A Simple Modified Transmission Line Model for Inset Fed Antenna Design

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Abstract

In this paper we propose the design of single inset fed printed antenna based on a simple modified transmission line model. The developed model is simple, accurate and takes into account all antenna characteristics and their feed system. To test the proposed model, the obtained results are compared to those obtained by the moment's method (Agilent Momentum software). Using this transmission line approach the resonant frequency, input impedance, return loss can be determined simultaneously. The paper reports several simulation results that confirm the validity of the developed model. The obtained results are then presented and discussed.

Keywords: *Printed inset fed antenna, transmission line model, moment's method (Momentum).*

1. Introduction

Microstrip antennas received considerable attention in the 1970's, although the first designs and theoretical models appeared in the 1950's. They are suitable for many mobile applications: handheld devices, aircraft, satellite, missile, etc. They have been extensively investigated in the literature [1-5].

Conventional microstrip antennas in general have a conducting patch printed on a grounded microwave substrate, and have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting hosts [10]. Traditional feeding techniques include the use of directly, electromagnetically, or aperture coupled microstrip lines, coaxial probes, and coplanar waveguides. Many types of microstrip antennas have been proposed and investigated [1-5]. Microstrip antennas that operate as a single element usually have a relatively large half power beam width, low gain and low radiation efficiency.

Many researchers studied their basic characteristics and great efforts were also devoted to their determination (resonant frequency, the band-width, radiation... etc) by using theoretical models. Over the years, many models have been used to analyze microstrip antennas. Among them, the transmission line model is a simple model due to its assumptions. This leads to a set of linear equations with low dimension.

In this paper we look into the design and development of single antenna and inset fed antennas arrays with corporate feed network by using a fast, simple and accurate modified transmission line model.

The most important parameter in our designing process is the simplicity of the antenna and its feeding structure so that the antenna can be fabricated easily in practice. Therefore, inset fed patch antenna with a microstrip line feed was considered as a base structure.

2. Transmission Line Model Analysis

In this section, an equivalent circuit model for the proposed antenna is developed. This model is capable of predicting the slot radiation conductance and the antenna input impedance near resonance. This approach provides very helpful insight as to how this antenna and its feed network operate. As mentioned before, this model is also needed to find a proper matching network for the antenna.

3. Three Ports Model of the Proposed Inset Fed Antenna

The used model is inspired from the three ports model [8]. On the figure below one presents the suggested configuration:

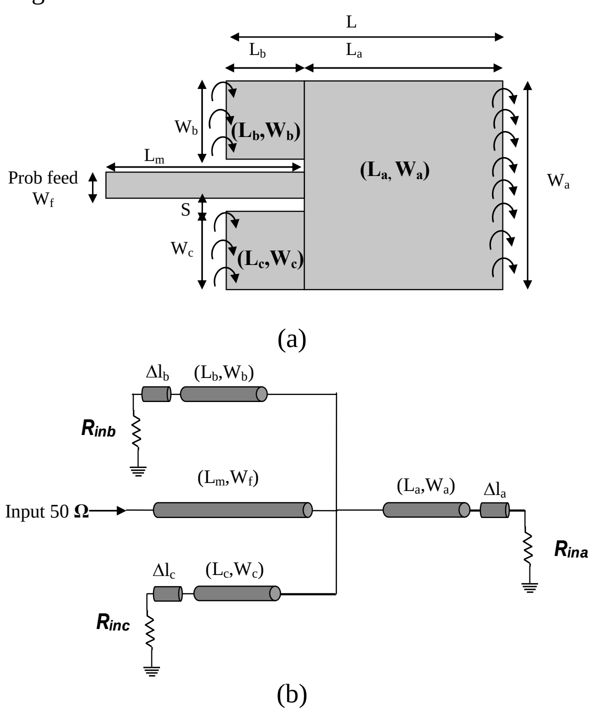

Fig. 1 (a) Inset fed antenna. (b) Equivalent circuit of the proposed antenna.

