad [16]$$

$$W_{12} = \frac{S_{11}}{S_{21}} \quad [17]$$

$$W_{21} = -\frac{S_{22}}{S_{21}} \quad [18]$$

$$W_{22} = \frac{1}{S_{21}} \quad [19]$$

From W to S:

$$S_{11} = \frac{W_{12}}{W_{22}} \quad [20]$$

$$S_{12} = \frac{\det(W)}{W_{22}} \quad [21]$$

$$S_{21} = \frac{1}{W_{22}} \quad [22]$$

$$S_{22} = \frac{-W_{21}}{W_{22}} \qquad [23]$$

Where $\det(S)$ indicates the determinant of the matrix (S).

III. RELATION BETWEEN SCATTERING FORMALISM AND BOND GRAPH APPROACH

Generally, any physical system exists in the form of a quadripole inserted between two particular ports P1 and P2 which respectively represent the entry (source) and the exit (load) of the total system, [6]. This system can be represented by a generalized bond graph model transformed and reduced as the Figure2 indicates it.

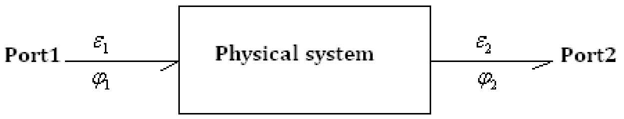

Figure 2: The reduced bond graph representation of physical system

ε_1 And ε_2 = respectively the reduced variable (effort) at the entry and the exit of the system. φ_1 And φ_2 = respectively the reduced variable (flow) at the entry and the exit of the system.

$$\varepsilon_i = \frac{effort}{\sqrt{R_0}} \qquad [24]$$

$$\varphi_i = flow * \sqrt{R_0} \qquad [25]$$

These are (equation 24 and 25) the reduced effort (e) and flow (f) with respect to R_0 .

To establish the output-input analytical relations, the bond graph model of the studied system must be transformed, reduced and especially be caused [6][7].

Depending on the direction of energy transfer we can get four cases of causality given below. For each type of reduced and causal bond graph model, we will have one matrix which connects the reduced wave-scattering variables to the integro-differentials operators H_{ij} .

A. *Case 1: Flow-effort causality*

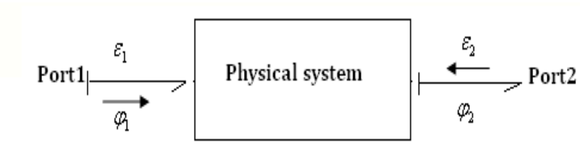

Figure3: Reduced bond graph model with flow-effort causality

$$\begin{bmatrix} \varepsilon_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varepsilon_2 \end{bmatrix} \qquad [26]$$

$$W = \begin{bmatrix} \frac{1-H_{11}+H_{22}-\Delta H}{2H_{21}} & \frac{-1+H_{11}-H_{22}-\Delta H}{2H_{21}} \\ \frac{-1-H_{11}-H_{22}-\Delta H}{2H_{21}} & \frac{1+H_{11}-H_{22}-\Delta H}{2H_{21}} \end{bmatrix} \qquad [27]$$

$$\Delta H = H_{11}H_{22} - H_{12}H_{21} \qquad [28]$$

B. *Case 2: Effort- flow causality*

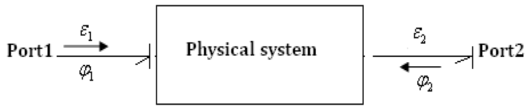

Figure4: Reduced bond graph model with effort-flow causality

$$\begin{bmatrix} \varphi_1 \\ \varepsilon_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varphi_2 \end{bmatrix} \qquad [29]$$

$$W = \begin{bmatrix} \frac{1-H_{11}+H_{22}-\Delta H}{2H_{21}} & \frac{1-H_{11}-H_{22}+\Delta H}{2H_{21}} \\ \frac{1+H_{11}+H_{22}+\Delta H}{2H_{21}} & \frac{1+H_{11}-H_{22}-\Delta H}{2H_{21}} \end{bmatrix} \qquad [30]$$

