Modelling and Determination of the Scattering Parameters Of Wideband Patch Antenna By Using A Bond Graph Approach

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ABSTRACT

In the setting of research works which study the modeling and the simulation of physical systems functioning at high frequency (transmission lines, filter based on localized elements, patch antenna, etc...) , we propose in this paper a new method to improve the analysis of the wideband antenna which is the bond graph approach. This type of antenna is gotten by using several shapes as the parasitic antenna that has a narrow bandwidth. This study describes the modeling of a parasitic antenna by bond graph approach and the simulation of the scattering parameters of this antenna. Our aim, also, is to control the bandwidth through the capacity of coupling between the main patch and the parasitic patch.

Keywords - Parasitic antenna, Bond Graph Modeling, Microstrip Patch Antenna (MPA), Square Patch, Scattering Formalism.

I. INTRODUCTION

A microstrip patch antenna is a critical component for any wireless communication systems because it has many favorable characteristics as planar configuration, low profile, light weight, easy analysis and easy integration with other microwave circuits but, in general, rectangular patch antennas have the disadvantage of a narrow bandwidth. This last parameter is an important one for certain systems as that to the reading level of systems known as Radio Frequency Identification (RFID). This type of antenna is gotten by the network of patch antennas or by the parasitic antennas [1]. In the setting of this article, we have constructed the precise and simple electric models from the geometric measurements of the patch antenna to be able to control the coupling between the two elementary (main patch and parasitic patch). On the other hand, we can follow the resonance frequency and width band of a simple way. This electric model has been constructed while even applying the technical for the simple patch [2]. First we have determined the model bond graph of the parasitic antenna. Then we have transformed this last model to the reduced bond graph model by the integro-differentials operators which is based on the causal ways [3] to determine the scattering parameters (reflection and transmission coefficient). Finally we repeat the simulation using ADS simulator to make a simple comparison between the two methods.

II. STRUCTURE OF WIDEBAND PATCH ANTENNA

To have an antenna with a wideband, we proposed parasitic antenna shown by figures 1(a) and (b) which represents respectively the 3D schematic structure and the side view of the proposed MPA. We chose the square shape, the main and the parasitic patch to follow the same equations for the rectangular shape, the same width and length of the patch was made to ease the determinations of the parameters of our antenna.

Fig. 1 (a) 3D schematic structure of parasitic antenna (b) side view of parasitic antenna

The proposed antenna is formed by two elementary patches, the main patch and the parasitic patch which has the same geometric measurements. We can apply the electric model to the parasitic patch without forgetting the importance of coupling between the two radiating elements [1] [4] as figure 2 shows, the main patch is considered as virtual ground plan for the parasitic patch. C1 denotes the capacitive coupling caused by the two resonators. These are the main patch (R1, L1, C1) and the parasitic patch (R2, L2, C2).
III. THEORETICAL CONSIDERATION

3.1 Analysis of parasitic antenna:

The width of (MPA) can be determined by using the following equation (2) [5]:

\[ W = \frac{1}{2f_r \sqrt{\mu_0 \epsilon_0}} \sqrt{\frac{2}{\epsilon_r + 1}} \] (1)

Where \( f_r \) is resonant frequency, \( \epsilon_r \) and \( \mu_0 \) are the permittivity and the permeability in free space, respectively.

The determinations of the parameters of the main and the parasitic are determined by the following equations:

\[ C = \frac{\epsilon_{eg} \epsilon_0 W^2}{2H} \cos^{-2} \left( \frac{\pi x_0}{W} \right) \] (2)

\( C \): capacitance

\( x_0 \): the distance of the feed point from the edge of the patch.

\( H \): thickness of dielectric

The inductance \( L \) is given by:

\[ L = \frac{1}{w_{res} C} \] (3)

\[ w_{res} = 2\pi f_r \] (4)

The resistance \( R \) is calculated using equation (5):

\[ R = \frac{Q_f}{w_0 C} \quad Q_f : \text{Quality factor} \] (5)

\[ Q_f = \left[ \frac{1}{Q_R} + \frac{1}{Q_C} + \frac{1}{Q_D} \right]^{-1} \] (6)

\[ Q_D = \frac{1}{T g6} : \text{Losses in the dielectric} \] (7)

\[ Q_R = \frac{\epsilon_0 \sqrt{\epsilon_{dyn}}}{4f_r V} : \text{Radiation quality factor} \] (8)

\[ Q_C = \frac{0.786 \sqrt{\pi Z_{a0}(W)H}}{P_a} : \text{Losses in the conductor} \] (9)

\[ Z_{a0}(W) = \frac{60\pi W}{3H} \left[ \frac{W}{2} + 0.441 + 0.082 \left( \frac{\epsilon_r - 1}{\epsilon_r + 1} \right) \right]^{1/2} \] (10)