In the present study, the model consists of breaking up the antenna into three areas *a*, *b* and *c*. Let us consider each part as being an antenna which finishes on the level of its ends by a length ΔL due to the slot radiation and a resistance in series representing the value of this resistance in the antenna extremity. The improved model consist of neglecting the radiations slots between the feed line and the areas *b* and *c* and replace the resistances in series by their true values due only to the areas *b* and *c*. Therefore resistances will be R_{inb} and R_{inc} instead of only one resistance R_{in} . The various values of the model are given as follows:

The input resistance is given by:

$$R_{ina} = \frac{1}{2(G_{1a}+G_{12a})}\left[\begin{array}{l} cos^2(\beta_g L_a) + \dfrac{G_{1a}{}^2 + B_{1a}{}^2}{Y_c{}^2} sin^2(\beta_g L_a) \\ -\dfrac{B_a}{Y_c} sin(2\beta_g L_a) \end{array}\right]^{-1} \quad (1)$$

$$R_{inb} = \frac{1}{2(G_{1b}+G_{12b})}\left[\begin{array}{l} cos^2(\beta_g L_b) + \dfrac{G_{1b}{}^2 + B_{1b}{}^2}{Y_c{}^2} sin^2(\beta_g L_b) \\ -\dfrac{B_b}{Y_c} sin(2\beta_g L_b) \end{array}\right]^{-1} \quad (2)$$

$$R_{inc} = \frac{1}{2(G_{1c}+G_{12c})}\left[\begin{array}{l} cos^2(\beta_g L_c) + \dfrac{G_{1c}{}^2 + B_{1c}{}^2}{Y_c{}^2} sin^2(\beta_g L_c) - \\ \dfrac{B_c}{Y_c} sin(2\beta_g L_c) \end{array}\right]^{-1} \quad (3)$$

The expressions of G_1 and B_1 are given by the relations below [9]:

$$G_{1a,b,c} = \frac{W_{a,b,c}}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right] \quad (4)$$

$$B_{1a,b,c} = \frac{W_{a,b,c}}{120\lambda_0}\left[1 - 0.636\, ln(k_0 h)\right] \quad (5)$$

The conductance of a single slot can also be obtained by using the expression field derivative from model cavity. In general, the conductance is defined by:

$$G_1 = \frac{2P_{rad}}{|V_0|^2} \quad (6)$$

By using the electric field one can calculate the radiated power:

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_0}\int_0^{\pi}\left[\frac{sin\left(\frac{K_0 W}{2}cos\,\theta\right)}{cos\,\theta}\right]^2 sin^3\theta\, d\theta \quad (7)$$

The self conductance can be calculated using the following expressions:

$$G_1 = \frac{I_1}{120\pi^2} \quad (8)$$

Where I_1 is the integral defined by:

$$I_1 = \int_0^{\pi}\left[\frac{sin\left(\frac{k_0 W}{2}cos\,\theta\right)}{cos\,\theta}\right]^2 sin^3\theta\, d\theta \quad (9)$$

The slots length for each region is given by:

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$$\begin{cases} \Delta L_a = \dfrac{1}{2 f_{ra}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - L_a \\ \Delta L_b = \dfrac{1}{2 f_{rb}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - L_b \\ \Delta L_c = \dfrac{1}{2 f_{rc}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - L_c \end{cases} \quad (10)$$

The resonant frequency in this case for each region is given by:

$$\begin{cases} f_{ra} = \dfrac{1}{2L_a\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \dfrac{v_0}{2(L_a+\Delta L_a)\sqrt{\varepsilon_r}} \\ f_{rb} = \dfrac{1}{2L_b\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \dfrac{v_0}{2(L_b+\Delta L_b)\sqrt{\varepsilon_r}} \\ f_{rc} = \dfrac{1}{2L_c\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \dfrac{v_0}{2(L_c+\Delta L_c)\sqrt{\varepsilon_r}} \end{cases} \quad (11)$$

4. Results and Discussions

The validity of the model suggested is highlighted by comparing the results of the return loss, the input phase and input impedance locus. In this section simulations were performed on inset fed antenna.

4.1 Inset Fed Antennas Array Operating at the Resonant Frequency 5.4 GHz

The antenna is to be designed on substrate which has a relative permittivity ε_r of 2.42, a dielectric thickness H of 1.27 mm, a loss tangent of about 0,002 and 0.05 mm conductor thickness.