C. *Case 3: Flow- flow causality*

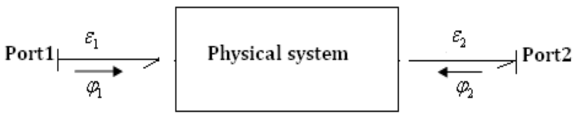

Figure5: Reduced bond graph model with flow-flow causality

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} \qquad [31]$$

$$W = \begin{bmatrix} \frac{-1+H_{11}-H_{22}+\Delta H}{2H_{21}} & \frac{-1+H_{11}+H_{22}-\Delta H}{2H_{21}} \\ \frac{1+H_{11}+H_{22}+\Delta H}{2H_{21}} & \frac{1+H_{11}-H_{22}-\Delta H}{2H_{21}} \end{bmatrix} \qquad [32]$$

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D. *Case 4: Effort-effort causality:*

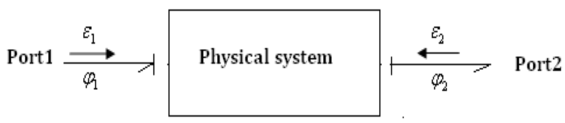

Figure 6: Reduced bond graph model with Effort-effort causality

$$\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \quad [33]$$

$$W = \begin{bmatrix} \dfrac{-1+H_{11}-H_{22}+\Delta H}{2H_{21}} & \dfrac{1-H_{11}-H_{22}+\Delta H}{2H_{21}} \\ \dfrac{-1-H_{11}-H_{22}-\Delta H}{2H_{21}} & \dfrac{1+H_{11}-H_{22}-\Delta H}{2H_{21}} \end{bmatrix} \quad [34]$$

We note that H_{ij} are the integro-differentials operators which are based in their determination, on the causal ways and algebraic loops present in the associated bond graph model.

$$H_{ij} = \sum_{k=1}^{N} \frac{G_k \Delta_k}{\Delta} \quad [35]$$

$$\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + ... + (-1)^m \sum ... + ...$$

[36]

Where: Δ = the determinant of the causal bond graph.

H_{ij} = complete gain between P_j and P_i

P_i = input port.

P_j = output port.

N= total number of forward paths between P_i and P_j

G_k = Gain of the k^{th} forward path between P_i

G_k = Gain of the k^{th} forward path between P_i and P_j

L_i = Loop gain of each causal algebraic loop in the bond graph model.

$L_i L_j$ = Product of the loop gains of any two non touching loops (no common causal bond).

$L_i L_j L_k$ =product of the loop gains of any three pair non-touching loops.

Δ_k = the factor value of Δ for the k^{th} forward path, with the loops touching the k^{th} forward path removed; i.e., Remove those parts of the causal bond graph which form the loop, while retaining the parts needed for the forward path.

IV. APPLICATION TO A MATCHING NETWORK OF A PLANAR INVERTED F ANTENNA

The low bandwidth is one of the main disadvantages of micro strip antenna. One of the most reliable methods to increase the bandwidth of micro strip antenna is to introduce multiple resonances by introducing parasitic elements or reactive matching circuit between the generator and the antenna.

This technique allows increasing the bandwidth not only for a single-band antenna, but also for a multi-band antenna. In this work we propose a circuit of PIFA antenna that resonates at 0.9GHz and 1.8GHz. This antenna is preceded by a matching circuit.

From the scattering bond Graph method we extract the different variation of reflection and transmission coefficient of the matching circuit.

The complete circuit is given below:

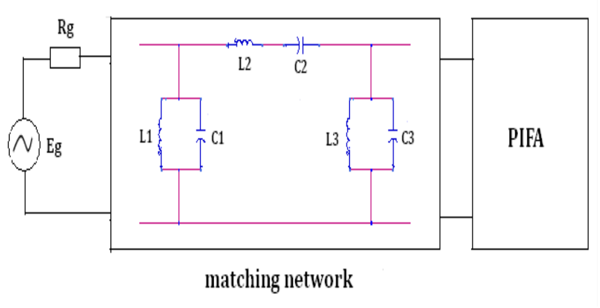

Figure7: System of matching Network adding to PIFA

L1= 1.529nH, L2=1.897nH, L3=2.162nH, C1=6.536pF, C2=4.865pF, C3=2.431pF

The following bond graph (Figure8) is presented to modeling the circuit and to show the distribution of electromagnetic waves. Here the antenna is considered as load and it's presented simply by resistance R.

