

Using Equivalent Dielectric Constant to Simplify the Analysis of Patch Microstrip Antenna with Multi Layer Substrates

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Abstract

This paper presents a method to simplify the calculations of cavity model analysis on a multi layer microstrip antenna. The main feature of this method is the simplification of a multi layer antenna structure into a single homogeneous layer antenna. This in effect completely eliminate the problem of mode matching between layers and thus reduces the amount of calculation and computing time. Theoretical results obtained using this method were compared with the experimental results and were found to give an error of less than 4 %.

Introduction

The microstrip patch antenna has become one of the most widely used antenna today because of its many desirable features such as low profile, light weight and small size. A considerable number of analysis techniques have been reported in the published literature [1-4]. While rigorous methods are more complete, they are quite complicated and can not be readily implemented especially for design work. It was reported [4] that the accuracy of the rigorous approach may not be much better than that of the simple transmission line or cavity models provided the latter are used within their range of validity. One draw back from cavity models is that it is not efficient when applied to the microstrip antenna structure having multi layer substrates as shown in figure 1. Each mode in any particular layer has to be solved and matched with adjacent layers [5].

This paper presents an experimental investigation in an attempt to simplify the cavity model calculation for a multi layer microstrip antenna structure.

Analysis

The main simplification proposed in this paper is to consider the antenna structure in figure 1 and simplify it into a single equivalent homogeneous substrate as shown in figure 2 where the cavity model is best applied. The equivalent substrate is considered lossless and has a permittivity given by

$$\epsilon_{eq} = \left(\sum_{n=1}^N \frac{t_n}{\epsilon_n} \right)^{-1} \cdot \left(\sum_{n=1}^N t_n \right) \quad (1)$$

where t_n = height of the nth substrate layer
 ϵ_n = permittivity of the nth substrate layer

From equation (1), the equivalent dielectric constant is given by

$$\epsilon_{req} = \left(\sum_{n=1}^N \frac{t_n}{\epsilon_{rn}} \right)^{-1} \cdot \left(\sum_{n=1}^N t_n \right) \quad (2)$$

The height of the equivalent substrate is taken to equal the total height of the substrates and is given by

$$t_{eq} = \sum_{n=1}^N t_n \quad (3)$$

The rest of the dimensions such as the width and the length of the patch were unchanged. For t_{eq} much less than the operating wavelength, the cavity model solution for the z-component electric field underneath the patch is given by [6]

$$E_z(x, y) = jI_0 \sqrt{\frac{\mu_0}{\epsilon_{eq}}} k \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{\psi_{mn}(x, y) \psi_{mn}(x_0, y_0)}{k^2 - k_{mn}^2} G_{mn} \quad (4)$$

where the notations in equation (4) are the same as in reference [6].

From equation (4) it can be shown [4] that the input impedance is given by

$$Z_{in} = \frac{V_f}{I_0} = -j\omega\mu_0 h \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{\psi_{mn}^2(x_0, y_0)}{k^2 - k_{mn}^2} G_{mn} \quad (5)$$

Three antennas were fabricated to test the simplified model as shown in figure 3.

Experimental and calculated results

A Wiltron Network Analyser System was employed to measure the return loss versus frequency characteristics of these antennas. Figure 4 shows typical results obtained from calculation and measurement while the other results were summarised in table 1 and table 2. These comparison results show a close agreement between calculated and measured data. The worst case shows a discrepancy of less than 4% for mode resonant frequencies TM_{10} , TM_{01} , TM_{02} , TM_{20} and TM_{11} .

Conclusions

By using the simplified antenna structure model, the problem of solving the modes in each layer of substrate is simplified to solving just the modes in a single layer. The problem with mode matching between layers is eliminated completely which in turn reduces the amount of calculation and computing time. Using one substrate of high value dielectric constant, ϵ_h , say, this investigation shows that other substrates having dielectric constants less than ϵ_h can be simulated by combining it with an appropriate layer of air dielectric having height calculated using equation (2).

