# HYBRID MODEL FOR PROBE-FED RECTANGULAR MICROSTRIP ANTENNAS WITH SHORTING PINS

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**Abstract**

For a probe-fed microstrip antenna, it is quite common to employ the cavity model to find the field distribution under the patch and other electrical properties. Therefore, a multiport analysis technique based on the cavity model is usually employed to predict the input impedance of a probe-fed microstrip antenna with shorting pins. However, this approach does not provide any information about the field distribution under the patch with the shorting pins, which is usually used to calculate the radiation properties of the patch antenna. In this study, shorting pins are considered as current sources with unknown amplitudes, and the field distribution under the patch is obtained as a linear superposition of the contributions from each source via cavity model. Then, the unknown current densities over the shorting pins are determined by implementing the boundary condition of the tangential electric field on the pins. This is a hybrid approach because the field distribution is calculated from the cavity model, and the current densities over the shorting pins are obtained from the point matching of the resulting field distributions over the shorting conductors. The input impedance results found from this approach agree extremely well with those obtained from the multiport analysis, which shows that the proposed approach predicts both the input impedance and the field distribution under the patch.

In addition, since the feeding probe is also made of PEC, the electric field under the patch should satisfy the boundary condition on this conductor as well. In the application of the cavity model, this is always ignored, with the assumption that the source probe is too thin to affect the field distribution under the patch significantly. In this study, the boundary condition of the electric field is implemented over the source, and its effect on the field distribution, in turn on the resonant frequency, is demonstrated.

## 1 INTRODUCTION

Shorting pins play an important role in the dual frequency operation of microstrip antennas. By properly placing shorting pins to the microstrip antenna, the ratio of the lowest useful cavity modes, namely (0,1) and (0,3), can be made less than 3, which is desired in many applications [1]. A shorting pin placed at the nodal lines of (0,3) mode does not affect the resonant frequency of (0,3) mode, but increases the resonant frequency of (0,1) mode. Using multiport analysis, the change in the resonant frequency of (0,1) mode due to the shorting pin can be predicted [1], [2]. However, this analysis does not provide any information about the field distribution inside the cavity. Considering the pins as current sources with unknown current densities, their effects on the field distribution can be predicted with the use of the cavity model in conjunction with the point matching technique. In this approach, the application of the point matching is actually the implementation of the boundary conditions over the shorting pins to determine the unknown current densities over these pins.

Imposing the boundary conditions on the shorting pins via point matching can be extended to the feeding probe, which is also made of PEC. In the traditional application of the cavity model, it is always assumed that the feeding probe is quite thin, and does not affect the field distribution under the patch, so no boundary condition is applied except for the discontinuity in the magnetic field by the amount of the known current source. However, in the development of broadband microstrip antennas, recently wider strips have been used as feeding probes, which significantly alters the resonant frequency and other electrical properties of the antennas. The above mentioned hybrid method is applied to this problem to assess the effects of the source

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conductor onto the electrical properties of the antenna. This approach uses the orthogonal modes of cavity model in finding the E-field under the patch and uses the point matching in making the E-field zero on the probe.

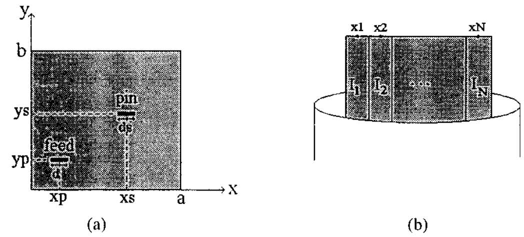


FIGURE 1: (a) Top view of a rectangular patch with thickness h;
(b) Point matching application on the exaggerated probe feed with N points.

## 2 THEORY AND RESULTS

To be able to predict the effect of a shorting pin on the E-field distribution under the patch, a hybrid approach is developed, in which it is assumed that the shorting pin behaves as a current source. Considering Fig. 1a, the current density on the shorting pin is assumed to be in the following form:

$$J_s = \hat{z} A \delta(y-y_s)\left[U(x-x_s+\frac{d_s}{2})-U(x-x_s-\frac{d_s}{2})\right] \quad (1)$$

where $U$ is unit step function, $d_s$ is the effective width of shorting pin, $A$ is an unknown coefficient to be determined. With this current density, the total E-field inside the cavity is a linear superposition of the contributions of both sources:

$$E_{z-total} = E_{z-feed} + E_{z-pin} \quad (2)$$

where $E_{z\text{-}feed}$ and $E_{z\text{-}pin}$ are the E-fields generated by the probe feed and the shorting pin, respectively. To determine the unknown coefficient $A$ in (1), the tangential E-field is set to zero on the shorting pin,

$$E_{z-total}(x_s, y_s) = 0\,. \quad (3)$$

In multiport analysis, the input impedance at the feed port is obtained by setting the voltage at the shorting pin port to zero, which is the circuit equivalent of applying the boundary conditions of the E-field on the shorting pin.

The results obtained from the hybrid method proposed here agree well with those obtained from the multiport analysis, as shown in Table 1. The frequencies shown in the table are the resonant frequencies of (0,1) mode, and $d_s=d=0.1$ *cm* is used.