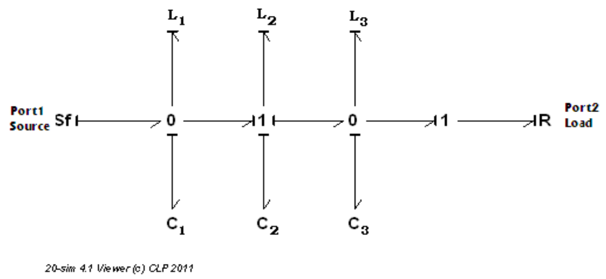

Figure8: bond graph model of circuit

To extract the scattering parameters from the bond graph representation and by using the new method which is described previously, we must transform the bond graph model given by figure above(Figure8) into a causal bond graph model often named reduced bond graph model only containing the decomposition junction (1-jonction or 0-jonction) and the reduced variables.

The causal bond graph of circuit is given by Figure9.

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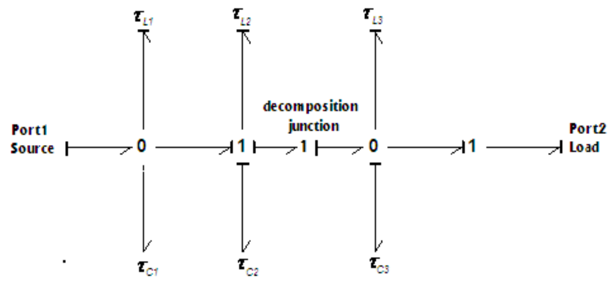

Figure9: The reduced and transformed bond graph model

$$\tau_{L_1} = \frac{L_1}{R_0} \qquad \tau_{L_2} = \frac{L_2}{R_0}$$

$$\tau_{L_3} = \frac{L_3}{R_0} \qquad \tau_{C_1} = C_1.R_0$$

$$\tau_{C_2} = C_2.R_0 \qquad \tau_{C_3} = C_3.R_0$$

By decomposition the reduced bond graph given by

figure 9, we will have the following bond graph representation:

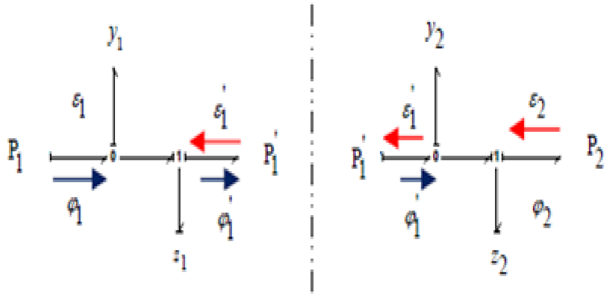

Figure10: The tow bond graph sub-model

Notice that:

• z_i : the reduced equivalent impedance of the element i put in series.

• y_i : the reduced equivalent admittance of the element i put in parallel.

So we have:

$$y_1 = \tau_{C_1}.s + \frac{1}{\tau_{L_1}.s} \qquad z_1 = \tau_{L_2}.s + \frac{1}{\tau_{C_2}.s}$$

$$y_2 = \tau_{C_3}.s + \frac{1}{\tau_{L_3}.s} \qquad z_2 = r_1 \text{ With } r_1 = \frac{R_1}{R_0}$$

s: The laplace operator

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

$B_1 = -\frac{1}{z_1.y_1}$: Loop gain of the algebraic loop by the first sub- model

$B_2 = -\frac{1}{z_2.y_2}$: Loop gain of the algebraic loop by the second sub- model

$\Delta_1 = 1 + \frac{1}{z_1.y_1}$: Determinant of causal bond graph of the first sub- model

$\Delta_2 = 1 + \frac{1}{z_2.y_2}$: Determinant of causal bond graph of the second sub- model

$$\begin{cases} H_{11} = \dfrac{z_1}{z_1.y_1 + 1} \\ H_{12} = \dfrac{1}{z_1 y_1 + 1} \\ H_{21} = \dfrac{1}{z_1.y_1 + 1} \\ H_{22} = -\dfrac{y_1}{z_1.y_1 + 1} \\ \Delta(s) = \dfrac{-1}{z_1.y_1 + 1} \end{cases}$$