Acknowledgement

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Reference

1. Carver, K.R. and Mink, J.W., 'Microstrip Antenna Technology', IEEE Trans. Antennas and Propagation, 1981, Vol. AP-29, No. 1, pp 2-24.
2. James, J.R. and Hall, P.S., 'Handbook of Microstrip Antennas', IEE Electromagnetic Waves, Series 28, Volume 1 and 2, Peter Peregrinus Ltd., London, 1989.
3. Itoh, T. (Editor), 'Numerical Techniques for Microwave and Millimetre-Wave Passive Structures', John Wiley & Sons, Inc., New York, 1989
4. Sainati, K.A., 'Cad of Microstrip Antennas for Wireless Application', Artech House, Norwood, USA, 1996
5. Shen, Z. and MacPhie, R.H., 'Waveguide Modal Analysis of Single and Stacked Probed Microstrip Antennas with Circular Geometries', IEEE Antennas and Propagation Society International Symposium, Montreal, Canada, July 13 - 18 1997.
6. Hirasawa, K. and Haneishi, M. (Editors), 'Analysis, Design and Measurement of Small and Low-Profile Antennas', Artech House, Inc., Norwood, USA, 1992.

	Mode frequencies (GHz)					
	Calculated values			Measured values		
	TM ₁₀	TM ₀₁	TM ₁₁	TM ₁₀	TM ₀₁	TM ₁₁
Antenna 3(a):						
1) $t_2 = 1.56\text{mm}$	1.518	1.350	2.032	1.509	1.359	2.033
2) $t_2 = 2.90\text{mm}$	1.532	1.374	2.057	1.533	1.334	2.083
Antenna 3(b):						
1) $t_2 = 2.00\text{mm}$	1.402	1.176	1.884	1.409	1.184	1.958
2) $t_2 = 3.12\text{mm}$	1.413	1.273	1.901	1.414	1.233	1.958

Table 1 Summary of the results obtained for antenna 3(a) and 3(b)

	Mode frequencies (GHz)					
	Calculated values			Measured values		
	TM ₂₀	TM ₀₁	TM ₀₂	TM ₂₀	TM ₀₁	TM ₀₂
Antenna 3(c):						
$t_2 = 0.02\text{mm}$						
& $t_3 = 0.635\text{mm}$	1.347	1.083	2.166	1.326	1.094	2.125
Antenna 3(c):						
$t_2 = 0.04\text{mm}$						
& $t_3 = 1.27\text{mm}$	1.244	0.995	1.991	1.236	1.012	1.961

Table 2 Summary of the results obtained for antenna 3(c)

