

Input Impedance Modeling of a Capacitively Coupled Wideband Microstrip Antenna

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1. Introduction

Microstrip antennas are versatile candidates for the modern broadband wireless applications because of their numerous advantages [1]. Yet most conventional geometries typically have narrow bandwidth, which limits their use in several applications. However it has been shown by several researchers that the bandwidth of microstrip antenna can be significantly improved by altering its basic configuration. These alterations include, increasing the height (or thickness) of the substrate, cutting slots in the basic shapes, changing the shape of the geometry, or using multi-layer techniques [2]. Bandwidth enhancement can also be achieved by modifying the feed networks (elements) such as meandered probe or changing the probe to L-shape or by reactive loading [3]. Many of these have relatively complex assembly, which in some cases is contrary to the fundamental attraction of microstrip antennas.

This group has recently reported a simple modification to the feed arrangement by which the impedance bandwidth of the antenna ($S_{11} < -10\text{dB}$) could be enhanced to 50% [4]. This configuration is similar to [5], but has significantly larger bandwidth. The bandwidth enhancement can be achieved by increasing the overall height of the dielectric medium. However this introduces the large probe inductance, which could be cancelled out by the capacitive feed strip is placed parallel to one of the radiating edges of the patch. The radiation patterns of this antenna have also been improved to be circularly symmetric by modifying the edge of the radiator patch close to the feed strip [6].

In this paper we propose a modelling scheme that is valid over a wide frequency range for this ultra wideband microstrip antenna. Details of the antenna model are examined in Section 2 and the results are compared with numerical simulations and experiments in Section 3. The simplicity of this model suggests that the wideband antenna proposed in [4] can be easily scaled for other frequency ranges.

2. Antenna Geometry and Analysis

The basic geometry of the antenna is shown in Figure 1 [4]. The configuration is basically a suspended microstrip antenna in which radiating patch and the feed strip are etched on the substrate of thickness " h " mm. A long pin SMA connector is used to connect the feed strip which couples the energy to a radiating patch by capacitive means. This antenna configuration is modelled by splitting this into its various parts: (i) the radiator patch, (ii) coupling gap between the feed strip and radiator, and (iii) the probe feed and the strip.

2.1 Radiator Patch

The equivalent circuit model of a rectangular microstrip antenna operating in the fundamental mode can be represented by a parallel tuned circuit (Figure 2 (a)) [1]. Since the feed is connected outside the radiator, for the convenience of modelling this can be treated as an edge fed microstrip antenna. The circuit elements in this model are calculated using [1]:

$$C_{patch} = \frac{\epsilon_0 \epsilon_{reff} LW}{2(g+h)} \quad (1)$$

$$L_{patch} = \frac{1}{C_{patch} \omega_c^2} \quad (2)$$

$$R_{patch} = \frac{Q_T}{\omega_c C_{patch}} \quad (3)$$

where ϵ_{reff} is the effective relative dielectric constant for this air-dielectric configuration [7]. In (3), Q_T is the total quality factor, represents the total losses in the radiator patch and is given by:

$$Q_T = \left[\frac{1}{Q_R} + \frac{1}{Q_D} + \frac{1}{Q_C} \right]^{-1} \quad (4)$$

where Q_R , Q_D , and Q_C are the factors associated with radiation losses, dielectric losses and conductor losses in the radiating patch respectively. These could be evaluated based on equations given in [8], [9] after making necessary corrections for the composite air-dielectric medium.

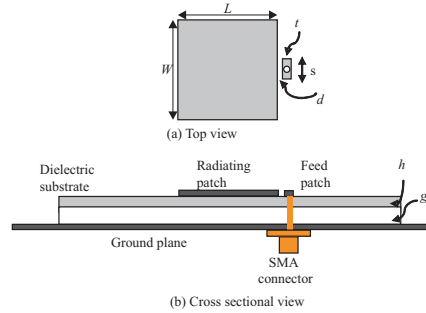


Figure 1: Geometry of a Rectangular Patch Antenna with a Capacitive Feed

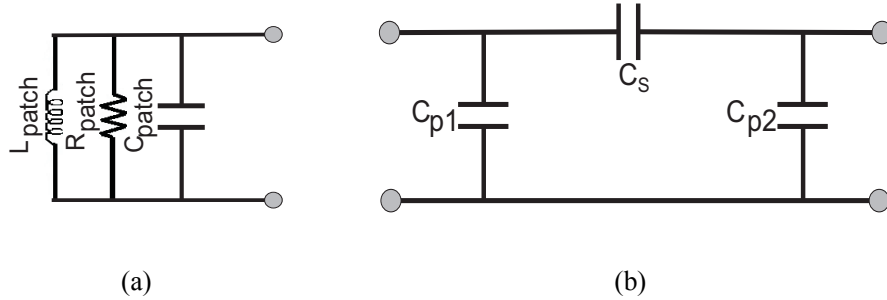


Figure 2: Equivalent Circuit for (a) Patch and (b) Asymmetrical Gap Between Patch and Feed Strip

2.2 Coupling gap between the Patch and Feed Strip

The separation between the radiator patch and feed strip can be modelled by the π -network as suggested in [10]. In Figure 2(b) two parallel capacitors represent the terminal capacitances of the two microstrip sections and the series capacitance represents the gap. These capacitance values (C_{p1} , C_s , and C_{p2}) can be calculated using equations given in [10] with minor modifications to represent the two layer air-dielectric medium.

