Impedance Matching of a Microstrip Antenna

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Abstract—**Microstrip patch antennas play a very significant role in communication systems. In recent years, the study to improve their performances has made great progression, and different methods have been proposed to optimize their characteristics such as the gain, the bandwidth, the impedance matching and the resonance frequency.**

This paper presents a new method that allows to ameliorate the impedance matching, thus to increase the gain of a rectangular microstrip antenna.

This method is based on the adaptation technique using a simple "L" matching network.

The originality of this work is the exploitation of the principle of causality that permits to detect the problems of reflected waves and to obtain the suitable placement of components that constitute the matching circuit.

Keywords—Impedance matching; microstrip antenna; "L" matching network; bond graph model; principle of causality; wave matrix; scattering matrix; transmission and reflection characteristics

I. INTRODUCTION

Microstrip patch antennas have been widely researched and developed in recent years. They are used in very specific communication applications such as radars, satellite, broadcasting, radio frequency identification [1].

In its simplest configuration, microstrip antenna consists of a radiating patch on one side of dielectric substrate, which has a ground plane on the other side [2], [3].

Compared with conventional antennas, microstrip patch antennas have better prospects and more advantages. They are lighter in weight, smaller in dimensions and they can be easily integrated with RF and microwave systems [4].

However, microstrip antenna have some drawbacks including narrow bandwidth, low power handling capability, low gain, low impedance matching [5]. But with technology advancements and extensive research into this area, these problems can be gradually overcome.

In this paper, we will present a new impedance matching

technique. This method is based on the principle of causality of bond graph and the "L" matching network and permits to improve the impedance matching of a rectangular microstrip antenna.

Firstly, we will present the notion of impedance matching and its different methods.

After that, we will choose the "L" matching network as the best method for improving the impedance matching and the gain of a microstrip antenna.

The principle of causality of bond graph will be exploited to detect the reflected waves and to deduce the appropriate structure of the "L" matching network.

II. IMPEDANCE MATCHING

In the high frequency domain, impedance matching is one of the most important applications used to improve the systems performances [6]. It requires adding a matching network between the source and the load of a system in the aim to ensure a maximum power transfer and to avoid the reflected waves [7].

The impedance matching network can be realized using a transformer, a quarter wave line or an "LC" network as "L", "T" or Π form. The most commonly used matching network in RF processing is the "L" network due to its simplicity, it is constituted only of two components; an inductance and a capacitance that can be controlled for adjusting the real and the imaginary part of the impedance without power loss.

The main principle of any impedance matching scheme is to force the load impedance to look like the complex conjugate of the source impedance, so a maximum power will be transferred to the load.

In RF domain, the first impedance matching concept was related to antenna matching with the aim to obtain desired characteristics such as the gain, the bandwidth and the resonance frequency without modifying the antenna geometry.

In the following, an "L matching network" will be used to improve the impedance matching of a microstrip antenna.

III. IMPEDANCE MATCHING OF A MICROSTRIP ANTENNA USING AN "L" NETWORK

A. Proposed Structure

The proposed model is given in Fig. 1, it is a microstrip antenna constituted by a substrate characterized by a dielectric constant $\varepsilon_r = 4.3$ and a thickness h=1.575 mm.

A rectangular copper patch characterized by a width W = 48.5 mm and a length L = 37.8 mm is deposited on one side of the substrate. On the other side is the ground plane.

This antenna is excited through a coaxial cable.

At the resonance frequency, this antenna behaves as a parallel RLC circuit such as given in Fig. 2. The values of RLC elements are determined using the antenna geometric parameters and the substrate characteristics [8].

S_e : Energy source

R_G : The characteristic impedance of generator

R1=20 ohms, L1=27.5 pH and C1=254.9pF

The behaviour of an antenna and its performance level can be deduced from the study of its reflection and transmission characteristics as function of frequency [9], [10].

In the following, we will use the "scattering-bond graph method" developed by A. Mami and H. Taghouti to determine the S-matrix describing the relationship between the incident and the reflected waves at the terminals of a system [11], [12].
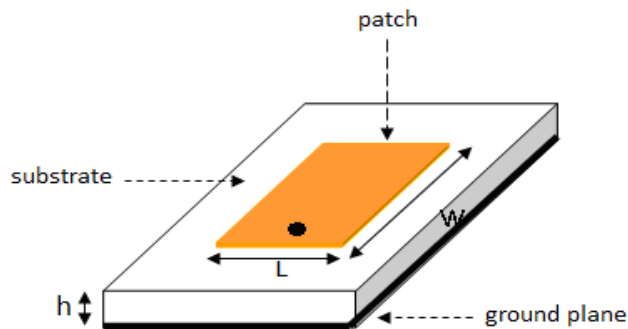
B. Presentation of the Scattering Matrix
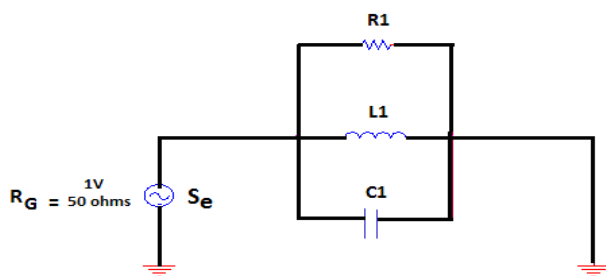
At microwave frequencies, it is difficult to measure the current and the voltage values. Instead, we can measure the transmission and the reflection waves using a network analyzer.