*TABLE 1: Comparison of the resonant frequencies obtained from the multiport analysis and the hybrid method. Dimensions are in cm, frequencies in Ghz.*

| a | b | h | $\varepsilon_r$ | $x_p$ | $y_p$ | $x_s$ | $y_s$ | $f_{multiport}$ | $f_{proposed}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.85 | 1.29 | 0.0170 | 2.22 | 0.425 | 0.415 | 0.3 | 0.215 | 9.35 | 9.44 |
| 2.00 | 2.50 | 0.0790 | 2.22 | 1.000 | 0.683 | 0.3 | 0.417 | 4.16 | 4.16 |
| 19.4 | 14.7 | 0.3175 | 2.62 | 9.700 | 0.000 | 5.0 | 2.45 | 0.649 | 0.649 |

Implementing the boundary condition on the shorting pins with the use of the point matching procedure has brought up the issue of implementing the boundary condition on the feeding probe, which is also a perfect conductor. In the traditional cavity model, the only boundary condition implemented at the source probe is the discontinuity of the magnetic field by the amount of the source current. The effect of the probe conductor in the cavity is negligible if the thickness of the substrate and the width of the feeding probe are very small as compared to wavelength. However, with the recent advances in the design of broadband microstrip antennas, thick substrates and wide strips for feeding structures have been quite popular, necessitating their effects to be accounted for. So the hybrid approach proposed for the starting pins can be easily extended to the feeding structure.

It is observed that the field distribution obtained from the traditional cavity model does not satisfy the boundary condition of the electric field on the feeding conductor, see Fig. 2a, b. To remedy this, the hybrid method using both cavity model and the point matching method is employed. In this approach, the E-field in the cavity is written as a sum of orthogonal modes as in the cavity model, and the tangential E-field is minimized in least square sense on the probe using point matching.

As illustrated in Fig. 1b, the total $z$ directed current on the feed can be written as

$$J_t = \sum_{l=1}^{N} J_l = I_l \delta(y - y_p)\left[ U(x - x_l + \frac{d}{2N}) - U(x - x_l - \frac{d}{2N}) \right]\frac{N}{d}, \qquad (4)$$

where $d$ is the effective width of the probe.

The total E-field inside the cavity can be obtained as

$$E_z = \sum_{l=1}^{N} E_{zl} = jw\mu_0 \sum_{l=1}^{N} I_l \left[ \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\psi_{mn}(x_l, y_p)\psi_{mn}(x, y)\sin c(md/2aN)}{k^2 - k_{mn}^{\ 2}} \right] \qquad (5)$$

where $\psi_{mn}$'s are orthogonal cavity modes [2].

The unknown coefficients $I_l$'s can be obtained by imposing the boundary condition onto the total electric field on the subsections of the feeding strip, resulting in a homogeneous matrix equation with the entries given as

$$A_{ij} = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\psi_{mn}(x_i, y_p)\psi_{mn}(x_j, y_p)\sin c(md/2aN)}{k^2 - k_{mn}^{\ 2}} . \qquad (6)$$

Setting the total current to *1 Amp* adds one more row of *1's* to the matrix. The least square solution of the matrix equation gives $I_l$*'s*. The resonant frequency of the patch is determined by finding the point where the determinant of matrix $A$ is zero.

For a rectangular patch (without shorting pin) with $a=1.81$ *cm*, $b=1.96$ *cm*, $\varepsilon_r=2.33$, $h=0.157$ *cm*, $xp=0.905$ *cm*, $yp=0.627$ *cm*, the normalized E-field plots are given in Fig.2. It is observed that the magnitude of the E-field drops faster for the hybrid method than that for the cavity model on the feed, and at the edges of feed it increases due to the edge effect. The resonant frequency is calculated as *4.801 Ghz*, which is very close to the experimental result of $f_{res}=4.805$ *Ghz*, given in [3]. Note that, in the calculations the effective dimensions of the patch are used.

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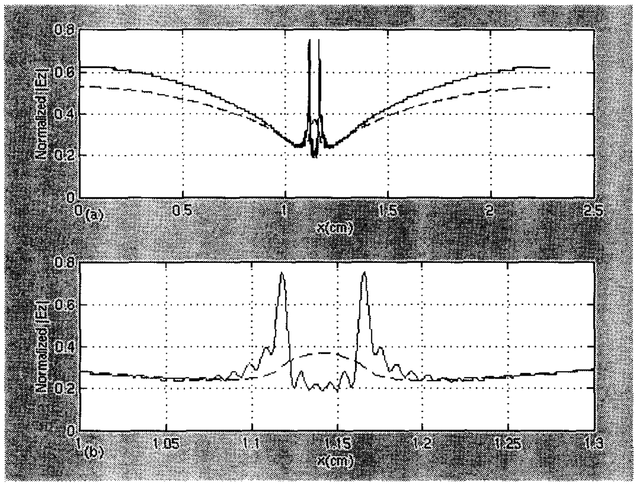


Figure 2: (a) Normalized magnitude of $E_z$ at $y=yp_{eff}$, varying $x$ along side $a$;
(b) Zoomed view of $|E_z|$ around the probe feed.
*$a=1.81cm$, $a_{eff}=2.28cm$, $b=1.96cm$, $b_{eff}=2.16cm$, $h=0.157cm$, $\varepsilon_r=2.33$, $xp=0.905cm$, $xp_{eff}=1.14cm$, $yp=0.627cm$, $yp_{eff}=0.73$ cm.*
*Dashed line: cavity model, solid line: hybrid method*