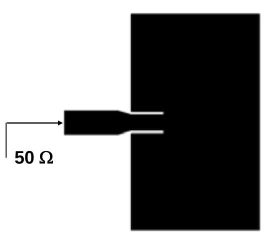

Fig. 2 The mask layout of the inset fed patch antenna design operating at 4.7GHz. The parameters are set to: W_a=32.4 mm, L=19.3 mm, H=1.27 mm, S=0.57 mm, W_f=2.4 mm, Y_0=4.9 mm.

Using the transmission line model, the antenna was designed to operate with a resonant frequency of 4.7 GHz. The input impedance of the antenna must be matched to the feed line by choosing the correct position for the feeding point. Because the antenna must be fed with the microstrip, the connection to a point inside the metal patch requires the use of an inset. The inset-feed technique integrates a patch antenna together with a microstrip feed on a single planar substrate. The input impedance of the inset-fed patch varies, similarly to the coaxial probe-fed patch, as the inset-depth of the feed line changes.

The simulated input return loss of the inset fed antenna is displayed for frequencies between 3.5 to 5.5 GHz in Fig.3.

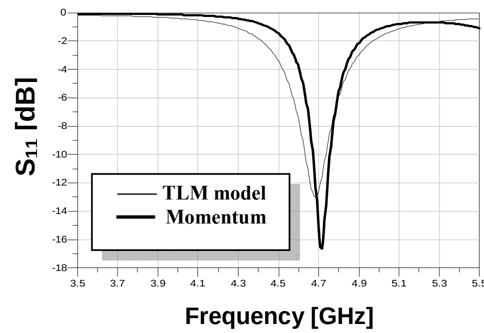

Fig. 3 Simulated input antenna return loss.

At the frequency 4.7 GHz one observe appearance of a resonant mode and a good adaptation. It appears a peak of -16.3 dB using the moment method and of -13 dB using the improved transmission line model.

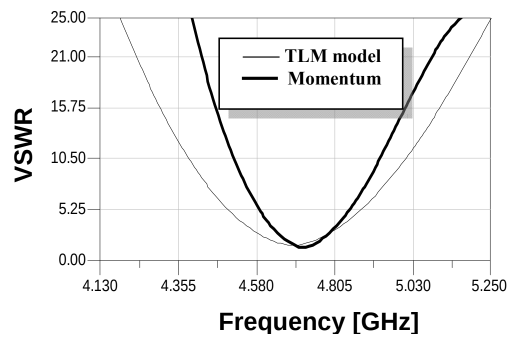

Fig. 4 Simulated input antenna VSWR.

The Moments results and those obtained from transmission line model of the input phase of return loss for this antennas array are shown in Fig. 5.

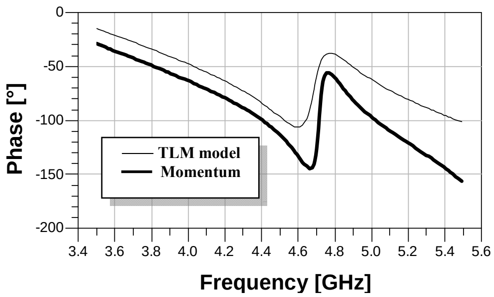

Fig. 5 Reflected phase at the antenna input.

One notices very well that the phase is null by the two models in spite of the shift observed. The impedance locus of the antennas array from 3.3 to 5.4 GHz is illustrated on Smith's chart in Fig. 6.

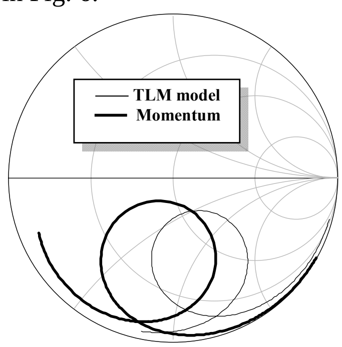

Fig. 6 Smith's chart of the input impedance return losses. Frequency points given by start = 3.3 GHz, stop = 5.4 GHz.

4.2 Inset Fed Antennas Array Operating at the Resonant Frequency 5.4 GHz

In this section, other geometry is analyzed by using the method proposed in this paper. The antenna is to be designed on substrate which has a relative permittivity ε_r of 4.6, a dielectric thickness *H* of 0.444 mm, a loss tangent of about 0,005 and 0.05 mm conductor thickness. The antenna was designed to operate with a resonant frequency of 5.4 GHz. The inset fed antenna architecture is shown in the figure below.