In other words, we can determine the relation between the incident and the reflected waves at each terminal of system to the incident and the reflected waves at all other terminals.

These relationships are completely represented by the scattering matrix called also "S- matrix" [13]-[15].

The problem with S-matrix is that it is not cascadable in its original form, that is to say, one cannot matrix multiply the individual S-matrices of cascaded two port networks to find the total S-matrix.

For this reason a W-matrix is defined. Contrary to S-matrix, this matrix is cascadable, and has a linear transformation relation with the S-matrix.

In the following paragraph, the bond graph model will be exploited to determine the W-matrix, thus the S-matrix of the studied antenna.

C. Using the Bond Graph to Deduce the S-matrix of the Studied Antenna

A bond graph is a graphical representation of physical dynamic system [16], [17]. By this approach, a physical system can be represented by symbols and lines identifying the power flow paths.

The lumped elements such as the resistance, the capacitance and the inheritance are interconnected in an energy conserving way by bonds and junctions resulting in a network structure.

From the pictorial representation of the bond graph, the derivation of system equations is so systematic.

The technique that permits to deduce the S-matrix of a system from its bond graph model is called the scattering-bond graph formalism [18].

Taking into account the impedance of generator " R_G ", the bond graph model of the studied antenna is given in Fig. 3.

Fig. 1.   Microstrip antenna.

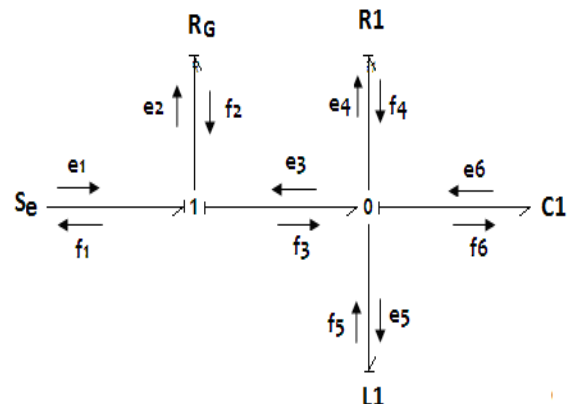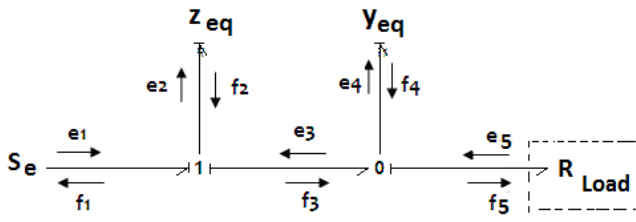Fig. 2.   Electrical model of antenna.

Fig. 3.   Bond graph model.

Fig. 4.   Reduced bond graph model.

The reduced bond graph model is given in Fig. 4, it is constituted only by an impedance z_{eq} linked to 1-junction and an admittance y_{eq} linked to a 0- junction [19], [20].

R_{Load} : is an imaginary load

The resistance of generator is replaced by reduced impedance z_{eq} linked to a 1-junction and the parallel elements R1, L1 and C1 are replaced by a reduced admittance y_{eq} linked to a 0-junction.

$$z_{eq} = r_g \tag{1}$$

$$y_{eq} = \frac{1}{r_1} + \frac{1}{\tau_{L1}} + \tau_{C1} \tag{2}$$

The normalized values of R_G, R1, L1 and C1 are given in the following equations:

$$r_g = \frac{R_G}{R_0} \tag{3}$$

$$r_1 = \frac{R1}{R_0} \tag{4}$$

$$\tau_{C1} = C1.R_0 \tag{5}$$

$$\tau_{L1} = \frac{L1}{R_0} \tag{6}$$

Basing on the bond graph theory, the impedance linked to the 1-junction can be represented by a wave matrix W_1 :

$$W_1 = \begin{bmatrix} \dfrac{z_{eq}+2}{2} & \dfrac{-z_{eq}}{2} \\ \dfrac{z_{eq}}{2} & \dfrac{2-z_{eq}}{2} \end{bmatrix} \tag{7}$$