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

$$\begin{cases} H_{11} = \dfrac{z_2}{z_2.y_2 + 1} \\ H_{12} = \dfrac{1}{z_2 y_2 + 1} \\ H_{21} = \dfrac{1}{z_2.y_2 + 1} \\ H_{22} = -\dfrac{y_2}{z_2.y_2 + 1} \\ \Delta(s) = \dfrac{-1}{z_2.y_2 + 1} \end{cases}$$

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

From these operators, we can deduce directly the wave matrix of the first and second sub-model by taking into account to equations 30 of the reduced bond graph model with effort-flow causality:

$$W^{(1)} = \frac{1}{2}\begin{bmatrix} z_1 y_1 - z_1 - y_1 + 2 & -z_1 y_1 + z_1 + y_1 \\ -z_1 y_1 - z_1 + y_1 & z_1 y_1 + z_1 + y_1 \end{bmatrix}$$

$$W^{(2)} = \frac{1}{2}\begin{bmatrix} z_2 y_2 - z_2 - y_2 + 2 & -z_2 y_2 + z_2 + y_2 \\ -z_2 y_2 - z_2 + y_2 & z_2 y_2 + z_2 + y_2 \end{bmatrix}$$

The wave matrix of the complete system can be given by the product of the first and the second wave matrix such us:

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

V. SIMULATION RESULTS OF THE SCATTERING PARAMETERS

A simple programming and simulation of the above scattering parameters equations, give the figure 12, figure 14, figure 16 and figure 18 below which represent respectively the reflection and transmission coefficients of the studied matching network.

To validate the results of the scattering equations we simulated the circuit of matching network by ADS software, the results obtained are Figure 13, 15, 17 and 19.