Is the impedance of an air filled microstrip line

\[ Z_{a0}(W) = Z_a(W, \epsilon_r = 1) \]

\[ P_0(\epsilon_r) = 2r \left[ \frac{W}{2H} + 0.94 \right]^{1/2} \] (11)

\( r \) is the tangent of loss in the dielectric and is given by:

\[ r = \frac{\mu_0 H_0}{\epsilon_r \epsilon_0} \] (12)

\[ \epsilon_{dyn} = \frac{C_{dyn}(\epsilon_r)}{C_{dyn}(\epsilon_0)} \] (13)

\[ C_{dyn}(\epsilon_r) = \frac{\epsilon_r \epsilon_0 A}{\epsilon_r H_0} + 1 \] (14)

\( A \): is the coupling between the two patches.

The effective dielectric constant of microstrip line and is given by:

\[ \epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left( 1 + 2 \frac{H}{W} \right) \] (17)

\( \gamma_{j} = \begin{cases} 1, & j = 0 \\ 2, & j \neq 0 \end{cases} \) (15)

The capacity of Gap in presence of dielectric which describes the coupling between the two patches is given by:

\[ C_{ed} = \epsilon_0 \epsilon_r \ln \cosh \left( \frac{\pi x}{4H} \right) + 0.65C \left[ \frac{0.02H}{S} \sqrt{\epsilon_r} + (1 - \frac{1}{\epsilon_r}) \right] \] (18)

\( C_f = C_{f1} + C_{f2} \)

\( C_{f1} = \frac{1}{2T g_6} \left[ \frac{Z(W, H, \epsilon_r = 1) - \epsilon_0 \epsilon_r W}{cZ^2(L, H, \epsilon_r)} \right] L \] (19)

\( C_{f2} = \frac{1}{2T g_6} \left[ \frac{Z(W, H, \epsilon_r = 1) - \epsilon_0 \epsilon_r W}{cZ^2(L, H, \epsilon_r)} \right] W \] (20)
3.2 Characteristics of parasitic antenna

The summary of antenna characteristics are shown on table1, the main patch and the parasitic patch have the same measurements and characteristics.

<table>
<thead>
<tr>
<th>Main patch characteristics</th>
<th>value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main patch width (W)</td>
<td>37.9mm</td>
</tr>
<tr>
<td>Relative permittivity (εr)</td>
<td>2.6</td>
</tr>
<tr>
<td>Tang (δ)</td>
<td>0.002</td>
</tr>
<tr>
<td>Thickness of dielectric (Ht)</td>
<td>3.2mm</td>
</tr>
</tbody>
</table>

Table 1. Summary of patch characteristics

I. SCATTERING PARAMETERS OF THE PARASITIC ANTENNA

First we propose to determine the scattering parameters [6] of the parasitic antenna [2] from its reduced bond graph model [7] without forgetting causality assignment. Finally we compare the results found by the method of bond graph with the results determined by using the classic method (HP-ADS software).

![Fig.3 Reduced bond graph model of the parasitic antenna](image)

4.1 Determination of the bond graph model of the parasitic antenna

The equivalent circuit of parasitic antenna that is already shown permits us to determine the reduced bond graph model [11] given by the following figure.

• zC: the reduced impedance of the element put in series

The figure 3 indicates that our system is composed of three main parts that are port 1 (power source), port 2 (load) and quadruple (process). The causality assignment in input-output of this process [10] is shown by figure 4

![Fig.4 Reduced bond graph model with flow-effort causality](image)

* ε₁ and ε₂ are respectively the reduced variable (effort) at the entry and the exit of the system.
* φ₀ and φ₂ are respectively the reduced variable (flow) at the entry and the exit of the system.