The admittance linked to 0-junction can be represented by a wave matrix W_2 :

$$W_2 = \begin{bmatrix} \dfrac{y_{eq}+2}{2} & \dfrac{y_{eq}}{2} \\ \dfrac{-y_{eq}}{2} & \dfrac{2-y_{eq}}{2} \end{bmatrix} \tag{8}$$

The total wave- matrix W_T of the system is obtained by the product of W_1 and W_2 :

$$W_T = W_1.W_2 = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \tag{9}$$

To determine the transmission and reflection coefficients, we must determine the Scattering matrix called S- matrix. The following linear transformation that links the S and W matrices can be exploited [21], [22], [23].

$$\begin{cases} S_{11} = W_{22}W_{12}^{-1} \\ S_{12} = W_{21} - W_{22}W_{12}^{-1}W_{11} \\ S_{21} = W_{12}^{-1} \\ S_{22} = -W_{12}^{-1}W_{11} \end{cases} \tag{10}$$

Thus, the total S- matrix describing the antenna is given in the following equation:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} W_{22}W_{12}^{-1} & W_{21} - W_{22}W_{12}^{-1}W_{11} \\ W_{12}^{-1} & -W_{12}^{-1}W_{11} \end{bmatrix} \tag{11}$$

The adaptation level of the antenna is determined from the characteristic of the reflection coefficient S11 as function of frequency given in Fig. 5.

According to the variation characteristic of S11 as function of frequency, the impedance matching is not ensured. In fact, in the antenna theory, a microstrip antenna is considered adapted only if the absolute value of S11 is greater than or equal to 15 dB.

To remedy this problem, thus to ensure a maximum power transfer, we will use the "L" matching network. The technique is explained in the following paragraph.
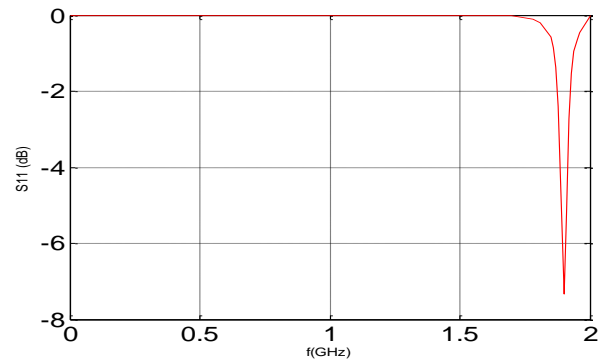

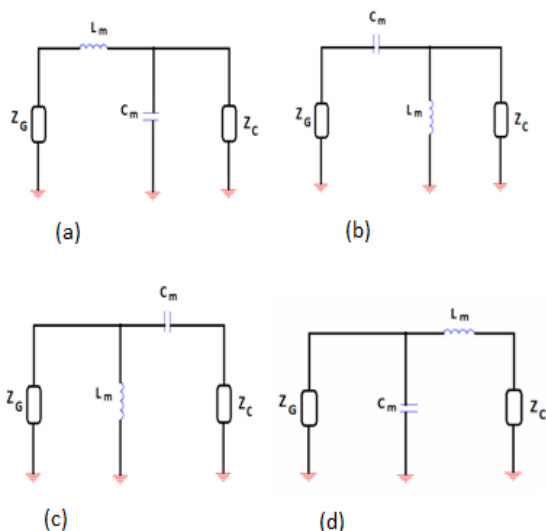Fig. 5.   Reflection coefficient S11 as function of frequency.

Fig. 6.   (a, b, c, d): Four configurations of L matching network.

D. "L" Matching Network Application

The "L" match circuit gets its name because the circuit topology can look like the letter "L". It is one of the easiest lossless ways of matching the source impedance to the load impedance.

The four configurations containing "L" matching network given in Fig. 6 are possible.

Z_G : is the impedance of the generator

Z_C : represents the characteristic impedance of antenna

L_m : Inductance of "L" matching network

C_m : Capacitance of "L" matching network

The concept of causality of bond graph can be used to choice the more appropriate disposition of the capacitance C_m and the inductance L_m in the L matching network [24]. In fact, the principle of causality imposes that:

- For 0-junctions, one of the bonds sets the effort for the rest, so only one causal stoke is on the junction, while the others are away from it.

- For 1-junctions, one of the bonds sets the flow for the rest, and its effort is computed from them, so all but one of the causal stokes are on the junction, while the remaining one is away from it.