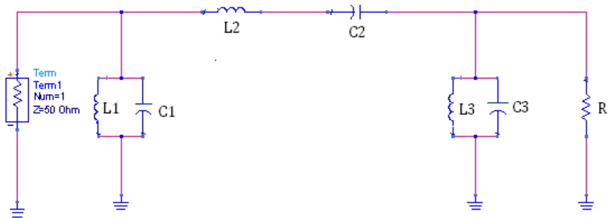

Figure11: circuit of matching network simulated by ADS

Simulation of scattering parameters by maple software

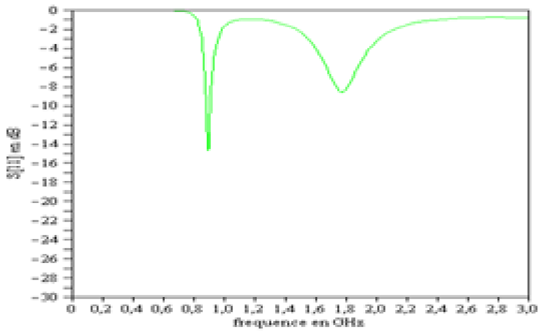

Figure12: Reflection coefficient S11 seen at entry

Simulation of matching network circuit by ADS

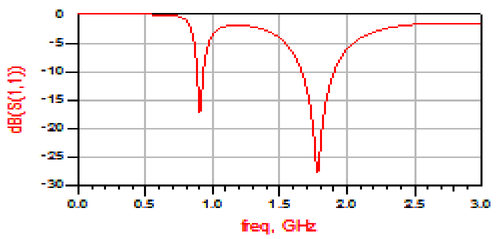

Figure13: Reflection coefficient S11 seen at entry

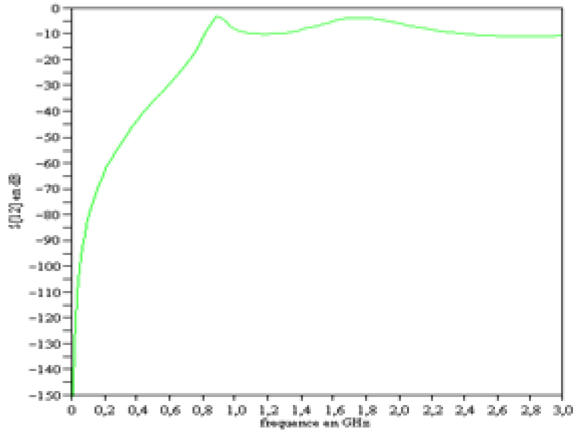

Figure14: Transmission coefficient S12 seen from exit to entry

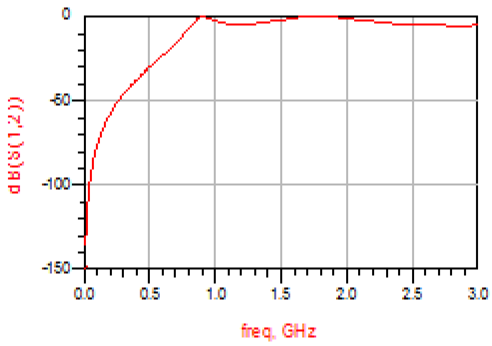

Figure15: Transmission coefficient S12 seen from exit to entry

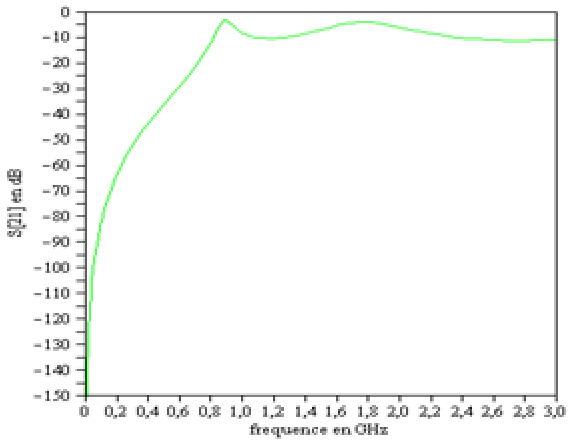

Figure16: Transmission coefficient S21 seen from entry to exit

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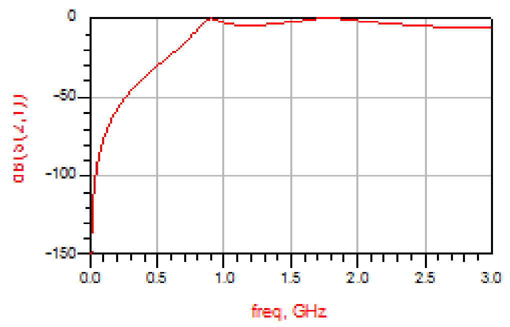

Figure17: Transmission coefficient S21 seen from entry to exit

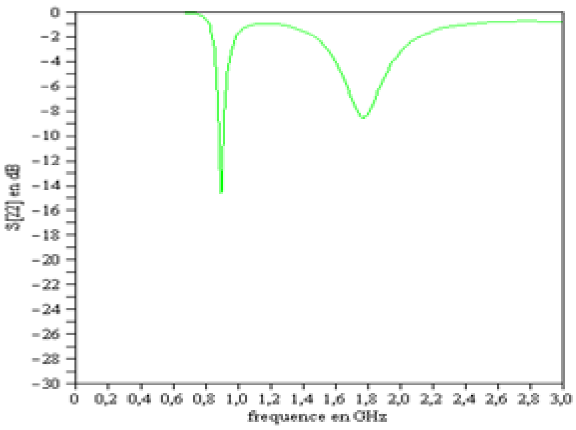

Figure18: Reflection coefficient S22 seen at exit

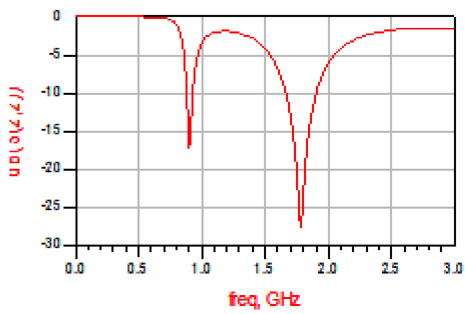

Figure19: Reflection coefficient S22 seen at exit

We note that the results obtained from the scattering bond graph method are similar to the results obtained by ADS. That implies the effectiveness of the chosen method

VI. CONCLUSION

In this work we presented a new method to analyze high frequency systems. This method is based on the combination of scattering formalism with the bond graph model; it is applied scattering bond graph method. We applied it to analyze a matching network circuit of PIFA. To validate the obtained results we compared them with the results of simulation circuit by ADS. The advantage of scattering bond graph method is the simplicity and speed execution. It can also get an idea about a high frequency system before conception step, such as gain, bandwidth, reflection and transmission coefficient.

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