APPLICATION OF A SIMPLIFIED PROBE FEED IMPEDANCE FORMULA TO THE DESIGN OF A DUAL FREQUENCY PATCH ANTENNA

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ABSTRACT: A simplified probe feed input impedance for a rectangular patch antenna based on the Green's function is used to design a dual frequency matched antenna. The predicted results at design frequencies of 1.9GHz and 2.4GHz are in close agreement with experimental measurements.

1. INTRODUCTION

As there is an increasing demand for wireless communications probe feeds are widely used in, dual frequency, broad band and multi-frequency band antennas[1, 4]. A number of analytical methods have been proposed for the design of the patch antennas including, full wave analysis [5, 6], cavity model [7, 8] and transmission-line [7, 9]. In the design of antennas having complicated geometries segmentation and de-segmentation analysis is normally used [10] and a probe feed impedance of a rectangular segment is required.

In this paper, the probe feed impedance for a rectangular segment is obtained from the coupling impedance between a probe feed and another port. This impedance is then simplified and then used to locate the required feed position to obtain matching at the two frequencies of a patch antenna.

The electrical and physical parameters of the substrate PCB FR4 used are: dielectric constant is 4.3, the height of substrate is 1.575 mm, the loss tangent is 0.019 and the thickness of the copper patch is 0.035mm.

2. DERIVATION OF THE SIMPLIFIED PROBE FEED IMPEDANCE

Figure 1 shows the locations of the probe fed port p and an arbitrary port q of a rectangular patch antenna.
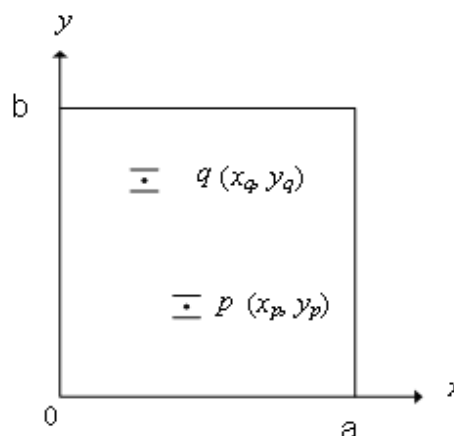

Figure 1 Locations of ports p and q

The coupling impedance (Z_{pq}) between the two ports in terms of the Green's function is given by

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$$Z_{pq} = \frac{1}{W_p W_q} \int\limits_{W_p} \int\limits_{W_q} G(x_p, y_p | x_q, y_q) \, dy_q \, dy_p \quad (1)$$

where dy_p and dy_q are incremental distances over the port widths W_p, W_q [11]. To ensure that the current density does not vary appreciably across the ports W_p, W_q $\;$ W_p, $W_q << \lambda$ [12]. The Green's function for a rectangular segment is given by [12]

$$G(x_p, y_p | x_q, y_q) = \frac{j\omega h}{ab} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \varepsilon_m^2 \varepsilon_n^2 \frac{\cos\frac{m\pi}{a}x_p \cos\frac{n\pi}{b}y_p \cos\frac{m\pi}{a}x_q \cos\frac{n\pi}{b}y_q}{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - k^2} \quad (2)$$

where, $\omega = 2\pi f$, h is the thickness of the dielectric substrate, $k^2 = \omega^2 \mu \varepsilon_0 \varepsilon_{reff}(1 - j/Q)$, Q is the total quality factor (Q is equal to 43.5), $A = ak/\pi$ and $B = bk/\pi$. Letting the 'q' approach 'p' and the integrating each part of the partition Green's function the probe feed impedance Z_{pp} is given by [14]

$$Z_{pp} = \frac{j\omega \cdot \mu \cdot h}{a \cdot b \cdot W_p^2}\left(-\frac{W_p^2}{k^2} + \frac{2 \cdot a^2 \cdot W_p^2}{\pi^2} S1 + \frac{2 \cdot b^4}{\pi^4} S2 + \frac{4 \cdot b^2}{\pi^4} S3\right) \quad (3)$$