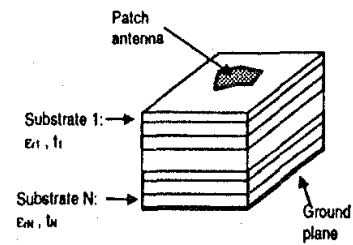


Figure 1 Antenna with multi layer substrates

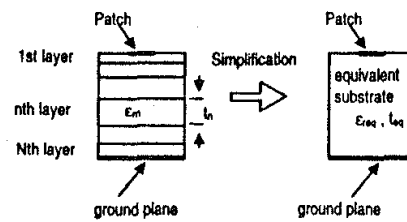


Figure 2 Simplification of multi layer antenna into a single layer

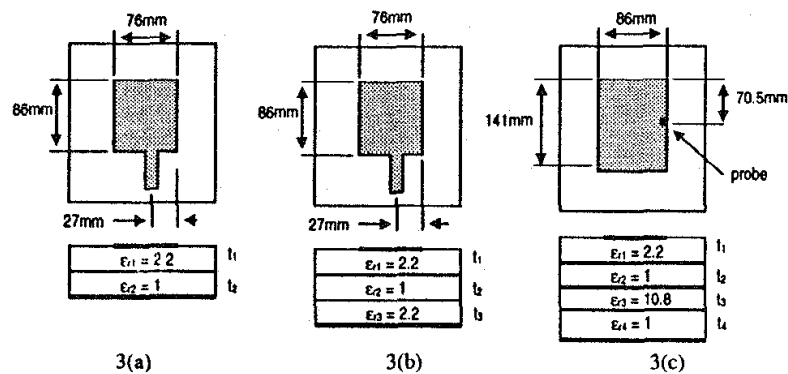
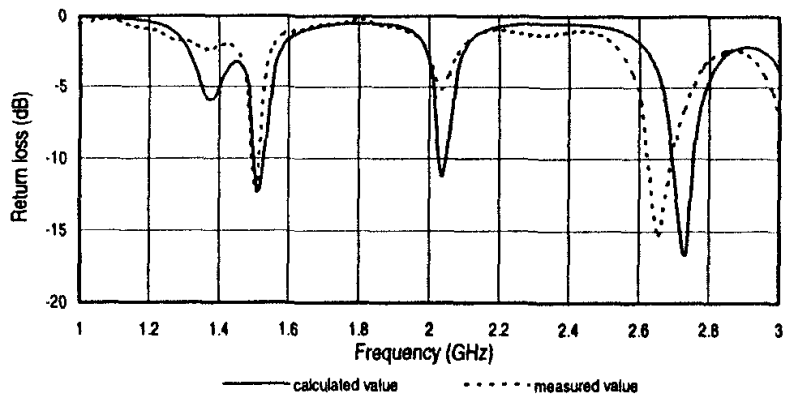
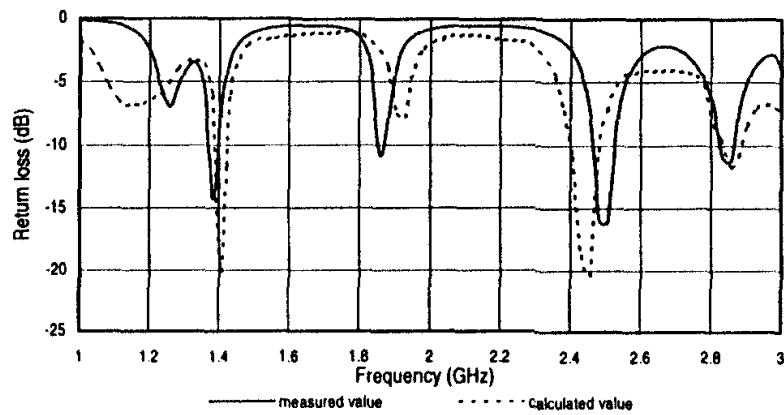


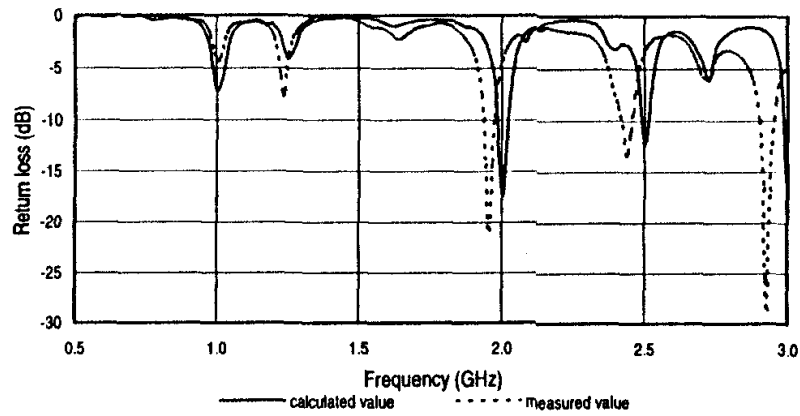
Figure 3 Microstrip patch antennas used in this investigation.



Return loss versus frequency for antenna 3(a) with $t_2 = 1.56\text{mm}$



Return loss versus frequency for antenna 3(b) with $t_2 = 2.00\text{mm}$



Return loss versus frequency for antenna 3(c) with $(t_2, t_3) = (0.04, 1.27)\text{ mm}$

Figure 4 Typical results of return loss versus frequency for antennas 3 a, b, c