Using the bond graph model, the previous four representations of matched antenna can be represented such as given in Fig. 7(a, b, c, d).

According to the principle of causality, for 0-junction, only one causal stroke must be on junction, while others must be away from it. This principle is not respected in the models given in Fig. 7(a) and 7(b).
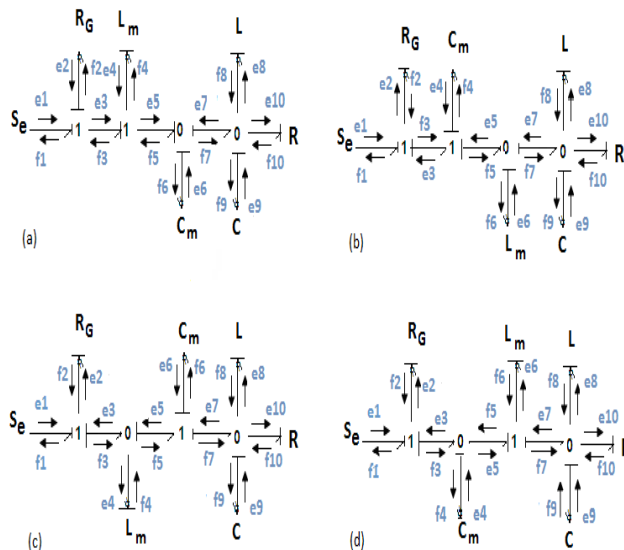

Fig. 7.   (a, b, c, d): Bond graph models of four matched antenna configurations.
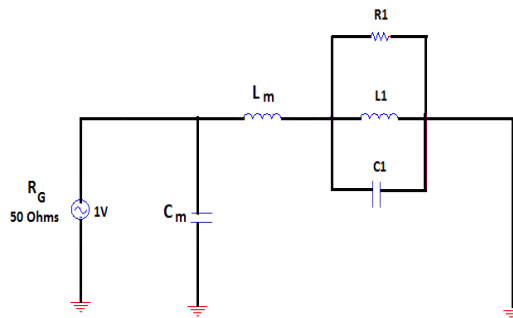

Fig. 8.   Electric model of matched antenna.

Thus, we will choose between the structure given in Fig. 7(c) and 7(d).

If we choose the model given by Fig. 7(d), the electric model of matched antenna is given in Fig. 8.

To find the values of L_m and C_m at a resonance frequency $f_r = 1.9 GHz$, we use the equations given below [25]:

$$C_m = \frac{1}{2\pi f_r} \sqrt{\frac{R_1 - R_2}{R_2}} \qquad (12)$$

$$L_m = \frac{R_2}{2\pi f_r} \sqrt{\frac{R_1 - R_2}{R_2}} \qquad (13)$$

Over a frequency range from 0 to 2GHz, we have compared the results of the variation of the reflection coefficient S11 as function of frequency with and without the "L" matching network. The result is shown in Fig. 9.
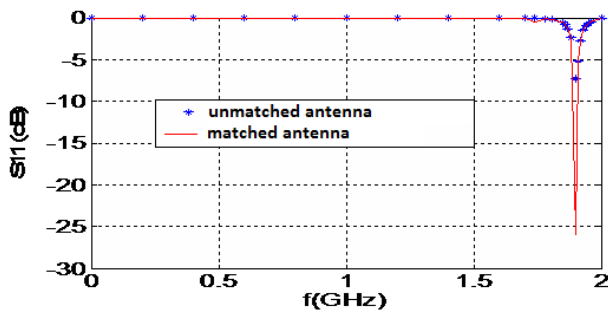
Fig. 9. S11 as function of frequency.

At the resonant frequency, the absolute value of S11 has gone up from 7.5 to 26 dB.

The "L" matching network permitted to improve considerably the gain of the microstrip antenna which is explained by a good impedance matching.

IV. CONCLUSION

Impedance matching is a widely used application in high frequency circuit design. It is concerned with matching one part of a circuit to another in order to achieve a maximum power transfer between the two parts and to minimize the reflected waves. There are different impedance matching network such as the "L" matching network, the transmission line matching circuit and the quarter wave impedance transformer.

In this work, we used the "L" matching network to match the impedance of a microstrip antenna, thus to improve its gain and resonant frequency. This choice is due to the simplicity, low cost and ease of design of an "L matching network"; it is only constituted by an inductance and a capacitance.

The principle of causality is used to detect the problem of reflected waves and to choice the more appropriate disposition of the "L" circuit components.

The method presented in the work of A. Mami and H. Taghouti is exploited to determine the scattering matrix of the antenna.

The simulation result of the reflection coefficient S11 as function of frequency with and without impedance matching shows that the gain of adapted antenna is more important.

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