Comparative Analysis of Analytical Models for Patch Antenna Approximation

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Abstract – **This study explores the behaviour of the two most - often used analytical models of printed antennas in the frequency domain. The article also contains recommendations for their use.**

Keywords – **cavity model, transmission line model**

I. INTRODUCTION

Microstrip antenna arrays are commonly used antennas in modern communication systems for telemetry and control, as well in radar and navigation technology. Design techniques are based on two main analytical models – the Transmission line model and the Cavity model. As usual, both techniques have good performance and in general produce accurate results, but detailed examinations show that properties of material structure should be taken into account when selecting the techniques.

II. BRIEF DESCRIPTION OF THE MODELS

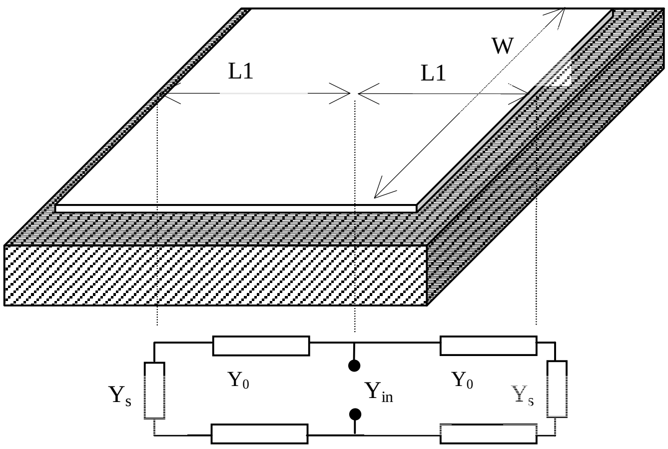

Fig. 1. Transmission Line Model

- Transmission Line Model interprets the radiating element as 2 parallel connected transmission lines with characteristic impedance, loaded with radiating edge impedance (Fig. 1). The total input admittance is presented in Eq. 1.

$$Y_{in} = Y_o \left[\frac{Y_0 + jY_s \tan(\beta l_1)}{Y_s + jY_0 \tan(\beta l_1)} + \frac{Y_0 + jY_s \tan(\beta l_2)}{Y_s + jY_0 \tan(\beta l_2)} \right] \quad (1)$$

$$+ jB_{in}$$

Where Y_0 is the characteristic admittance of the transmission line, B_{in} is imaginary part of the input admittance; Y_s – admittance of the radiating edge and l_1, l_2 is the length of the transmission lines, $l_1 + l_2 = L$ – the electrical length of the patch.

- Cavity model. The cavity model is based on the Eigen solution of the Helmholtz equation – Eq. 2

$$\begin{aligned} \nabla^2 E_z + k^2 \nabla^2 E_z &= j\omega\mu_0 z^{\varpi} J \\ E_z(x,y) &= \sum_m \sum_n A_{mn} \psi_{mn}(x,y) \end{aligned} \quad (2)$$

For a rectangular patch the boundary conditions as shown in Eq. 3 apply and the final form of the Eigen solution is shown in Eq. 4.

$$\begin{aligned} &\left.\frac{\delta \psi_{mn}}{\delta x}\right|_{x=0} = \left.\frac{\delta \psi_{mn}}{\delta x}\right|_{x=L} = 0 \\ &\left.\frac{\delta \psi_{mn}}{\delta y}\right|_{y=0} = \left.\frac{\delta \psi_{mn}}{\delta y}\right|_{y=W} = 0 \\ &\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + k_{m,n}^2 \right) \psi_{m,n} = 0 \\ &\psi_{mn}(x,y) = \sqrt{\frac{q_m q_n}{LW}} \cos(k_m x) \cos(k_n y) \end{aligned} \quad (3)$$

Where m,n= 0, 1,2,…i; $k_m = m\pi/L$, $k_n = n\pi/W$, $k^2mn = k_n^2 + k_n^2$. As a result, the input impedance is a function of the Eigen solution (Eq. 4). C_{feed} is a constant that takes into account the influence of the feeder (microstrip feeding line).

$$Z_{in} = -j\omega\mu_0 h \sum_m \sum_n \frac{\psi_{mn}{}^2(x_0, y_0) C_{feed}}{k_0^2 \varepsilon_r (1 - j\delta_{eff}) - k_{mn}^2} \quad (4)$$

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III. RESULTS

Analysis of the structures was performed with electromagnetic simulation software, based on the method of moments at frequency of 5 GHz. The results are taken as reference in the examination. TRL and Cavity lines at the drawings are based on values calculated using the methods mentioned above, and with consideration that Z_{in} depends only of S_{11}.

