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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 witch 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 (reflexion 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.

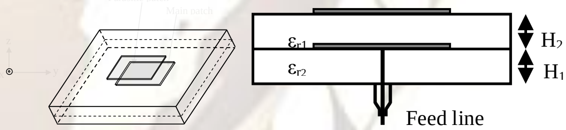

Fig. 1 (a) 3D schematic structure of parasitic antenna (b) side view of parasitic antenna

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. C_c denotes the capacitive coupling caused by the two resonators. These are the main patch (R_1 L_1 C_1) and the parasitic patch (R_2 L_2 C_2).

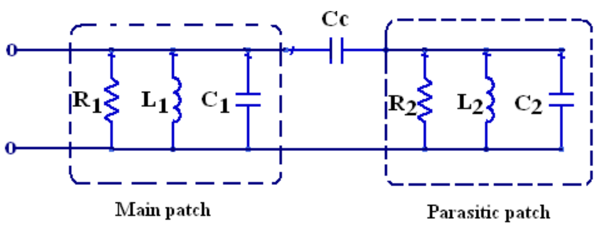

Fig. 2 Equivalent circuit of the proposed parasitic patch antenna

III. THEORETICAL CONSIDERATION

3.1 Analysis of parasitic antenna:

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

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where f_r resonant frequency

ε_0 and μ_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

$$C = \frac{\varepsilon_{eff}\varepsilon_0 W^2}{2H}\cos^{-2}\left(\frac{\pi x_0}{W}\right) \qquad (2)$$

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:

$$L = \frac{1}{w_{res}^2 C} \qquad (3)$$

$$w_{res} = 2\pi f_r \qquad (4)$$

The resistance R is calculate using equation (5)

$$R = \frac{Q_T}{w_r C} \qquad Q_T \text{ : Quality factor} \qquad (5)$$

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

$$Q_D = \frac{1}{Tg\delta} \text{ : Losses in the dielectric} \qquad (7)$$

$$Q_R = \frac{c_0\sqrt{\varepsilon_{dyn}}}{4f_r H} \text{ : Radiation quality factor} \qquad (8)$$

$$Q_C = \frac{0.786\sqrt{f_r Z_{a0}(W)}H}{P_a} \text{ : Losses in the conductor} \qquad (9)$$

$$Z_a(W) = \frac{60\pi}{\sqrt{\varepsilon_r}}\left\{\frac{W}{2H}+0.441+0.082\left(\frac{\varepsilon_r-1}{\varepsilon_r^2}\right) + \frac{(\varepsilon_r+1)}{2\pi\varepsilon_r}(1.451+\ln[\frac{W}{2H}+0.94])\right\}^{-1} \qquad (10)$$

Is the impedance of an air filled microstrip line

$$Z_{a0}(W) = Z_a(W, \varepsilon_r = 1)$$

$$P_a(W) = 2\pi\left(\frac{W}{H}+\frac{\frac{W}{H\pi}}{\frac{W}{2H}+0.94}\right)\left(1+\frac{W}{H}\right)\left\{\frac{W}{H}+\frac{2}{\pi}\ln[2\pi\exp(\frac{W}{2H}+0.94)\right\}^{-2} \qquad (11)$$

Tgδ: is the tangent of loss in the dielectric and is given by:

$$\delta = \left[\frac{H}{W}0.882+\left[0.164(\varepsilon_r-1)/\varepsilon_r^{\ 2}+((\varepsilon_r+1)(0.756+\ln(\frac{W}{H}+1.88))/\pi\varepsilon_r\right]\right] \qquad (12)$$

$$\varepsilon_{dyn} = \frac{C_{dyn}(\varepsilon)}{C_{dyn}(\varepsilon_0)} \qquad (13)$$