Where,

$$S1 = \sum_{m=1}^{\infty} \frac{\cos\left(\frac{m \cdot \pi}{a} \cdot Xp\right)}{m^2 - A^2}$$

$$S2 = \sum_{n=1}^{\infty} \left[\frac{(\sin(n \cdot \theta1) - \sin(n \cdot \theta2))^2}{n^2 \cdot (n^2 - B^2)}\right] \quad \text{and}$$

$$S3 = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \left[\frac{\cos\left(\frac{m \cdot \pi}{a} \cdot Xp\right)\left[(\sin(n \cdot \theta1) - \sin(n \cdot \theta2))^2\right]}{n^2 \cdot (m^2 + D^2)}\right]$$

$$\theta1 = \frac{\pi}{b}\left(Yp + \frac{Wp}{2}\right), \quad \theta2 = \frac{\pi}{b}\left(Yp - \frac{Wp}{2}\right),$$

$$D = \frac{a}{b} \cdot \sqrt{n^2 - B^2}$$

And Wp = 1.3 mm, which is the diameter of the probe feed.

In examining equation 3 it is found that the combined contribution of the terms $-Wp^2/k^2$, and the infinite series S_3 is negligible so that equation for the final simplified probe impedance Z_{PP} becomes

$$Z_{pp} = \frac{j \cdot \omega \cdot \mu \cdot h}{a \cdot b \cdot W_p^2} \cdot \left(\frac{2 \cdot a^2 \cdot Wp^2}{\pi^2} \cdot S1 + \frac{2 \cdot b^4}{\pi^4} \cdot S2\right) \quad (4)$$

3. DESIGN OF A DUAL FREQUENCY MATCHED PATCH ANTENNA

For a rectangular patch antenna shown in figure 2, the physical lengths L (1.9GHz), W (2.4 GHz) and the feed position 'C' for matching need to be determined.
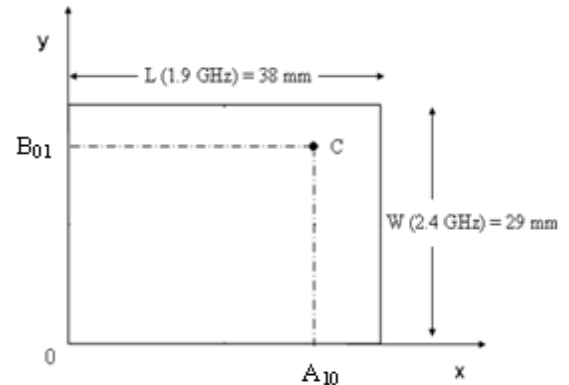

Figure 2 Dimensions and Feed Position of the Patch Antenna

The effective dimensions of the patch and the permittivity for the TM_{10} and TM_{01} modes are given by the equations below [13]

$$L_{eff} = \lambda_{g1} / 2 = c / 2*f_1*\sqrt{\varepsilon_{reff}\,(W)} \qquad (5a)$$

$$W_{eff} = \lambda_{g2} / 2 = c / 2*f_2*\sqrt{\varepsilon_{reff}\,(L)} \qquad (5b)$$

$$\varepsilon_{reff}(L,W) := \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \cdot \left[\frac{1}{\left[1 + \frac{12}{\frac{(L,W)}{h}} \right]^{\frac{1}{2}}} \right] \qquad (5c)$$

In Table 1 the initial length L_1 is obtained assuming $\varepsilon_r = \varepsilon_{reff} = 4.3$ and then W_1 is determined using equation 5(b). The final values L_5 and W_5 are determined by an iterative process (see table 1) where a very rapid conversion is obtained. The final physical dimensions of the antenna are L (1.9GHz) =38mm and W (2.4GHz) =29mm.

Iterative Process	Length (mm)	Width (mm)
Round 1	L_1 =38.0718	W_1=31.25459
Round 2	L_2 =39.71005	W_2=31.21821
Round 3	L_3 =39.71149	W_3=31.21818
Round 4	L_4 =39.71149	W_4=31.21818
Round 5	L_5 =39.71149	W_5=31.21818

Table 1

The approximate feed position 'C' is shown on in Figure 2 [14], where matched feed positions 'A_{10}' and 'B_{01}' are for the TM_{10} and TM_{01} modes respectively.