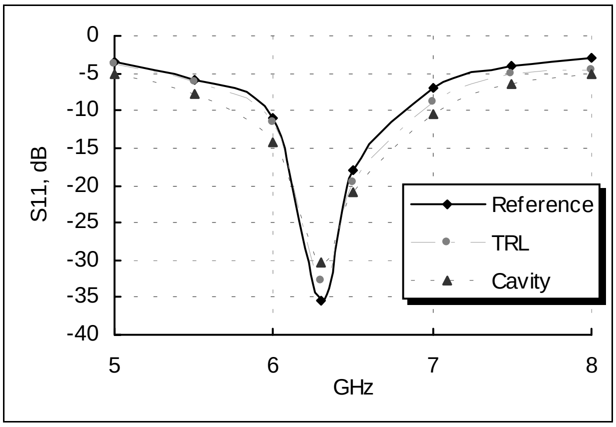

Fig. 2. Substrate thickness λ/30

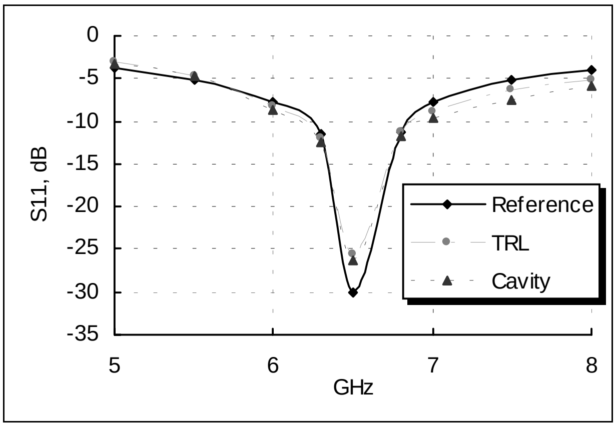

Fig. 3. Substrate thickness λ/20

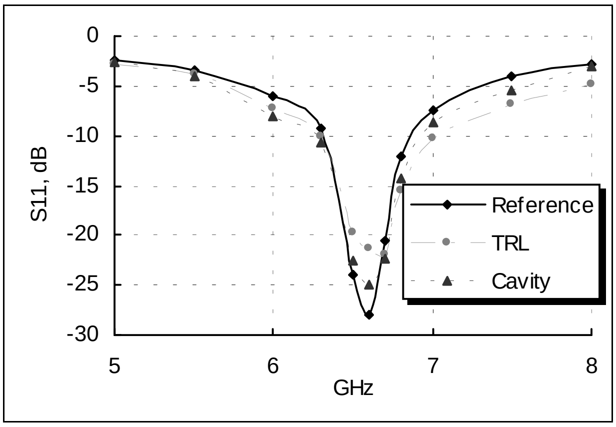

Fig. 4. Substrate thickness λ/10

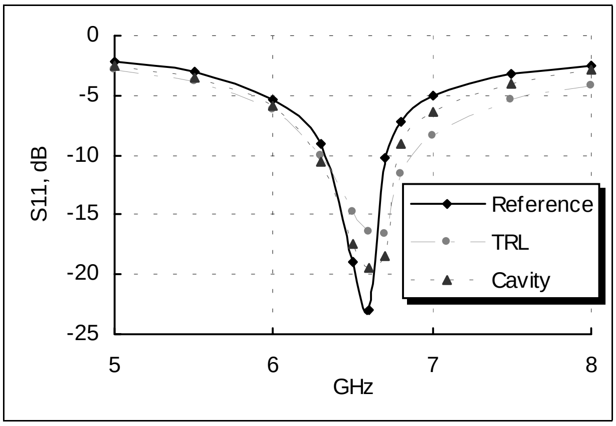

Fig. 5. Substrate thickness λ/5

From the Figures 2÷5 and theoretical background outlined above the following conclusions can be drawn:

1. The Transmission Line Model is simple, easy to use and gives accurate results in thin substrates. A very convenient feature is that it is easy to use in antenna arrays. A negative side is that it cannot solve the problems concerning circular patches and structures with existence of higher modes.

2. The Cavity Model is more complex and is based on physical processes in the microstrip radiating structure. It yields the most accurate results in cases with relatively thick substrates therefore its use in such cases is highly recommended. It determines the current distribution of electric and magnetic currents not only for the base mode, but also for the higher modes and multilayer antennas. That also gives the possibility for analytical determination of the antenna pattern. Its main disadvantage is the fact that it cannot be used for analysis of antenna arrays.

IV. CONCLUSION

This paper examines and explains the basic features of two methods for modelling patch antennas. The main conclusion is that both models give accurate enough results when they are selected taking into account substrate properties. Future research in this field will be focused on the analysis of model behaviour with regard to the dielectric permittivity of the substrate.

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