2.3 Feed Section

In the present geometry (Figure 1), the coaxial probe is not directly connected to the radiator patch instead it is connected to a small rectangular strip placed nearby the radiator patch. Feed strip can be treated as a rectangular microstrip disc capacitor as its dimensions are much smaller in comparison with the wavelength of interest. It is basically a degenerated microstrip line and all sides (open ends) can be represented by terminal capacitances. The proposed equivalent circuit for this feed section is shown in Figure 3.

In Figure 3, $C_{width(s)}$ represents fringing fields through the “longer sides” of the feed strip:

$$C_{width(s)} = \left[\frac{Z(t, (g+h), \epsilon_r = 1)}{c_0 Z(t, (g+h), \epsilon_{reff})^2} - \frac{\epsilon_0 \epsilon_{reff} S}{(g+h)} \right] \times s \quad (5)$$

A similar expression could be obtained for $C_{length(t)}$. These could be derived based on [8] after making necessary corrections for air dielectric composite medium. It should be noted that the one of the width sides (close to radiator patch) capacitance ($C_{width(s)}$) will be associated with the parallel gap capacitance C_{p2} .

R_{strip} is the strip resistance associated with the losses in the feed strip. Although at lower frequencies radiation losses from the feed strip may be insignificant, at the higher frequency end of this wideband antenna the strip dimensions become comparable with the wavelength, and hence radiation losses should be included in the model. The strip resistance can be calculated based on the expressions for the equivalent resistance of the microstrip patch. Similarly, the strip capacitance C_{strip} is the parallel plate capacitance for the strip. At high frequencies, probe inductance dominates other parameters and can be treated as an inductive reactance (X_{probe}) [8], [9].

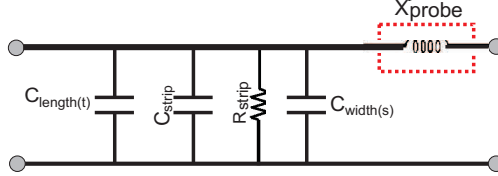


Figure 3: Equivalent Circuit of Feed Section

2.4 Model for the Complete Antenna

The complete model can be obtained by combining Figures 2 and 3. The total input impedance is calculated from its constituents. The total input impedance of the patch and the feed section are:

$$Z_{patch} = Y_{patch}^{-1} = \left[\frac{1}{R_{patch}} + j \left(\omega C_{patch} - \frac{1}{\omega L_{patch}} \right) \right]^{-1} \quad (6)$$

$$Z_{feed_section} = \left[\frac{1}{R_{strip}} + j \omega (C_{strip} + C_{length} + 0.5 C_{width}) \right]^{-1} + j X_{probe} \quad (7)$$

The antenna input impedance including the gap section elements is therefore:

$$Z_{in} = \left[\frac{1}{Z_{patch}} + j \omega C_{p1} \right]^{-1} + \frac{1}{j \omega C_s} + \left[\frac{1}{Z_{feed_section}} + j \omega C_{p2} \right]^{-1} \quad (8)$$

3. Comparison of Results

The complete model for the antenna derived in Section 2 was implemented in MATLAB. As this a wideband antenna, the model is required to cover a large range of frequencies. The reference antenna is designed on Rogers RT duroid 3003 (dielectric constant=3, loss tangent = 0.0013, thickness=1.56mm). The substrate is suspended above the ground with an air layer of 6mm. A prototype of this antenna is also fabricated and tested using a VNA [4]. The results obtained through measurements and simulations are compared with the above model in Figure 4.

4. Conclusions

The model for coplanar capacitive fed ultra wideband microstrip antenna has been developed based on equivalent circuit approaches. The return loss characteristics have been investigated using this model and is found to be in good agreement with the simulated and experimental results over a wide range of frequencies. The model and the antenna are relatively simple and hence are suitable for applications at various frequency ranges.

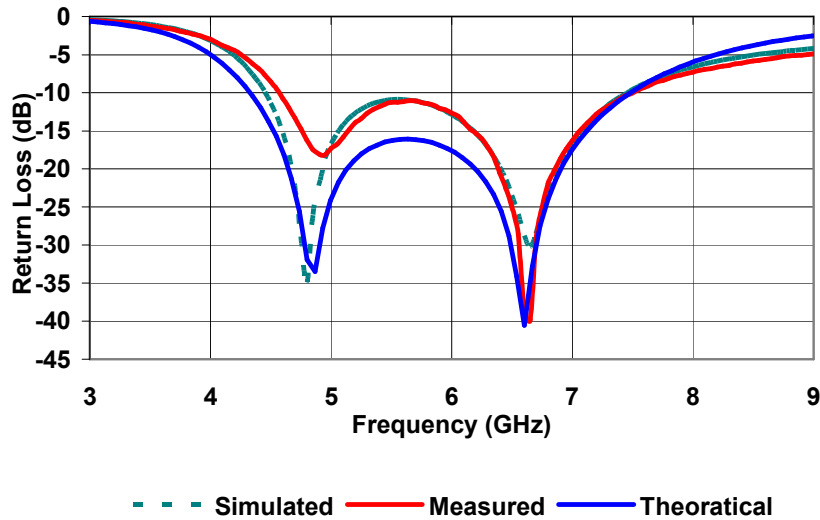


Figure 4: Return Loss Characteristics Obtained from Different Techniques for the Antenna Shown in Figure 1 with $L=15.5\text{mm}$, $W=16.4\text{mm}$, $s=3.7\text{mm}$, $t=1.2\text{mm}$, $d=0.5\text{mm}$, $h=1.56\text{mm}$.

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