$$C_{dyn}(\varepsilon) = \frac{\varepsilon_0\varepsilon_r A}{H\gamma_n\gamma_m}+\frac{1}{2\gamma_n}\left[\frac{\varepsilon_{reff}(\varepsilon_r,H,W)}{c_0 Z(\varepsilon_r=1,H,W)}-\frac{\varepsilon_0\varepsilon_r A}{H}\right] \qquad (14)$$

$$\gamma_j = \begin{cases}1, & j=0\\ 2, & j\neq 0\end{cases}$$

$$Z(W,H,\varepsilon_r) = \frac{377}{H}\left[\frac{W}{H}+1.393+0.667\ln\left[\frac{W}{H}+1.44\right]\right]^{-1} \qquad (15)$$

$$f(\frac{W}{H}) = 6+(2\pi-6)\exp(-\frac{36.66H}{W})0.7528 \qquad (16)$$

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

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\frac{H}{W}\right)^{-\frac{1}{2}} \qquad (17)$$

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

$$C_{gd} = \frac{\varepsilon_0\varepsilon_r}{\pi}\ln\coth\left(\frac{\pi s}{4H}\right)+0.65C_f\left[\frac{0.02H}{S}\sqrt{\varepsilon_r}+(1-\frac{1}{\varepsilon_r^2})\right] \qquad (18)$$

$C_f = C_{f1}+C_{f2}$ $\qquad C_f$: Fringe capacity

$$C_{f1} = \frac{1}{2\gamma_n}\left[\frac{Z(W,H,\varepsilon_r=1)}{cZ^2(L,H,\varepsilon_r)}-\frac{\varepsilon_0\varepsilon_r W}{H}\right]L \qquad (19)$$

$$C_{f2} = \frac{1}{2\gamma_m}\left[\frac{Z(W,H,\varepsilon_r=1)}{cZ^2(L,H,\varepsilon_r)}-\frac{\varepsilon_0\varepsilon_r W}{H}\right]W \qquad (20)$$

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.

Main patch characteristics	value (mm)
Main patch width (W)	37.9mm
Relative permittivity (ε_{r1})	2.6
Tang (δ)	0.002
Thickness of dielectric (H_1)	3.2mm

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).

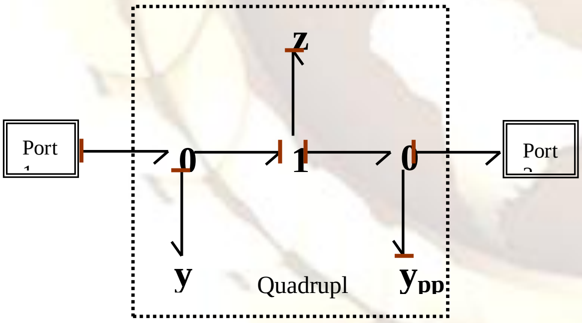

Fig.3 Reduced bond graph model of the parasitic antenna

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.

• ymp and ypp: are respectively the reduced equivalent admittance of the main patch and parasitic patch.

• zCc: 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

▪ ε_1 and ε_2 are respectively the reduced variable (effort) at the entry and the exit of the system.

▪ $\varphi_1$and φ_2 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:

$$\begin{bmatrix} \varepsilon_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varepsilon_2 \end{bmatrix} \quad (21)$$

We can note

$$H = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \quad (22)$$

H_{ij} represent the integro-differentials operators associated to the causal ways connecting the port P_j to the port P_i and obtained by the general form given below.

$$H_{ij} = \sum_{k=1}^{n} \frac{T_k \Delta_k}{\Delta} \quad (23)$$

$$\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + \ldots + (-1)^m \sum \ldots \quad (24)$$

▪H_{ij}= complete gain between P_j and P_i.

▪ Δ= the determinant of the causal bond graph

▪P_i= input port.

▪P_j= output port.

▪T_k= gain of the k^{th} forward path between P_i and P_j

▪n= total number of forward path between P_i and P_j

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

▪L_iL_j= product of loop gains of any tow non-touching loops (no common causal bond).