For the TM_{10} mode the position 'A_{10}' is obtained using

$$Zin = 50 = R_{10} \cdot \cos^2\left(\frac{\pi \cdot A_{10}}{L} \right) \qquad (6a)$$

For the TM_{01} mode the position 'B_{01}' is obtained using

$$Zin = 50 = R_{01} \cdot \cos^2\left(\frac{\pi B_{01}}{W} \right) \qquad (6b)$$

The equivalent circuit of the antenna shown in figure 3 was fine tuned using AWR software to obtain the optimum feed position (A_{10}= 25.42 mm and B_{01}= 20.92 mm) for matching at both frequencies.
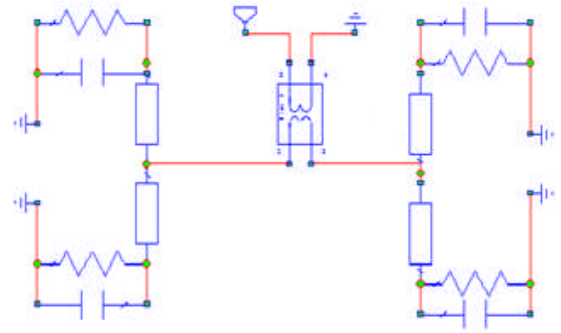

Figure 3 Transmission Line Equivalent Circuit of the Antenna

4. Results and Conclusions

A photograph of the fabricated antenna is shown in figure 4.

Figure 4 Photograph of the Fabricated Patch Antenna

The frequency responses of the return loss obtained from practical measurements and from the derived probe feed equation are shown in figure 5.
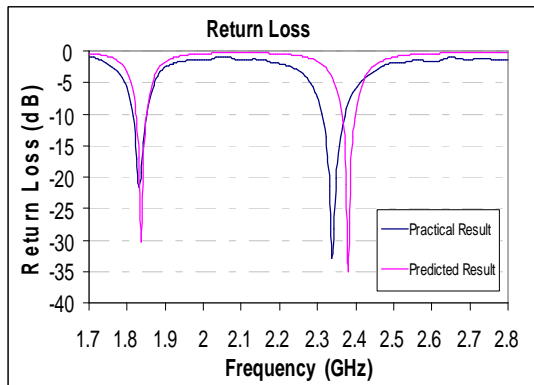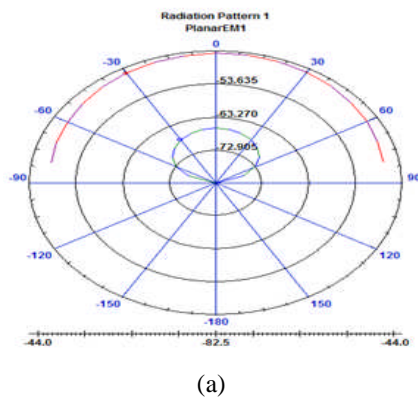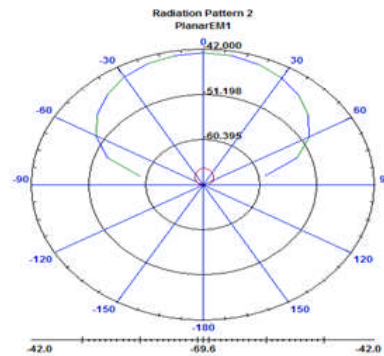

Figure 5   Practical and Simulated Results for the Return Loss

The polar patterns of the antenna at 1.9GHz and 2.4GHz are shown in figure 6 where there is a very good isolation between the two modes has been obtained.

(a)

(b)

Figure 6   Polar Pattern at (a) 1.9 GHz and (b) at 2.4 GHz

Conclusion

A simplified equation for the probe fed rectangular patch has been derived and used in the design of a dual frequency rectangular patch antenna. The predicted results for the feed impedance were compared with those obtained from the transmission line model and from practical measurements. A very good agreement has been obtained for all results.

The derived equation can also be used in segmentation/d-segmentation analysis of complicated antenna geometries where the probe feed segment has rectangular geometry.

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