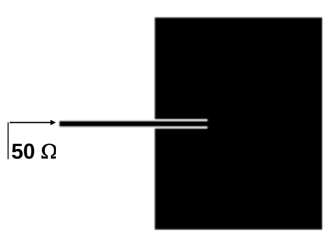

Fig. 7 The mask layout of the inset fed patch antenna design operating at 5.4 GHz. The parameters are set to: W_a=16.28 mm, L=12.7 mm, S=0.42mm, W_f=0.42 mm, Y_0=4 mm.

The simulated input return loss of the antennas array is displayed for frequencies between 4.0 to 7.0 GHz in Fig.8.

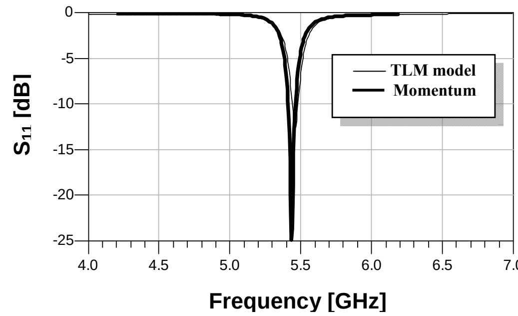

Fig. 8 Computed return loss of the inset fed antenna.

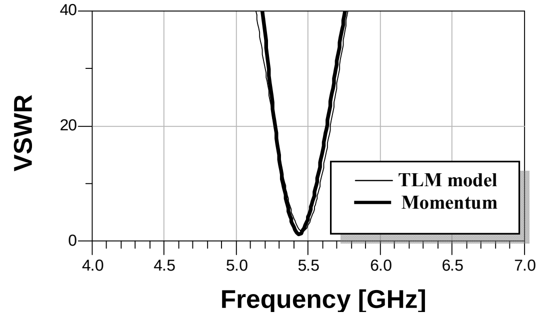

Fig. 9 Computed VSWR.

We note from Fig. 9 that the two curves are identical. In the vicinity of the resonant frequency the VSWR is close to unity.

In Fig. 10 we present the reflected phase at the antenna input.

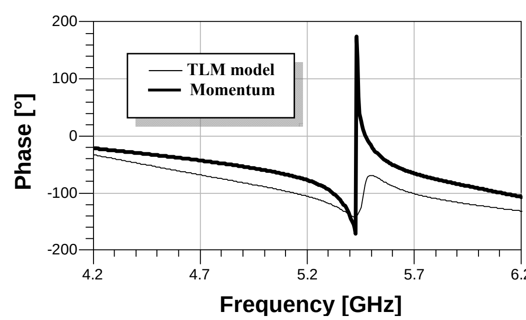

Fig. 10 Reflected phase at the antenna input.

The impedance locus of the antennas array from 4.0 to 7.0GHz is illustrated on Smith's chart in Fig. 11.

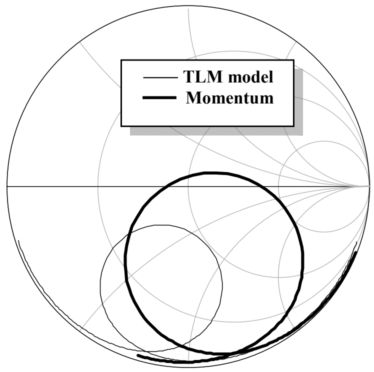

Fig. 11 Smith's chart of the input impedance return losses. Frequency points given by start = 4.0 GHz, stop = 7.0 GHz.

5. Conclusion

In this paper, a highly-flexible and computation-efficient transmission line model is developed to analyze the inset fed antenna. The results so far show that the transmission line model can be successfully used to design the inset fed antennas array and even though the model is conceptually simple, it still produces accurate results in a relatively short period of computing time. The results obtained highlighted an excellent agreement between the transmission line model and the moment's method. A comparison of the results produced by the final model with the moment's method data showed the validity of the proposed model. This allows the analysis of very large arrays even on rather small computer. Based on these characteristics, the proposed antennas array can be useful for EMC applications.

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