This type of reduced and causal bond graph has the following matrix:

\[
\begin{bmatrix}
\varepsilon_1 \\
\phi_2
\end{bmatrix} =
\begin{bmatrix}
H_{11} & H_{12} \\
H_{21} & H_{22}
\end{bmatrix}
\begin{bmatrix}
\phi_1 \\
\varepsilon_2
\end{bmatrix}
\]

We can note

\[
H =
\begin{bmatrix}
H_{11} & H_{12} \\
H_{21} & H_{22}
\end{bmatrix}
\]

Hᵣ represent the integro-differentials operators associated to the causal ways connecting the port Pᵢ to the port P j, and obtained by the general form given below.

\[
Hᵣ = \sum_{k=1}^{n} \frac{T_k \Delta}{\Delta}
\]

\[
\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + \ldots + (-1)^n \sum 
\]

* Hᵣ: complete gain between Pᵢ and P j
* Δ: the factor value of Δ for the kᵗʰ forward path, this value calculates himself as Δ when one only keeps the causal loops without touching the kᵗʰ chain of action.

We noted:

\[
a_i = \frac{\varepsilon_i + \phi_s}{2}, \quad a_i = \frac{\varepsilon_i - \phi_s}{2}
\]
\[ \varepsilon_i = \frac{V}{\sqrt{R_0}}, \quad \phi_i = I \sqrt{R_0} \]  

(26)

These are reduced voltage and current.

\[ \begin{pmatrix} \varepsilon_i \\ \phi_i \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} \]  

(27)

\[ \begin{pmatrix} \varepsilon_2 \\ -\phi_2 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} \]  

(28)

\[ \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ b_2 \end{pmatrix} = (W) \begin{pmatrix} a_1 \\ b_2 \end{pmatrix} \]  

(29)

We use the preceding equations; we can find for each case of causality one wave matrix.

\[ W = \frac{1}{2H_{i1}} \begin{pmatrix} 1 + H_{11} + H_{22} + \Delta H & 1 - H_{11} - H_{22} + \Delta H \\ 1 + H_{11} + H_{22} + \Delta H & 1 - H_{11} - H_{22} + \Delta H \end{pmatrix} \]  

(30)

With

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

(31)

The following scattering matrix gives us the scattering parameters:

\[ \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ b_2 \end{pmatrix} = (S) \begin{pmatrix} a_1 \\ b_2 \end{pmatrix} \]  

(32)

The relation between equations permits us to get the following equations:

\[ \begin{align*}
  w_{11} & = -s_{22}s_{21} \\
  w_{12} & = s_{21} \\
  w_{21} & = (s_{12}s_{21} - s_{11}s_{22})s_{21} \\
  w_{22} & = s_{11}s_{21}
\end{align*} \]

The corresponding scattering matrix is given by:

\[ S = \begin{pmatrix} w_{11}w_{22} - w_{12}w_{21} & w_{12}w_{22} - w_{11}w_{21} \\ w_{21}w_{22} - w_{22}w_{21} & -w_{21}w_{22} - w_{22}w_{21} \end{pmatrix} \]  

(33)

We can make a decomposition of the reduced bond graph model [3] [9] [10] given by figure 3 to determine the W matrix easily, this decomposition is given by figure 5 and 6.

\[ H_{11} = \frac{z_{CC}}{z_{CC}y_{mp} + 1} \]  

(34)

\[ H_{12} = \frac{1}{z_{CC}y_{mp} + 1} \]  

(35)

\[ H_{21} = \frac{1}{z_{CC}y_{mp} + 1} \]  

(36)

\[ H_{22} = \frac{z_{CC}y_{mp} + 1}{z_{CC}y_{mp} + 1} \]  

(37)

Fig. 5 Decomposition of reduced bond graph model

Fig. 6 The first and the second sub-model
The simulation given by figure 8 shows the variation of parasitic antenna bandwidth according Cc if we use the HP-ADS software.

We can see that the two results are similar, if we use the traditional method (HP-ADS software) or we used this new method (the bond graph approach), we find the same characteristics of the reflection coefficient.

IV. CONCLUSION

This study designed the parasitic antenna that has a narrow bandwidth. We notice that the bandwidth is variable by varying the coupling capacity which is proportional to the dimensions of the parasitic patch and the distance between the two patches. In this paper we chose the tool of modelling using bind graph approach to analyze the parasitic antenna, this tool offers us several advantages as the possibility to simulate structures of a simple, fast, efficient and more economic manner. For these reasons, it is possible to apply this new analysis method in many wireless systems and microwaves domain.

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