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THE RESONANT FREQUENCY OF RECTANGULAR MICROSTRIP ANTENNA ELEMENTS WITH VARIOUS SUBSTRATE THICKNESSES

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KEY TERMS
Resonant frequency, various substrate, patch antenna, microstrip

ABSTRACT
Formulas based on transmission-line, cavity, and magnetic-wall models to determine the resonant frequencies of a rectangular microstrip antenna element have been studied and their validity assessed. Their variations were experimentally verified by analyzing a set of newly designed antenna elements with substrates satisfying the criteria $h \le 0.0815\lambda_0$ for $2.22 \le \varepsilon_r \le 10.2$, where λ_0 is the free-space wavelength, h the thickness, and ε_r the relative permittivity of the dielectric substrate. © 1996 John Wiley & Sons, Inc.

1. INTRODUCTION

The resonant frequency of microstrip antenna elements must be determined accurately, as they have narrow bandwidth and can only operate effectively in the vicinity of the resonant frequency.

Factors for determining the frequency at which resonance occurs include

(a) The voltage standing-wave ratio (VSWR), referred to the input terminals of the antenna, is at a minimum. This corresponds to a minimum in the magnitude of the reflection coefficient.

(b) The input impedance, referred to the input terminals, is real ($Z_{in} = R_{in}$), which means the input impedance has no reactive part. Generally, this point is very close to the frequency where the resistance reaches a maximum. Therefore the resonant frequency may also be defined as the point at which the resistance reaches a maximum, independent of the value of reactance.

This article is primarily concerned with antenna elements that are matched to their transmission-line feeds. In this case, the frequency at which the input impedance is real is equal to the frequency at which the VSWR is at a minimum.

Several methods have been proposed and used to determine performance properties of microstrip antenna elements [1–17]. These methods have different levels of complexity, require vastly different computational efforts, and can generally be divided into two groups: simple analytical methods and rigorous numerical methods. Simple analytical methods can give a good intuitive explanation of antenna radiation properties. Exact mathematical formulations in rigorous methods involve extensive numerical procedures, resulting in round-off errors, and may also need final experimental adjustments to the theoretical results. They are also time consuming and not easily included in a computer-aided-design system. Basically, there is no clear-cut rule as to which one of these is the best to use; the first guideline would be the thickness of the substrate.

Based on this observation, simplified analytical methods are used in this work. Formulas based on transmission-line, cavity, and magnetic-wall models to determine the resonant frequencies of a rectangular microstrip antenna element have been investigated. Their respective regions of validity in theory and applicability for a given antenna element have also been established. For the above-specified range of substrates, a transmission line model has been verified and successfully used to calculate the resonant frequencies of rectangular microstrip antenna elements without involving complicated, time-consuming, and difficult numerical methods. These results are then compared with specified design frequencies.

2. ANALYSIS

The configuration of a probe-fed rectangular microstrip antenna element is shown in Figure 1. The transmission-line [1–4], the cavity [5–10], and the magnetic-wall models [11] have been used for calculating the resonant frequencies, and there have been variations compared with measurements.

The basic formulas for computing the resonant frequencies are given in the following sections.

2.1. Formulas Based on the Transmission-Line Model. To calculate the resonant frequency of a rectangular microstrip antenna element, the antenna is regarded as two parallel radiating slots [3] with dimensions W and h having constant field aperture distributions and separated by the element length L of approximately half the wavelength in the dielectric.

In reality the electric field at the open end of the patch is distorted by an abrupt termination at the edges, resulting in fringing electric fields. This fringing effect is incorporated into the formula for the resonant frequency.

A formula for the resonant frequencies of rectangular antenna elements with thin substrates was given by Bahl [2] and Derneryd [4] as

$$f_r = \frac{c_0}{2(L + 2\Delta W)\sqrt{\varepsilon_e(W)}}, \tag{1}$$

where c_0 is the velocity of electromagnetic waves in free space and $\varepsilon_e(W)$ is the effective dielectric constant, which is obtained from [18]

$$\varepsilon_e(W) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 10h/W}}; \tag{2}$$

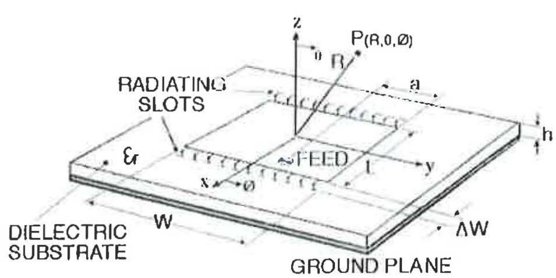

Figure 1 Configuration of a rectangular microstrip antenna element with dimensional parameters

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