▪$L_iL_jL_k$= product of the loop gains of any three pair wise no touching loops.

▪Δ_k= the factor value of Δ for the k^{th} forward path, this value calculates himself as Δ when one only keeps the causal loops without touching the k^{th} chain of action.

We noted:

$$a_i = \frac{\varepsilon_i + \varphi_i}{2}, \quad a_i = \frac{\varepsilon_i - \varphi_i}{2} \quad (25)$$

$$\varepsilon_i = \frac{V}{\sqrt{R_0}}, \quad \varphi_i = I\sqrt{R_0} \tag{26}$$

These are reduced voltage and current.

$$\begin{pmatrix} \varepsilon_1 \\ \varphi_1 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} \tag{27}$$

$$\begin{pmatrix} \varepsilon_2 \\ -\varphi_2 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} \tag{28}$$

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{pmatrix} \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = (W) \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} \tag{29}$$

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

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

With

$$\Delta H = H_{11} H_{22} - H_{12} H_{21} \tag{31}$$

The following scattering matrix gives us the scattering parameters:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \begin{pmatrix} a_2 \\ a_2 \end{pmatrix} = (S) \begin{pmatrix} a_1 \\ A_2 \end{pmatrix} \tag{32}$$

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

$$\begin{cases} w_{11} = -s_{22}\, s_{21}^{-1} \\ w_{12} = s_{21}^{-1} \\ w_{21} = (s_{12}s_{21} - s_{11}s_{22})\, s_{21}^{-1} \\ w_{22} = s_{11}\, s_{21}^{-1} \end{cases}$$

The corresponding scattering matrix is given by:

$$S^T = \begin{bmatrix} w_{12} w_{22}^{-1} & (w_{11}w_{22} - w_{21}w_{12})\, w_{22}^{-1} \\ w_{22}^{-1} & -w_{21} w_{22}^{-1} \end{bmatrix} \tag{33}$$

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

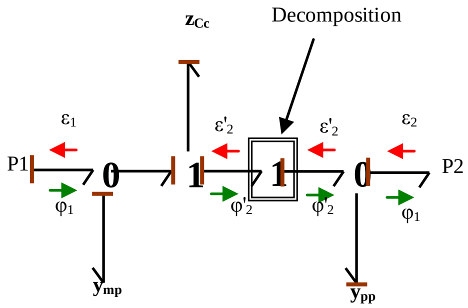

Fig. 5 Decomposition of reduced bond graph model

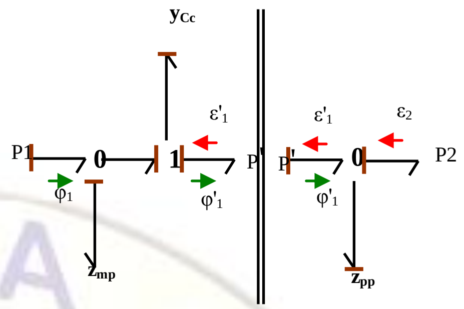

Fig. 6 The first and the second sub-model

$$y_{mp} = \tau_{cmp} s + \frac{1}{\tau_{Lmp} s} + \frac{1}{\tau_{Rmp}} \tag{34}$$

$$y_{pp} = \tau_{cpp} s + \frac{1}{\tau_{Lpp} s} + \frac{1}{\tau_{Rpp}} \tag{35}$$

$$z_{Cc} = \tau_{Cc} s \tag{36}$$

Where:

$$\tau_{Ci} = R_0 * C_i$$

$$\tau_{Li} = \frac{L_i}{R_0}$$

R_0: the scaling resistance and s: The Laplace operator.

We have the integro-differentials operators given by the previously equations.

$L_1 = \frac{-1}{z_{mp} y_{Cc}}$: Loop gains of algebraic given by sub-model.

$\Delta_1 = 1 + \frac{1}{z_{mp} y_{Cc}}$: Determinant of causal bond graph of the first sub model.

The following equations represent the integro-differentials operators of the model

$$\begin{cases} H_{11} = \dfrac{z_{Cc}}{z_{Cc} y_{mp} + 1} \\ H_{12} = \dfrac{1}{z_{Cc} y_{mp} + 1} \\ H_{21} = \dfrac{1}{z_{Cc} y_{mp} + 1} \\ H_{22} = \dfrac{-y_{mp}}{z_{Cc} y_{mp} + 1} \\ \Delta H = \dfrac{-1}{z_{Cc} y_{mp} + 1} \end{cases} \tag{37}$$

The equation 23 we permit to extract in the following matrix.

$$W_1 = \frac{1}{2}\begin{bmatrix} z_{Cc}y_{pp} - z_{Cc} - y_{pp} + 2 & z_{Cc}y_{pp} - z_{Cc} + y_{pp} \\ z_{Cc}y_{pp} + z_{Cc} - y_{pp} & z_{Cc}y_{pp} + z_{Cc} + y_{pp} + 2 \end{bmatrix} \quad (38)$$

With the same method we can determine W_2

$$W_2 = \frac{1}{2}\begin{bmatrix} 2 - y_{mp} & y_{mp} \\ y_{mp} & 2 + y_{pp} \end{bmatrix} \quad (39)$$

The wave matrix of the complete model can be given by the product of the first and the second wave matrix [8].

$$W_T = W_1 * W_p = \begin{pmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{pmatrix} \quad (40)$$

4.2 Simulations results

We used a simple programming and simulation under Maple software to determine scattering parameters. The variation of parasitic antenna bandwidth according to the capacity of coupling between the two patches is represented by figure 6.

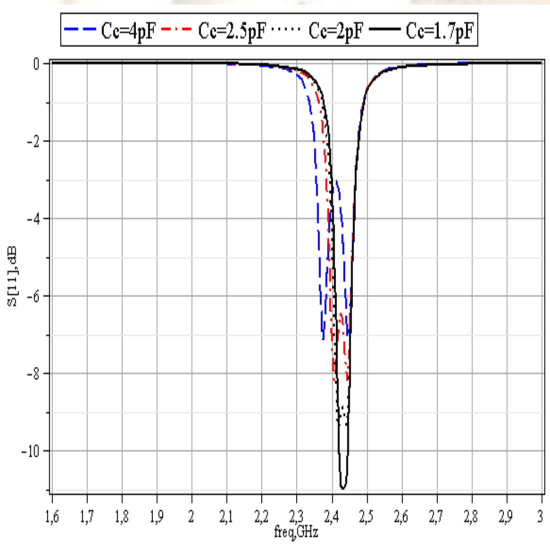

Fig.7 Variation of parasitic antenna bandwidth according Cc (using bond graph approach)

Our survey showed us that the variation of the coupling capacity C_c modifies the bandwidth as shown on the figure 7.

Indeed, Cc essentially depends on surfaces occupied by the two patches, the permittivity of substrate that separates them as well as the distance between the two resonant poles. Figure 6 show that the wideband increases progressively if the capacity of C_c coupling increases; the variation of C_c between 1.7pF and 4pF increases the wideband with 50 MHz.

The simulation given by figure 8 shows the variation of parasitic antenna bandwidth according Cc if we use the HP-ADS software.

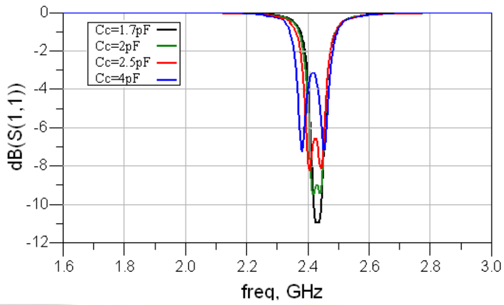

Fig.8 Variation of parasitic antenna bandwidth according Cc (under HP-ADS software)

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 band 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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